RI/FS-EIS DOCUMENT: DOE/EIS-0185D
REMEDIAL INVESTIGATION: DOE/OR/21548-074, VOL. I

Remedial Investigation for the Chemical Plant Area of the Weldon Spring Site

Volume I

November 1992

prepared by

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prepared for

U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, under Contract DE-AC05-86OR21548

Documents Comprising the Draft Remedial Investigation/Feasibility Study-Environmental Impact Statement for the Weldon Spring Site Remedial Action Project

DOE/EIS-0185D

Baseline Assessment for the Chemical Plant Area of the Weldon Spring Site, DOE/OR/21548-091, U.S. Department of Energy, Oak Ridge Field Office, Oak Ridge, Tennessee, November 1992.

Feasibility Study for Remedial Action at the Chemical Plant Area of the Weldon Spring Site, DOE/OR/21548-148, Volumes I-II, U.S. Department of Energy, Oak Ridge Field Office, Oak Ridge, Tennessee, November 1992.

Proposed Plan for Remedial Action at the Chemical Plant Area of the Weldon Spring Site, DOE/OR/21548-160, U.S. Department of Energy, Oak Ridge Field Office, Oak Ridge, Tennessee, November 1992.

Remedial Investigation for the Chemical Plant Area of the Weldon Spring Site, DOE/OR/21548-074, Volumes I-II, U.S. Department of Energy, Oak Ridge Field Office, Oak Ridge, Tennessee, November 1992.

Addendum to the Remedial Investigation for the Chemical Plant Area of the Weldon Spring Site, DOE/OR/21548-272, U.S. Department of Energy, Oak Ridge Field Office, Oak Ridge, Tennessee, November 1992.

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is responsible for management of the Weldon Spring Site Remedial Action Project (WSSRAP) under its Environmental Restoration and Waste Management Program. Major goals include eliminating potential public and environmental hazards due to site contamination and releasing the property for alternate uses to the maximum extent practicable.

The purpose of the remedial investigation described in this report was to determine the extent of contamination associated with the portion of the Weldon Spring site known as the chemical plant and raffinate pit area. The DOE has assumed responsibility for investigating and remediating all on-site soil contamination and off-site soil which is radiologically contaminated as a result of uranium and thorium processing operations. The DOE has also assumed the responsibility for radiologically contaminated groundwater on and off site. The Weldon Spring site remedial investigation also involved the evaluation of the sources, nature and extent, and environmental fate and transport of contaminants to provide a basis for defining the risks that the contaminants may pose to human health and the environment. Data are included in this report to support the screening of remedial technologies and to permit the development and detailed analysis of alternatives for remedial action at the site during the feasibility study process.

The Weldon Spring site is located 48 km (30 mi) west of St. Louis, Missouri, near the town of Weldon Spring (Figure ES-1). It is surrounded by large tracts of land owned by the federal government and the state of Missouri. The site's operational history began in 1941 when the U.S. Department of the Army (DA) operated the site as part of the Weldon Spring Ordnance Works for the production of trinitrotoluene (TNT) and dinitrotoluene (DNT). Following World War II, the DA transferred portions of the ordnance works property to various governmental agencies. The U.S. Atomic Energy Commission (AEC) subsequently operated the site from 1957 to 1966 as a uranium processing facility. The portion of the Weldon Spring Ordnance Works transferred to the AEC is about 1% of the original acreage used for ordnance production. The remainder of the area is presently operated by the DA as the Weldon Spring Training Area and by the Missouri Department of Conservation as the August A. Busch and Weldon Spring Wildlife Areas.

The Weldon Spring site consists of two non-contiguous areas: 1) the raffinate pit and the chemical plant area and 2) the quarry area (Figure ES-2). The U.S. Environmental Protection Agency (EPA) has included these areas on the National Priorities List. The site is required to comply with the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA), which directs the EPA to meet remedial investigation/feasibility study requirements. In addition, the DOE has determined that site activities will also incorporate the values of the National Environmental Policy Act (NEPA).

The DOE has implemented a multifaceted management approach at the Weldon Spring site to meet the requirements of CERCLA and incorporate the values of NEPA. This approach provides for information exchange among the DOE, EPA Region VII, the Missouri Department of Natural Resources, the DA, the U.S. Geological Survey, local government agencies, public interest groups, and members of the general public. The management approach is designed to protect the health and safety of on-site workers and the public, mitigate actual or potential uncontrolled contaminant releases, provide for public participation through an active community relations program, and achieve timely initiation of cleanup activities.

Under CERCLA guidelines, the remedial investigation (RI) proceeds in parallel with a baseline assessment (BA) and a feasibility study (FS). The BA interprets the significance of contamination at the site and evaluates the potential threat to human health and the environment, while the FS evaluates alternative approaches to remediation of such contamination. The RI, BA, and FS are interactive in nature. Each study supports the other two, and each may be modified as a result of preliminary findings or conclusions developed in one of the other studies. Thus, while the RI is described in this document, it may occasionally be necessary to refer to the *Baseline Assessment for the Chemical Plant Area of the Weldon Spring Site* (DOE 1992a) and the *Feasibility Study for Remedial Action at the Chemical Plant Area of the Weldon Spring Site* (DOE 1992b) for additional detailed information or supporting analyses. A fourth document, the *Proposed Plan for Remedial Action at the Chemical Plant Area of the Weldon Spring Site* (DOE 1992d), describes the preferred remedial action identified for site cleanup. The Weldon Spring site evaluation documents prepared under CERCLA to support cleanup decisions for the chemical plant have been supplemented to incorporate NEPA values for an Environmental Impact Statement (EIS). The resulting integrated document package is termed the RI/FS-EIS. The FS summarizes information developed during the RI/FS process and identifies remedial action alternatives. The comparison of remediation alternatives in the FS document will consider the requirements of CERCLA/SARA and incorporate NEPA values to support the remedial action decision presented in the Record of Decision (ROD).

Interaction between the RI, BA, and FS requires that each study proceed in iterative phases. The initial characterization effort focuses on obtaining information about the site. Subsequent phases develop information to fill data gaps or to otherwise meet needs of the risk assessment or feasibility study activities. This RI document is relatively complete. The characterization data presented in this document is sufficient to evaluate and select the preferred remedial action alternative. However, data gaps or additional study needs have been identified. The data gaps will be filled by pursuing additional definitive characterization efforts to support the remedial design phase of the project.

Site Background

Past operations at the Weldon Spring Ordnance Works introduced nitric and sulfuric acids and various metals, as well as nitroaromatic compounds, to the soils and water on the site. Contamination was mainly located near TNT processing plants, wastewater discharge lines and lagoons, and areas used for burning of wastewater sludge (Plate 1). In the early days of TNT production, the wastewater (commonly called red water) was stored in lagoons constructed in surface drainages. Historical records suggest that the lagoons frequently overflowed into ditches and streams. The major component in the wastewater was sellite (sodium sulfite) used in the purification of trinitrotoluene (TNT).

In preparing the site for use by the AEC as the Weldon Spring uranium feed materials plant, partial decontamination of the ordnance works was completed. Soil and building materials contaminated with nitroaromatic compounds were removed and burned. Extensive cut and fill grading was performed on the site to prepare for construction of the feed materials plant. Production of uranium metal from processed uranium ore (yellowcake) at the feed materials plant involved the use of nitric, sulfuric and hydrofluoric acids, magnesium, sodium carbonate, and other miscellaneous chemicals. Raffinate pits were constructed from local soils to contain neutralized acidic waste from the uranium processing operations. Decant water from the pits (supernatant liquid after deposition of raffinate sludge) was discharged off site in a natural drainage to the southeast of the site. Ash Pond was constructed to contain the ash from the on-site, coal-fired steam generating plant. The area of Ash Pond also contains the south burn area where uranium-contaminated materials were burned and general refuse was disposed of. Frog Pond was constructed over the TNT processing areas and is thought to have functioned as a catch basin for fire suppression water from the uranium processing buildings. Several thousand cubic meters of contaminated material removed from the feed materials plant were buried at the Weldon Spring quarry after production was terminated.

Contaminant Sources

Currently, the Weldon Spring chemical plant and raffinate pit areas include contaminated soils and sludges which contain chemical and radioactive constituents. Included in the chemical plant and raffinate pit areas are: four raffinate pits, Ash Pond, Frog Pond, the coal storage area, and soils near former processing facilities. In addition, these areas are potential sources of groundwater and surface water contamination.

Chemical analyses of the soils showed that concentrations greater than background exist for all of the metals and anions included in the analyses. The metals and anions occurring with the greatest frequency above the background range include silver, arsenic, cadmium, fluoride, mercury, nickel, nitrate, lead, antimony, sulfate, and zinc. Low levels of nitroaromatic compounds were detected, particularly in the area of Ash Pond. Low concentrations of volatile organic compounds, pesticides, and polychlorinated biphenyls (PCBs) in soils were detected in limited areas. Low concentrations of semivolatile organic compounds are present in areas related to burning and coal storage.

The radiological sampling of soils across the site showed widespread surface contamination of uranium with a lesser extent of contamination of radium and thorium. Using reference levels of 5 pCi/g (top 15 cm) and 15 pCi/g (subsurface) for radium plus thorium and a reference level for uranium of 15 pCi/g, approximately 63,700 m^3 (83,300 yd^3) of exposed soil over an area of 19.2 ha (47.4 ac) requires remediation. Varying depths of soil with radionuclide concentrations in excess of reference levels are present in Ash Pond, Frog Pond, the south dump, and the north dump. Radionuclide concentrations above reference levels scattered throughout the soils in the other site areas are mostly within the top 30 cm (1 ft).

It is important to understand that the radionuclide reference levels presented in this report are not intended to guide site remediation. The reference levels were used because site-specific cleanup guidelines had not yet been developed. The RI presents reference levels only for the purpose of estimating area and volumes of soil containing elevated radionuclide concentrations. Once final cleanup guidelines have been established, the estimated areas and volumes will be revised. Section 5 provides further details regarding the purpose and justification of reference levels.

Radiological analysis of the raffinate pits showed that the sludges contained several hundred to several thousand pCi/g of uranium, radium, and thorium isotopes. The ranges of isotopes in raffinate pits 1, 2, and 3 are similar, reflecting sludges from similar process operations. Raffinate pit 4 contains the same type of neutralized raffinate solids as raffinate pits 1, 2, and 3 with the addition of waste from processing thorium and drums and rubble from the shutdown of the uranium feed materials plant.

Chemical analysis of the sludge in the raffinate pits also showed relatively homogeneous material in all of the pits except for raffinate pit 4. The sludge contains concentrations greater than background for all of the metals and anions included in the analysis. The pH of greater than 7 in the raffinate pits maintains low concentrations of the heavy metals in the water. The inorganic anions, including uranium, vanadium, and molybdenum which exist as anionic species at the pH and redox potential conditions of the raffinate material, are quite soluble in the raffinate pit water and are available for migration through the subsurface.

Groundwater and surface water monitoring suggest that the raffinate pits are the primary source of nitrate in the groundwater and springs off site. Leaching and suspension of uranium-contaminated soils are the major source of uranium in surface water discharged from the site. Nitroaromatics in the groundwater are thought to be primarily from contaminated soils at depth and possibly below Frog Pond. Additional off-site source areas for nitroaromatic contamination may include portions of the Weldon Spring Training Area, which is not included as part of the Weldon Spring site in this document. Contaminated soils distributed throughout the site are probably sources of elevated metal concentrations in localized areas of groundwater on site. The raffinate pits are not a likely source of metal contamination in the groundwater because of the low solubility of most metals under the alkaline conditions of the raffinate pits water. Analysis for nitroaromatic and semivolatile compounds in the water and sludges of the raffinate pits did not detect these compounds.

Some site contaminants and contaminated materials do not have a significant potential for water contamination. These include the buildings which contain radioactive materials, process chemicals, asbestos, and PCBs. At least one-half of the swipe and bulk samples taken from the nonprocess buildings at the chemical plant exceeded cleanup standards for PCBs. Sampling of the buildings for asbestos revealed the presence of asbestos-containing material in the insulation on pipes, steam valves, heating ducts, and in corrugated siding. Radiological sampling of the interior and exterior of the buildings, equipment within the buildings, and air showed that roughly half of the buildings meet the standards for release for unrestricted use. Ninety-one percent of the air samples were below the occupational standards for radiological exposure.

Geology/Hydrology

The groundwater and surface water pathways are dependent upon the geology and the hydrology of the area. Contaminant transport is controlled by geochemical processes coupled with the hydrogeologic regime. Two primary mechanisms contribute to the transport of contaminants to the groundwater: leaching and seepage from the surface and near surface sources through the unsaturated zone into the groundwater, and infiltration of surface water into the groundwater in losing streams off site.

The geology beneath the site is characterized by 5 to 18 m (15 to 60 ft) of clayey overburden overlying an argillaceous cherty limestone bedrock. The overburden has been divided into six recognizable units based upon physical characteristics. These are, in ascending order, residuum, basal till, clay till, Ferrelview Formation, loess, and topsoil/fill. The overburden is generally thickest over bedrock lows (Figure ES-3). The Mississippian limestone bedrock has been divided into two units determined by the degree of fracturing and weathering exhibited in the rock. The upper weathered unit ranges in thickness from 3 to greater than 15 m (9 to greater than 50 ft). The competent unit extends to about 40 m (130 ft) to another unit of limestone. The bedrock surface exhibits a high on the eastern portion of the site and a low on the north/northwest portion of the site. The upper unit is highly weathered at the top, exhibiting solution features ranging from pinpoint vugs to small cavities which are generally filled with clay. No large-scale closed depressions characteristic of solution features have been identified on the surface of the bedrock. Linear depressions developed on the bedrock surface are interpreted to be preglacial drainages (Figure ES-4). The formation of these features appears to have been controlled by northeasterly and northwesterly trending joint sets.

The hydrologic regime of the site consists of intermittent surface drainages incised into the unsaturated zone, six surface impoundments, an unsaturated zone containing perched water, and saturated residuum and bedrock. Much of the original drainage system across the site was destroyed by the cut and fill activities for the construction of the Weldon Spring Ordnance Works and later the uranium feed materials plant. In the saturated limestone, the potentiometric surface shows an east-northeasterly trending groundwater divide corresponding roughly to the regional surface divide (Figure ES-5). The groundwater divide passes within approximately 100 to 200 m (330 to 660 ft) of the southern border of the site. To the north of the divide, groundwater moves toward the Mississippi River. South of the divide, groundwater moves in a direction perpendicular to and toward the Missouri River. The deeper groundwater wells completed below about 18 to 24 m (60 to 80 ft) into the bedrock show a potentiometric surface approximately 1.5 m (5 ft) lower than the wells completed in the upper 12 m (40 ft) of the aquifer.

North and northwest of the site, intermittent streams lose flow to the subsurface. The lost discharge resurges at springs in an adjacent drainage (Figure ES-6). Other surface flow in the vicinity is the result of a series of springs which discharge shallow groundwater into drainages flowing to Dardenne Creek and the Mississippi River, and into drainages flowing to the Missouri River. Several man-made lakes are present in the drainages contributing flow to Dardenne Creek. Drainage to the southeast of the site consists of a series of losing stream segments with associated springs.

The site is divided into three general drainage systems: the Ash Pond area draining to the northwest; Frog Pond and related streams draining the northeast portion of the site; and the southeast drainage flowing from the site to the Missouri River (Figure ES-6). Surface runoff from Ash Pond and the outside embankment of the raffinate pits flows off site via National Pollutant Discharge Elimination System (NPDES) permitted discharge points into ephemeral tributaries and then into Schote Creek. Much of the water discharged to the tributaries is lost to the subsurface and resurfaces at Burgermeister Spring. Frog Pond receives runoff from the northeast portion of the site and discharges through an NPDES-permitted outfall into a tributary of Schote Creek and into Lake 36. Surface water from Lake 36 is lost to the groundwater and is assumed to resurge in the watershed for Burgermeister Spring. Surface water leaving the southeast portion of the site flows through the southeast drainage. Groundwater in this drainage may be in part due to infiltration of stormwater collected by the chemical plant storm sewer system.

Groundwater movement in the limestone aquifer below the site is believed to occur predominantly by diffuse flow and along horizontal bedding planes, and to a lesser extent through small vertical fractures. As the intensity of weathering and fracturing decreases with depth, the lithology of the aquifer becomes more homogeneous, flow paths are more widely spaced, and the influence of vertical fractures is more limited. Groundwater flow off site may occur by diffuse-flow as well as free-flow conduits on both sides of the groundwater divide.

Discharge points for the conduits are perennial springs such as Burgermeister Spring and springs in the southeast drainage.

Nature, Extent, and Transport of Contaminants

Off-site transport of contaminants is primarily occurring through groundwater and surface water pathways as conceptualized in Figure ES-7. Contamination in the groundwater is generally confined to the shallow portion of the aquifer. Only low levels of sulfate and nitroaromatics were measured in the deeper portion of the aquifer.

During ordnance works and uranium feed materials plant operations, air-borne contamination was also a likely pathway for transport off site. Recent air monitoring for asbestos, organic vapors, and radioactivity indicates that levels of constituents are similar to background or decrease rapidly with distance from the on-site source.

Based upon analysis of sludge and surface water, the raffinate pits appear to be a potential source of nitrate, fluoride, uranium, and other elements associated with uranium ore. Except for nitrate, the elements from the raffinate pits exhibit similar transport patterns. They are present in the groundwater very near the raffinate pits, but are not transported beyond the vicinity of the pits in quantities or levels significantly greater than background because of immobilization by precipitation and adsorption to solids. Four wells within the chemical plant area and two wells in the vicinity of the southeast drainage contain mean uranium concentrations slightly in excess of background. In general, the concentrations of uranium in the surface water flowing from the site are much greater than the groundwater concentrations. A conceptual source/transport model of the site suggests that, during storm events, surface runoff increases and transports uranium from contaminated soils through NPDES-permitted discharge points and through the Ash Pond, Frog Pond, and the southeast drainage. The uranium is probably transported in both dissolved and particulate forms. In the drainages downstream from Ash Pond and the raffinate pits area, surface water is lost to the subsurface. Although a portion of the uranium is transferred to solid phases by chemical precipitation and sedimentation, some uranium is transported through groundwater and resurfaces in springs.

Seepage from the raffinate pits is the major source of nitrate to the groundwater. Nitrate is not significantly retarded, and therefore high concentrations of nitrate are found in wells in the western portion of the site near the raffinate pits and Ash Pond. The nitrate-contaminated groundwater, flowing according to the conceptual model of diffuse flow, likely enters the conduits leading off site and is transported to Burgermeister Spring. Surface water discharged off site contains nitrate (lower observed concentration relative to groundwater concentrations) and may contribute to the nitrate concentrations measured in the springs.

Nitroaromatic compounds in the groundwater on site are believed to be the result of infiltration due to process line leakage, wastewater discharge, and leaching of contaminated soils.

Characterization related to the site remedial investigation indicates that the highest concentrations of nitroaromatics are found in wells near the raffinate pits and Frog Pond where former TNT processing and wastewater lines were located. The concentrations of TNT in the groundwater at the site decrease markedly with distance from the sources. Low level concentrations of nitroaromatic compounds are present in most groundwater wells within the site and in many springs in the drainages around the site. Transport of nitroaromatics likely occurs via groundwater to the springs off site; however, sources of the nitroaromatics related to the Weldon Spring Ordnance Works probably exist both on and off site.

Low levels of nitroaromatic compounds have also been detected in the groundwater at the Twin Island Lake development. Although these nitroaromatic occurrences are not within the scope of this remedial investigation or within the DOE's stated responsibility for remediating off-site radiological contamination, the DOE recognizes the concern for groundwater contamination by nitroaromatic compounds. The DOE has established a coordination group with the DA to help define nitroaromatic sources and transport mechanisms.

Of the many metals contained in the raffinate pit sludges and soils, only nickel and chromium are present in groundwater above background levels within the site. The data suggest that nickel, being the more mobile element, may be above the background concentrations in wells immediately off site. Chromium is expected to be in the trivalent state under the chemical conditions within the aquifer, and would be retarded by precipitation and adsorption. The sources of nickel and chromium in the groundwater are most likely contaminated soils.

Sediments sampled from the drainages and lakes off site show that uranium has accumulated to levels in excess of background. This is probably due to the chemical precipitation and deposition of uranium-bearing sediment transported with the surface water. Lead and barium are two constituents which also appear at levels slightly elevated above background at a few specific locations.

Biological Uptake of Contaminants

From 1987 through 1991 fish have been collected from Busch Wildlife Area Lakes 34, 35, and 36 and analyzed for radium 226, thorium 230, thorium 232, and total uranium. Thorium and radium concentrations were below detection limits. Fish from Busch Wildlife Area Lakes 35 and 36 have significantly higher concentrations of total uranium than from the background Lakes 33 and 37. In Lake 36, total uranium concentrations in whole fish ranged from 0.002 to 1.863 pCi/g; fish fillets ranged from 0.004 to 0.041 pCi/g. In Lake 35 total uranium concentrations in whole fish ranged from not detected to 0.385 pCi/g: fish fillets ranged from not detected to 0.094 pCi/g. Total uranium in Lake 33 ranged from non-detected (0.001 pCi/g) in flesh samples to 0.007 pCi/g in whole crappie sample. Lake 37 uranium concentrations ranged from non-detected (0.001 pCi/g) in bass fillet samples to 0.013 pCi/g in whole catfish samples.

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ADDENDUM

1 INTRODUCTION

1.1 Remedial Investigation Purpose and Objectives

The remedial investigation/feasibility study (RI/FS) process is the procedure designated by the National Contingency Plan (NCP) to investigate and evaluate waste sites on the National Priorities List (NPL). This process is also used at sites which are not on the NPL, but must comply with the NCP during the process for selection of remedial actions. The RI contains information on site and waste characterization. The baseline assessment (BA) uses this information to evaluate the potential threat to human health and the environment in the absence of remedial action. The FS relies on the RI for information necessary for the development, screening, and detailed evaluation of the possible remedial alternatives to be applied at a specific waste site.

One of the more important aspects of the RI/FS process is the concurrent development of the RI and FS in stages or phases. This phased RI/FS approach, as described in the October 1988 interim final "Guidance for Conducting Remedial Investigations and Feasibility/Studies Under CERCLA" (EPA 1988), allows rapid focusing on areas of data needs critical to the overall characterization process. The RI/FS process continually reshapes the field data collection efforts in support of the selection of a remedial action. Through this iterative process, the collection of extraneous data is minimized, data quality is maximized, and the overall time frame to make informed decisions is compressed. The need and advantages of the phased RI/FS process are particularly evident for complex sites such as the Weldon Spring site.

As described in subsequent sections, the Weldon Spring site has a complicated operational history, numerous contaminant sources and types, and a complex array of transport pathways. The phased approach has permitted not only the development of an effective strategy for site characterization studies and the identification of separate operable units, but also the identification of interim response actions (IRAs). The IRAs are executed to reduce threats to the public health and welfare of the environment, reduce waste volume, reduce site worker risks, and interrupt potentially significant contaminant transport pathways.

1.1.1 Scope of the Remedial Investigation

Four separate remedial investigations have been planned for the Weldon Spring Site Remedial Action Project (WSSRAP). The RI described in this report addresses the larger portion of the Weldon Spring site, including the raffinate pits, the chemical plant, and on-site and off-site areas which have been contaminated by releases from the raffinate pits and chemical plant source areas. The remaining three RIs address the quarry bulk waste (DOE 1989), the quarry residuals and vicinity, and groundwater management at the chemical plant site.

The purpose of the site RI is to determine the extent of contamination associated with the chemical plant and raffinate pits. The U.S. Department of Energy (DOE) has assumed the responsibility for the investigation and remediation of all on-site soil contamination and off-site soil which has become radiologically contaminated as a result of uranium and thorium processing operations. The DOE has also assumed the responsibility for radiologically contaminated groundwater on and off site.

The report has been organized to follow the U.S. Environmental Protection Agency's (EPA) October 1988 interim guidance (EPA 1988), with differences in the suggested outline addressing the specifics of the Weldon Spring site. Following the site-specific background information, Section 1 of the report outlines contaminants of concern, sources of contamination, and contaminant transport mechanisms. Data management is addressed in Section 2. Previous investigations at the site are described in Section 3. Section 4 of the remedial investigation report describes the physical characteristics of the study area with respect to surface waters, groundwaters, soils, geology, geotechnical/geophysical properties, terrestrial and aquatic ecology, and air. Results of previous studies and the recent characterization studies performed by the Project Management Contractor (PMC) were used to determine the contaminant sources, the nature and extent of radiological and chemical contamination, and the environmental fate and transport of contaminants (Sections 5 and 6). Section 7 of this report presents the summary and conclusions of the remedial investigation. References cited, a glossary of terms, acronyms and abbreviations, units of measure, SI conversion factors, and a list of contributors are included in Sections 8, 9, 10, 11, 12, and 13, respectively. Additional information is contained in the appendices to support interpretations within the RI report and to provide additional information for the FS process. The attached Addendum describes the environmental characteristics of the off-site disposal locations being considered in the FS.

1.1.2 Site RI/FS-EIS Management Approach

The DOE has implemented a multifaceted management approach at the Weldon Spring site to incorporate values from the National Environmental Policy Act (NEPA) and meet the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA). This approach will provide a cooperative environment for information exchange among the DOE, EPA Region VII, the Missouri Department of Natural Resources, the DA, the U.S. Geological Survey, local government agencies, public interest groups, and members of the general public. The project is designed to reduce the health or safety threats to on-site workers and the public, mitigate actual or potential uncontrolled contaminant releases, provide for public participation through an active community relations program, and lead to timely initiation of response actions. The DOE approach for implementing the Weldon Spring site program consists of the following major elements:

- A site characterization program.

- Development of a baseline assessment.
- Preparation of an RI/FS-Environmental Impact Statement (EIS) consistent with both NEPA and CERCLA.
- Initiation and completion of interim response actions.
- Removal of quarry bulk wastes as a separate operable unit.
- Preparation of a separate RI/FS and baseline assessment for the quarry as a separate operable unit.

This RI report does not address the potential risk to public health and the environment from quarry contaminant sources. The difficulty in characterizing the wastes and environmental media at the quarry has led to the identification of the quarry as a separate operable unit. Quarry bulk waste will be removed and transported to the chemical plant site for temporary storage. This remedial action is addressed under a separate RI/FS-Environmental Assessment (EA) (DOE 1989). The quarry bulk waste will ultimately be disposed of with wastes from the chemical plant and the raffinate pits. Subsequent to the removal of the bulk wastes from the quarry, an RI/FS and baseline assessment for the quarry environs will be conducted. The results will be presented in separate documents which will be consistent with overall WSSRAP objectives, CERCLA requirements, and NEPA values.

1.2 Site Background

1.2.1 Site Description and Location

The Weldon Spring site is located approximately 48 km (30 mi) west of St. Louis in western St. Charles County, Missouri (Figure 1.2-1). The largest city in St. Charles County is the city of St. Charles, which is located approximately 24 km (15 mi) northeast of the site. The communities of Weldon Spring and Weldon Spring Heights are located approximately 3 km (2 mi) east of the site and have a combined population of about 800. The site is surrounded by large tracts of land owned by the federal government and the State of Missouri (Figure 1.2-2)(Peterson et al. 1988).

For the purposes of this RI, the Weldon Spring site consists of two areas which total 88 ha (217 ac). The Weldon Spring raffinate pits and chemical plant encompass 21 and 67 ha (51 and 166 ac), respectively (Figure 1.2-2). The chemical plant and raffinate pits areas are located just west of State Route 94, approximately 3 km (2 mi) southwest of the junction of U.S. Highway 40 (also known as Interstate 64 or U.S. Highway 61) and State Route 94 (Peterson et al. 1988).

The 21-ha (51-ac) raffinate pits area contains four surface impoundments covering approximately 11 ha (26 ac) (Figure 1.2-3). These pits contain wastes primarily from uranium and thorium processing. The 67-ha (166-ac) chemical plant consists of 13 major buildings and approximately 30 support structures (Figure 1.2-3)(MKF and JEG 1987o) and the Ash Pond and Frog Pond areas. The chemical plant area was contaminated by trinitrotoluene (TNT) and dinitrotoluene (DNT) production as well as subsequent uranium and thorium processing. Ash Pond and Frog Pond are the two surface water bodies within the chemical plant area (Figure 1.2-3). Frog Pond is a settling basin located near the northeast edge of the site, and Ash Pond is a surface impoundment near the northwest edge of the site (MKF and JEG 1988t). Low-level nitroaromatic contamination exists in these areas as well as contamination by radionuclides, metals, and inorganic anions.

Bordering the site to the west is the U.S. Army Reserve Weldon Spring Training Area (Figure 1.2-2). It consists of 746 fenced ha (1,660 ac). The land is relatively level, and portions of the property are cleared and easily accessible while other sections are wooded or overgrown with heavy brush (ORAU 1986a).

Immediately north of the site is the 2,800-ha (6,919-ac) August A. Busch Memorial Wildlife Area as indicated in Figure 1.2-2. The area is a park-like tract managed by the Missouri Department of Conservation (MDOC). It is open throughout the year to the general public and is dedicated to various types of recreational uses (DOE 1987).

The Weldon Spring Wildlife Area is located to the south of the site (Figure 1.2-2) and covers approximately 2,900 ha (7,200 ac). It is also managed by MDOC and is open throughout the year to the general public for a variety of recreational uses (MKF and JEG 1987l).

Francis Howell High School is located approximately 1 km (0.75 mi) east of the site on State Route 94 (Figure 1.2-2). The school stands on 16 ha (40 ac) of land owned by the St. Charles County Public School District.

Between the site and Francis Howell High School is a building which housed the St. Charles County Extension Center which was operated by the University of Missouri and closed in 1988. The building is currently used as the Francis Howell High School Administration Annex (Figure 1.2-2). This building is approximately three-quarters of a km (one-half mi) east of the site entry gate on State Route 94. The university also owns 300 ha (750 ac) of land immediately east of the extension center which is used as a research park (DOE 1987).

A State of Missouri highway maintenance facility is located 183 m (600 ft) northeast of the site main entry gate (Figure 1.2-2).

1.2.2 Site History

From 1941 to 1945, the U.S. Department of the Army (DA) operated the Weldon Spring ordnance works, constructed on the land that is now the Weldon Spring site, for production of TNT and DNT. One shutdown occurred in January 1944 when the site was placed on standby status. Operations were reactivated in October 1944 and the WSOW was in full operation until the end of World War II. Details on operation of the ordnance works are presented in Appendix D. The Army used the quarry for disposal of rubble contaminated with TNT. In the mid 1950s, 83 ha (205 ac) of the ordnance works property was transferred to the U.S. Atomic Energy Commission (AEC). This tract is now occupied by the raffinate pits and chemical plant area. An additional 6 ha (15 ac) was later transferred to the AEC for expansion of waste storage capacity. From 1957 to 1966, the AEC operated a uranium processing facility at the Weldon Spring uranium feed materials plant, which subsequently became the Weldon Spring chemical plant. Details on operation of the feed materials plant are presented in Appendix D. Ore concentrates and some scrap metal were processed at the plant. Products that included uranium metal were shipped to other sites. Thorium-containing materials were processed on an intermittent basis. Radioactive raffinates from the processing were placed in four on-site pits. Other radioactive wastes were disposed of in the quarry.

After closure by the AEC, the chemical plant was reacquired by the Army in 1967. The Army partially decontaminated several buildings, dismantled some of the equipment, and began converting the facilities to produce herbicides. In 1969, prior to becoming operational, the herbicide project was canceled. As successor to the AEC, DOE assumed responsibility for the raffinate pits. In 1984, the Army repaired several of the buildings at the chemical plant, decontaminated some of the floors, walls, and ceilings, and isolated some contaminated equipment.

In May 1985, DOE designated the control and decontamination of the Weldon Spring site as a Major Project (this project has since been designated as a Major System Acquisition). In October 1985, custody of the chemical plant was transferred to the DOE. A PMC for the Weldon Spring Site Remedial Action Project was selected in February 1986, and a DOE project office was established on the site in July 1986. The PMC, MK-Ferguson Company and Jacobs Engineering Group, assumed control of the Weldon Spring site on October 1, 1986.

On October 15, 1985, the EPA proposed to include the quarry on the NPL. This listing was effected on July 30, 1987. On June 24, 1988, the EPA proposed to expand this designation to include the raffinate pits and chemical plant area (Peterson et al. 1988). On March 30, 1989, these areas were also included in the listing and resulted in a single designation as the Weldon Spring site. A chronology of events at the site is compiled in Appendix E.

1.2.3 Previous Investigations

Numerous investigations have been conducted at the site to obtain data to confirm the presence or absence of contaminant migration and to determine the effect of the contaminants on public health and the environment. The investigations undertaken to achieve this purpose are listed by reference in Table 1.2-1. Some of these studies have been used, along with the PMC characterization studies, in the assessment of contaminant sources, transport, and the extent of contamination to satisfy the requirements of the RI. Generally, the purpose of these additional characterization studies is to gather the necessary data to describe the nature and extent of contamination as necessary to support an FS-EIS. Additional investigations will be performed as a need for supplemental data is identified.

1.2.4 Interim Response Actions

IRAs, including decontamination of certain vicinity properties, removal of certain buildings and support facilities, and contaminated soil removal, have been initiated prior to the issuance of the Record of Decision (ROD). The scopes of the IRAs have been limited to activities which would not have adverse environmental impacts or preclude the choice of reasonable alternatives for ultimate site remedial actions (CERCLA requirements or NEPA values).

The IRAs proposed for the WSSRAP are described in Table 1.2-2. The objectives of these IRAs are to (1) expedite cleanup of the site, (2) reduce threats of releases of chemical and radioactive contaminants into the nearby environment, (3) minimize the health and safety risks associated with site conditions for on-site personnel and local populations, and (4) contribute to the long-term, overall remediation of the site by reducing on-site waste volume and facilitating waste disposal activities. Additional IRAs may be proposed as the project proceeds. The selection of those actions will continue to involve DOE coordination with EPA Region VII, the State of Missouri, the DA, and the general public.

1.3 Overview of Site Contamination

Because of the history, size, and complexity of the Weldon Spring site, large amounts of data characterizing a variety of environmental media were necessary. In order to gain an understanding of the nature and extent of contamination at the site, data were collected to determine contaminants of concern, sources of contaminants, release mechanisms, transformation processes, transport, and fate. A summary discussion of site contamination is presented in this section followed by more detailed presentations in Sections 5 and 6.

1.3.1 Primary Contaminants

Possible contaminants were identified during a review of chemicals used in past site operations. A wide variety of chemicals had been used at the site, as part of operational processes (Table 1.3-1). Because of this history, a comprehensive environmental monitoring program was established at the site. In addition, extensive characterization studies were initiated. Table 1.3-2 lists the substances which were analyzed during the initial soil and water investigations (MKF and JEG 1987o and 1988l).

The focus of the monitoring and investigation program not only included groups of contaminants known to be present in source areas and in environmental media, but also included contaminants which were not expected to be present. Based on program results, primary contaminants, or those which were detected at significant levels in source areas, were identified and are listed in Table 1.3-3. These contaminants include radionuclides, organic constituents such as nitroaromatics and polychlorinated biphenyls (PCBs), and inorganic constituents, including trace metals and asbestos. The risk-based contaminants of concern and the risk assessment process are presented in the *Baseline Assessment for the Chemical Plant Area of the Weldon Spring Site* (DOE 1992a). The contaminants of concern have been evaluated to determine associated potential risks to human health and the environment at, and in, the vicinity of the Weldon Spring site.

1.3.2 Contaminant Sources

Numerous primary sources for the contaminants are present at the Weldon Spring site. Past operations at the ordnance works created localized concentrations of nitroaromatics in soils and groundwater. Releases of nitric acid, sulfuric acid, and various metals from the past operations are also evident. Contamination was mainly associated with TNT processing plants, wastewater discharge lines, and burning of wastewater sludge. Wastewater (commonly called red water), which was primarily sodium sulfite, was stored in lagoons.

Existing buildings and other facilities of the chemical plant are radiologically contaminated. They also contain process chemicals, asbestos, and PCBs. Soils have been contaminated throughout the process area. The raffinate pits contain radioactive contaminants as well as metals and inorganic ions such as nitrate and sulfate. Ash Pond and Frog Pond and portions of the upstream drainages on site have been identified as sources of uranium, nitrate, and possibly nitroaromatics. Detailed discussions of contaminant source investigations are in Section 3.1 and Section 5.1 of this report.

1.3.3 Conceptual Site Model

The conceptual site model for contaminant pathways at the Weldon Spring site has served as a design guide for various characterization studies and interpretations. The basic framework of the conceptual model guides the assessment of contaminant sources, release mechanisms, physical-chemical-biological processes affecting contaminant migration, transport pathways, and contaminant fate. The conceptual model continues to evolve as additional environmental information is obtained and interpreted. The major source areas in the chemical plant and raffinate pit areas and the dominant identified transport routes and potential receptor areas are shown in Figure 1.3-1.

Results of the environmental characterization studies indicate that only certain chemicals appear to have migrated from these source areas. For example, while the raffinate pits contain various metals, it appears that there is minimal migration from the pits due to the attenuating mechanisms of adsorption and chemical precipitation. Similarly, no significant movement of thorium and radium from the source areas has occurred based on the analysis of off-site media. Asbestos and PCB occurrence is also localized and has been identified in specific on-site areas.

1.3.3.1 Contaminant Release. Releases from the major contamination sources at the Weldon Spring site have contaminated both on-site and off-site environmental media (soils, surface water, sediments, groundwater). The significant release mechanisms at the site include:

- Runoff, leaks, spills, and infiltration which contaminated surface water, groundwater, and soils.
- Dissolution or leaching of contaminants from surface or subsurface materials to groundwater.
- Fugitive dust from traffic, construction, and chemical processing activities. (This probably contributed to contamination of soils and sediments during the time that the facilities were operating.)

1.3.3.2 Processes Affecting Contaminant Release and Migration. Chemical precipitation and dissolution and the adsorption and desorption of contaminants (particularly with respect to radionuclides and metals) are the most significant processes which affect the release, migration, and environmental distribution of contaminants on and near the site. These processes are controlled by the character of the water, soils, and rocks which includes the presence of complexation agents, adsorption capacity, pH, redox potential, and temperature. Biological degradation and volatilization may be the dominant mechanism affecting the continued migration and environmental distribution of organic contaminants such as nitroaromatics. Photochemical reactions may also be important for organic compounds present at the site, while oxidation-reduction reactions may be important for certain metals and organic compounds such as uranium, chromium, selenium, nitrobenzene, and inorganic nitrogen species. Dilution also significantly modifies the behavior and distribution of contaminants in surface water, groundwater, soils, and sediments. The dominant processes regulating environmental transport and fate of chemicals at the Weldon Spring site are discussed in detail in Sections 5 and 6.

1.3.3.3 Migration Pathways and Contaminant Fate. The significant migration pathways by which both on-site and off-site environmental media have been contaminated include:

- Atmospheric dispersion and deposition on soils or surface water bodies.
- Overland storm runoff and conveyance in ephemeral and perennial drainages.
- Groundwater resurges to surface waters and sediments.
- Surface water recharge to groundwaters.
- Unsaturated flow through the vadose zone to ground waters.
- Groundwater and surface water transport.

Air transport of contaminants is not presently a significant pathway at the site because processing operations have been shut down since the 1960s. Although not a present concern, air transport could become a factor during remedial actions. Engineering controls that would be implemented to mitigate potential air transport are discussed further under the Remedial Action Alternatives section of the FS. Air transport of particulates from past processing operations resulted in on-site soil and building contamination. Characterization studies and a monitoring program have been undertaken to determine the nature and extent of contaminants. Air monitoring by DOE for asbestos, organic vapors, and airborne radioactive particulates and gases has been part of the monitoring program. Results of the monitoring program currently indicate that levels of constituents are similar to background levels or decrease rapidly with distance.

Runoff from the areas around the raffinate pits and the chemical plant is an important pathway for surface water transport of contaminants. The runoff generally follows the slope of the land to a surface channel near its point of origination. Transport over longer distances in the affected surface water system is then possible. Significant drainage systems include the channel from the Ash Pond spillway, the southeast drainage area, and the Frog Pond drainage channel. Surface water transport takes place from the Ash Pond, raffinate pit, and Frog Pond areas to the northwest toward Lakes 34, 35, and 36; Schote Creek; and Dardenne Creek. Runoff and sewer discharges to the southeast drainage are conveyed southeast toward the Missouri River.

The subsurface pathways in the vicinity of the raffinate pits and the chemical plant area which contribute to contaminant migration include:

- Buried sewer and process pipelines.

- Natural subsurface layers that encourage lateral spreading, including low permeability layers in the unsaturated zone.

- Solution features, fractures, joints, or other potential continuous lateral or vertical pathways in bedrock.

- Permeable media, such as permeable limestone, with an array of fractures, joints, or solution features.

Transport via groundwater has been shown to be one of the significant on-site and off-site pathways for contaminant migration to the north, northwest, and southeast areas of the site. Groundwater flow in the bedrock in the immediate vicinity of the site is characterized as a diffuse-flow system, with flow occurring along horizontal bedding planes and fractures, and vertical fractures with limited solution features. Off-site free-flow conduits caused by solution activity also appear to transport contaminants north of the groundwater divide toward Burgermeister Spring, Lake 34, Twin Island Lake, and Dardenne Creek and toward the southeast drainage area. With continued data collection and interpretation, other transport routes and areas of contamination may be identified. These areas are not expected to include significant contamination compared to the identified sources.

1.4 Applicable or Relevant and Appropriate Requirements

In Section 121 (d), CERCLA/SARA requires the cleanup of a site to comply with all applicable or relevant and appropriate requirements (ARARs). ARARs are the minimum requirements that a remedial action must meet. Under CERCLA/SARA, remedial actions must be protective of human health and the environment, be cost effective, and utilize permanent solutions and alternative treatment technologies to the maximum extent possible. ARARs may be classified in three general categories:

- Contaminant-specific — related to a particular pollutant in various environmental media (soil, water, air, biota).

- Location-specific — related to the particular geographical or archaeological area on or near the site.

- Action-specific — related to a particular remedial alternative identified for the site.

A discussion of the ARARs for the Weldon Spring chemical plant and raffinate pits remedial action is presented in the Feasibility Study for Remedial Action at the Chemical Plant Area of the Weldon Spring Site (DOE 1992b).

2 ENVIRONMENTAL DATA ACQUISITION & MANAGEMENT

A wide variety of environmental data have been collected in support of the Weldon Spring Site Remedial Action Project (WSSRAP). While a substantial amount of information was available from previous studies, the previous data were not sufficiently complete for Weldon Spring site characterization. Additional data collection activities were required. Those site characterization and environmental monitoring activities to be conducted at the site were identified through evaluation of remedial investigation/feasibility study (RI/FS)-environmental impact statement (EIS) requirements and existing preliminary data on contaminant sources. These activities included the acquisition of data relating to the chemical and physical characteristics of soil, groundwater, surface water, sludges and sediments, building waste and debris, and existing facilities.

The data resulting from these additional characterization activities have been used to further define the extent of soil, groundwater, surface water, and air contamination. Those media and existing structures and facilities were sampled in accordance with project quality assurance procedures, sampling plans, and health and safety plans to ensure that characterization data acquisition was performed in a controlled, systematic, and technically sound manner.

The database compiled from the characterization studies has been validated in accordance with the *Environmental Data Administration Plan* (EDAP) (MKF and JEG 1992a) for use in the RI/FS-EIS. Data validation was not completed for the data as presented in the characterization studies, and discrepancies may therefore exist between these earlier studies and the data presented in this RI Report. Where discrepancies may be noted, the data presented in the RI supersede the data presented in the earlier characterization documents.

2.1 Quality Assurance for Environmental Data

Procedural requirements for collection and analysis of characterization data and for database management are defined in the WSSRAP Environmental Quality Assurance Project Plan (EQAPjP) (MKF and JEG 1992e); soil investigation sampling plan; hydrogeologic investigation sampling plan; waste assessment sampling plan; geophysical/geotechnical investigation sampling plan; building characterization sampling plan; lake and stream sediment characterization and biouptake investigation sampling plans; and health and safety plans.

Data collected during this characterization effort provide a basis for modifying current health and safety plans (where required) to ensure worker protection, evaluating risk to public health and environment, defining site conditions for development of remediation measures, and modifying current and proposed monitoring programs. The following subsections present brief descriptions of the primary WSSRAP procedures and plans used to guide characterization data collection, analyses, and database management.

2.1.1 Project Management Contractor Quality Assurance Program

The *Project Management Contractor Quality Assurance Program* (QAP) (MKF and JEG 1992f) establishes quality assurance requirements for all activities performed at the WSSRAP by the PMC. The QAP is designed to comply with the quality assurance program requirements for nuclear facilities; ANSI NQA-1-1989, established by the American National Standards Institute (ANSI 1989), and the quality assurance criteria contained in U.S. Department of Energy (DOE) Order 5700.6C.

2.1.2 Environmental Quality Assurance Project Plan

Within the framework of the QAP, implementation of specific quality assurance/quality control (QA/QC) procedures for RI/FS activities is addressed in the Environmental Quality Assurance Program Plan (EQAPjP). The EQAPjP focuses on the U.S. Environmental Protection Agency (EPA) quality assurance requirements for characterization of the WSSRAP. The EQAPjP meets the requirements of applicable EPA guidance documents, including Part 1 of Region VII's Quality Assurance Program Plan (EPA 1986c) and EPA's Interim Guidelines and Specifications for the Preparation of Quality Assurance Project Plans, QAMS-005/80 (EPA 1983).

The EQAPjP presents the QA/QC program for conducting remedial investigations and environmental monitoring in support of the WSSRAP RI/FS-EIS. The purpose of the EQAPjP is to ensure that all data used to support decisions made by the DOE meet quality requirements imposed by Federal and State regulatory agencies. Specifically, the data collected at the Weldon Spring site must be of adequate quantity and quality to accurately characterize the site for use in evaluating and determining remedial measures.

The EQAPjP is supported by the WSSRAP standard operating procedures (SOPs), the WSSRAP Health and Safety Program, and investigation sample plans written for specific environmental tasks. Specific quality control procedures are detailed in the SOPs and in the individual remedial investigation sampling plans.

The EQAPjP addresses all 16 QA elements (see Table 2.1-1), as specified for environmentally related measurements by EPA's Office of Monitoring Systems and Quality Assurance (EPA 1983). Detailed descriptions of the procedures for each of these elements, as implemented in the site remedial investigation are presented in the EQAPjP.

2.2 Field Activities

The objectives of sample collection and field measurements were to obtain data that were representative and comparable. The locations of the sampling and field measurements were selected to meet the data gaps identified during evaluation of preliminary data. Field sampling plans provided guidance for all field work by defining in detail the sampling and data collection methods to be used for remedial investigation work. Field activities were also guided by health and safety plans. Adherence to procedures for field activities ensured the integrity of the data collected and the safety of the personnel involved in the collection process.

2.2.1 Field Sampling Plans

The purpose of the field sampling plans was to guide collection of data to confirm the presence or absence of contaminants and to identify the contaminant sources, modes of transport, directions of contaminant migration, and effect of the contaminants on public health and the environment. The field sampling plans included descriptions of objectives, work tasks, specific quality assurance procedures, and level of effort required for site characterization. The intent of the field sampling plans was to provide a detailed sampling rationale, including the sampling locations and the types and number of samples. Coupled with standard operating procedures and data quality objectives, the sampling plans presented a well-defined approach to data acquisition and were designed to permit detailed characterization of the site wastes, soil, groundwater, surface water, and facilities. Additional investigation requirements may be recommended during a later stage of the RI/FS-EIS process, if specific needs are identified. Investigation sampling plans are briefly described below. Each specific plan should be consulted for a detailed explanation of sampling procedures. The results of these field investigations are summarized in Section 3 of this report.

2.2.1.1 Soil Investigation. The soil investigation sampling plan was designed to establish the appropriate sample collection procedures and methods required to generate the data necessary to determine the extent and magnitude of chemically contaminated soil, to evaluate contaminant migration pathways, to document uncontaminated areas, to establish background concentrations, and to provide identification of soil contaminant concentrations in both qualitative and quantitative terms for the 88-ha (217-ac) raffinate pits and chemical plant area (MKF and JEG 1988j).

2.2.1.2 Hydrogeologic Investigation. The purpose of the hydrogeologic investigation sampling plan was to guide the collection of data necessary to characterize the groundwater and surface water conditions at the raffinate pits and chemical plant area. The sampling plan was divided into subtasks that included groundwater monitoring, aquifer testing, analysis of hydrogeology, assessment of surface water hydrology and quality, and studies of regional hydrogeology and water balance (MKF and JEG 1988t).

2.2.1.3 Waste Assessment. The purpose of the waste assessment sampling plan was to establish data collection procedures necessary to acquire sufficient information to characterize the wastes, sludge, and sediment contained in the raffinate pits and the wastes resulting from decontamination and decommissioning of the buildings and associated equipment at the chemical plant area (MKF and JEG 1988i).

2.2.1.4 Geophysical/Geotechnical Investigation. The purpose of the geophysical/ geotechnical investigation sampling plan was to establish the necessary guidelines for obtaining the information required to physically characterize the site soil, substrata, and bedrock; to delineate the tests necessary to support the risk assessment; and to evaluate on-site earthen materials proposed for suitability as a containment liner for the disposal cell (MKF and JEG 1988n).

2.2.1.5 Buildings Characterization. The purpose of the buildings characterization sampling plan was to provide a systematic approach to collecting the samples required to characterize radiological, asbestos, and chemical contamination in and around the buildings and structures at the Weldon Spring chemical plant site. The purpose of these sample collection activities was to determine the magnitude of radiological, asbestos, and chemical contamination; to document uncontaminated areas; and to identify radiological, asbestos and chemical concentrations in qualitative and quantitative terms (MKF and JEG 1988o).

2.2.1.6 Other Investigations. Other investigations included biouptake study and a lake and stream sediment characterization (MKF and JEG 1987l). The purpose of the lake and stream sediment characterization was to determine the extent and magnitude of potential chemically and radioactively contaminated sediments in off-site streams and surface water bodies. The objective of the sampling effort was to determine the concentrations of uranium, nitroaromatic compounds, PCBs, semivolatile compounds, and metals in lake and stream sediments affected by drainage from the raffinate pits and chemical plant area.

The purpose of the biouptake study (MKF and JEG 1987b) was to determine and characterize the level of potential human exposure to chemical and radiological contamination through ingestion of potentially contaminated fish and game in the vicinity of the raffinate pits and chemical plant area. The objective of the study was to sample biota available for human consumption from various locations around and within the raffinate pits and chemical plant area.

2.2.2 Health and Safety Plans

Health and safety plans have been developed to ensure the health and safety of on-site personnel during the performance of site characterization and response action activities. The plans include the safety standards that must be met by all personnel and subcontractors during the conduct of their assignments. Addressing the health and safety of on-site personnel also serves to minimize any potential impacts on the general public and the nearby environment. Key elements of these plans are the use of appropriate protective equipment and safeguards and the performance of specific tasks under the supervision of trained technicians and safety specialists. On-site personnel are trained to be cognizant of all appropriate safety equipment and procedures, locations and types of on-site hazards, standard operating procedures, and procedures to be followed in emergency situations. Health and safety training and medical surveillance of all potentially exposed personnel are required elements of these plans.

2.2.3 Emergency Preparedness Plan

An emergency preparedness plan has been developed to provide on-site personnel with appropriate procedures for notification/reporting and organizing personnel in the event of an on-site emergency. This plan also includes the procedures for responding to potential credible emergencies that could result in off-site release of hazardous materials. Such emergencies include fire, tornado, failure of a raffinate pit dike, and spills of hazardous materials. This plan fulfills the requirements of DOE Order 5500.2.

2.2.4 Sample Management and Tracking

A major component required for all field investigation sampling plans is maintenance of sample integrity from collection through data reporting. The process of preserving sample integrity includes the use of shipment seals, sample labels with sample identification numbers to allow for sample tracking, field logbooks, field data record forms, chain-of-custody records, sample analysis request sheets, receipts, bills of lading, and field and laboratory tracking forms. To maintain and document sample possession, chain-of-custody procedures are followed. These procedures specify that field and laboratory sample custodians or their designated representatives are responsible for maintaining custody of samples.

Samples obtained during this investigation were collected and preserved in accordance with WSSRAP specific procedures and approved sampling plans. These plans and procedures were developed using EPA guidance regarding sample collection and preservation as well as sample integrity. WSSRAP procedures include documentation requirements for sample identification, recording of sampling locations, and specific considerations associated with sample acquisition. Applicable forms for recording these collection data and sample tracking, as required by the chain-of-custody procedures, are presented in the SOPs. In-situ measurements, e.g., pH, temperature, conductivity and flow measurements, and air monitoring data, are recorded in field logbooks or on field data record forms. All shipments of samples to laboratories are accompanied by field chain-of-custody records.

All samples are packaged and shipped to the laboratories in accordance with U.S. Department of Transportation procedures with a separate custody record accompanying each shipment. Samples are shipped in a timely manner to ensure that holding times for extraction (if required) and analysis as specified by EPA or other analytical protocol are met. An authorized sample custodian at the laboratory facility signs for incoming field samples, obtains documents of shipment, and verifies data entered onto the sample custody records. The laboratory is required to inform the PMC of receipt of samples within one working day. If any damage or shipping discrepancy is noted upon receipt of samples, the laboratory is required to inform the PMC immediately. Contract laboratories are required to maintain custody of samples as described in the EQAPjP.

2.3 Analytical Methods

Analytical methods used for analyses of WSSRAP samples are listed in Table 2.3-1. These analytical methods correspond to Level 3 and Level 4 analyses as defined in the *Data Quality Objectives for Remedial Response Activities* (EPA 1987). Detections limits are presented in the EDAP.

2.4 Database Management

The database management process began with the recording of environmental sample information on field data sheets by the sampling personnel. This sample information was recorded at each of the locations where groundwater, surface water, source samples, sediments, air particulates, soils, asbestos, or biota were collected. The field data forms included sampling date, sampling personnel, sample identification, sample location, in situ test results, and other data applicable to the conditions at the time of the sampling event (and the location where the data are stored and filed in the WSSRAP filing system).

Samples were prepared for shipment to the laboratory according to defined methods for handling and preservation of various sample types. Site-specific sample labels, laboratory authorizations, and completed chain-of-custody forms accompanied the samples to the laboratory. Chain of custody was recorded at each stage of sample transfer.

After the samples were analyzed for the parameters indicated on the laboratory authorization, the data were received in hard copy and electronic format from the laboratory. The information received from the laboratory included the WSSRAP sample identification; the laboratory sample identification; the date sampled, the date extracted (if applicable), the date analyzed; the method of analysis, matrix, and parameter; the data (concentration), error limit (+/-), and units; the detection limit (lab method detection limit), and a discussion of interferences as well as comments about the samples.

The electronic data were added to the WSSRAP environmental database. The analytical values for soils, sediments, and sludges were added to the database on a dry weight basis. However, due to the protocols associated with radiochemical analyses and due to the extreme toxicity of the raffinate pit sludges, the data for these analyses were added on a wet weight basis. The laboratory data sheets were compared directly with the electronic data to detect any transmission or transcription errors, thereby maintaining the integrity of the sample data. The database was equipped with controlled access security and was backed up at appropriate intervals on magnetic tape according to standard operating procedures.

The structure of the database and the use of custom software permits retrieval of the environmental data under a variety of options. This structure has been designed to facilitate data retrieval using sample identification as well as location-specific and media-specific search capabilities. This ability greatly enhances the usefulness of the database for continuing interpretation and for application within the FS process.

2.5 Data Quality Assessment

The data have been examined to verify their validity and to determine whether they meet the Data Quality Objectives (DQOs) for completeness, precision, accuracy, and representativeness. All available information has been reviewed by independent parties to assess the characteristics of the data.

2.5.1 Data Validation Objectives

The goal of the validation effort was to determine whether data quality requirements were met. Meeting this goal required the review of the records from field, laboratory, and audit activities to evaluate the quantity, quality, and integrity of the data. Laboratory and field quality control information was reviewed and compared to previously established performance criteria to determine whether precision and accuracy goals were met.

2.5.2 Data Validation Methods

The data validation process involved a detailed review of the laboratory records and procedures associated with the acquisition and reporting of the data. Analytical documents, such as instrument printouts, sample and standard preparation logs, analytical run logs, and data summary sheets, were reviewed to trace the analyses from beginning to end; calculations were repeated; accuracy and precision measured; and the final results compared to those previously reported. The usefulness and confidence level of the reported data were assessed based on the availability of laboratory documentation and the outcome of the validation review process. The reviewed analyses and data were judged against the WSSRAP Data Quality Requirements as presented in the EDAP, and the accepted analytical protocols (i.e., EPA Contract Laboratory Program (CLP), U.S. Army Toxic and Hazardous Materials Agency (USATHAMA)). A series of validation qualifiers were assigned to each data point which signified its acceptance or rejection. The qualifiers were made available to the data users through the qualifier field in the WSSRAP database. Table 2.5-1, Data Quality Assessments, outlines the data characteristics, the records which were reviewed, and the criteria to be met.

2.5.3 Data Validation Report

The database validation process was initiated to ensure the quality of the data for use in the WSSRAP. The results have been documented in a comprehensive report (MKF and JEG 1992b). Each of the data characteristics, which are listed in Table 2.5-1, are addressed using the data collected during the review process. The report describes the methodology used to evaluate each characteristic. In addition, data quality statements are prepared for each contaminant of concern for each medium in which it was found. A review of in situ radiological measurement data is presented to indicate collection methods, data handling procedures, and data quality.

3 WELDON SPRING SITE INVESTIGATIONS

This section briefly describes previous site investigations. Results of these investigations are presented in Section 5 of this report.

3.1 Contaminant Source Areas

Six main contaminant source areas exist at the Weldon Spring site which affect the various environmental media. These areas were identified as contaminant sources based on records of past site activities, including processing and burning, and based on the locations of known storage facilities, dumps, and spills.

The six main contaminant source areas are:

- Chemical plant buildings and facilities, including the coal storage area and the portion of the ordnance works underlying the present site.
- Raffinate pits.
- Ash Pond area, including the south dump.
- The north dump.
- Frog Pond.
- The southeast drainage, including the southeast site area.

These areas are shown on Figure 3.1-1. Sources, contaminants, and affected media are summarized in Table 3.1-1.

Numerous previous investigations, summarized in Table 1.2-1, provided preliminary information on the nature and extent of contamination from these sources. Many of these data served as background information for the design of sampling plans for the characterization studies later conducted by the Project Management Contractor (PMC).

3.1.1 Chemical Plant Buildings and Facilities

The U.S. Department of the Army (DA), Ryckman, Edgerly, Tomlinson and Associates (RETA), Bechtel National, Inc. (BNI), and the PMC conducted investigations to determine the types and amounts of chemical and radiological contamination associated with the chemical plant buildings and other facilities, including overhead outdoor utilities, railroad rails and ties, and electrical transformers. Each investigation is summarized below. Additional detail concerning individual building descriptions and radiation measurement results can be found in the Weldon Spring chemical plant buildings radiological characterization report (MKF and JEG 1990a).

Although the RETA report, the BNI report, and the PMC report all use the term "releasable," they do not necessarily mean the same thing. RETA used different criteria for releasability than BNI or the PMC. BNI and the PMC used the same surface contamination guidelines (DOE Order 5400.5, Radiation Protection of the Public and the Environment), but the BNI report is not always clear about which guidelines for which radionuclide are being applied. Both the RETA and the BNI report discuss the percentage of a surface that is releasable, but the PMC report states that a surface either is or is not releasable for unrestricted use. For example, 65% of a floor contaminated heterogeneously cannot be released for unrestricted use while the remainder is designated as restricted. Only the PMC survey required that a set of measurements on a surface conform to the six criteria listed in Section 3.1.1.4 for that surface to be considered potentially releasable for unrestricted use.

3.1.1.1 U.S. Department of the Army - 1969. The first major building survey for radiological contamination was conducted by the DA in May 1969. The results of this survey were reported by Colonel Walter J. Davies, Acting Commander of the Weldon Spring Site, to William L. Hungate, U.S. House of Representatives, on October 7, 1969 (DA 1969). Twenty-nine buildings were included in the survey. Eleven of these buildings were considered grossly contaminated, and the remaining 18 were contaminated to a limited degree or were considered free of radioactive contamination. Buildings 302, 401, 406, 408, 409, 410, 412, 413, 414, 417, 429, 433, 435, 436, 437, and 438 either were estimated to be free of radioactive contamination or could be cleaned to meet Atomic Energy Commission (AEC) guidelines. No information is provided in the survey report addressing the specific AEC guidelines applied. Buildings 103 and 105 would require some work to be decontaminated to AEC guidelines for unrestricted use. The refining facilities, buildings 101, 108, 201, 202, 301, 403, 404, 405A and B, 407, and 434, were so highly contaminated that decontamination of these buildings was not considered economically feasible.

For most of the buildings only estimates of contamination, based on professional judgment, are available. Specific measurement locations and results are available for buildings 101, 103, 105, and the surrounding concrete pads. However, these results cannot be considered an accurate representation of existing radioactive contamination levels, since there have been unquantifiable changes in site conditions since these measurements were taken. The DA survey is therefore useful only as a very general indicator of which buildings are contaminated.

The DA conducted additional radiological surveys during the period from 1969 to 1972. These surveys were conducted in 23 buildings to determine the decontamination effort necessary to release the buildings for unrestricted use. The results of these surveys indicated that only three minor structures, the magnesium storage building, the cooling tower, and the steam plant, could possibly be released for unrestricted use without decontamination. It is further indicated, however, that if more comprehensive surveys were performed in these three structures, contamination in excess of unrestricted use release guidelines may be present (DA 1976).

3.1.1.2 Ryckman, Edgerly, Tomlinson and Associates - 1977. Thirty-five buildings were surveyed by RETA in 1977, under contract to the DA. RETA was to determine if the buildings, equipment, and realty of the Weldon Spring chemical plant could be released for public or private use where contamination was not detrimental to such use or where decontamination for unrestricted use could be achieved. If unrestricted use was not feasible, the DA was interested in identifying alternatives to maximize the site's use while maintaining compatibility with surrounding land uses.

RETA used four methods to determine the level of radioactivity on building and equipment surfaces: surface wipes for loose alpha radiation, total alpha radiation measurements, total beta-gamma radiation measurements, and gamma spectroscopy using a portable spectrometer. These methods are discussed in detail in the RETA Phase II report (1977). In addition to the four measurement types discussed above, swipes and residues from the buildings and the equipment were measured with alpha and gamma spectroscopy. These measurements identified the particular isotope or isotopes present.

RETA collected two types of air samples in the buildings: area samples and lapel (breathing zone) samples. The samples were exclusively of airborne radioactive particulates. The filters were analyzed for alpha particle emission rate using a gas flow proportional counter.

An engineering and radiological survey of process, utility, maintenance, and laboratory equipment was also conducted. The engineering survey included inspection of equipment items for general salvageability and the tagging of items for identification. A total of 921 items were inspected and tagged. The inspection and tagging effort was not an exhaustive inventory of plant equipment but focused on major components and items offering the greatest potential for salvage and recovery. The radiological survey of equipment throughout the plant revealed that 21% of the items surveyed exhibited no contamination.

The results of the RETA survey indicated that, in general, horizontal surfaces (floors, ledges, platforms) were the most contaminated. Vertical surfaces were usually either uncontaminated or could be decontaminated with a general wash down. Major exceptions were the wall surfaces adjacent to equipment which processed radioactive material in a manner that caused dust or material to be sprayed onto the wall surface. Uranium was found to be the main radioactive contaminant. Natural thorium, thorium-232, and radium-226 were also detected in some buildings.

In addition to documenting the levels of contamination on buildings and equipment, the RETA report provides estimates of the percent of radiation measurements that fall into each of the previously defined categories of contamination. The report also identifies the general areas in a building which contain elevated contamination levels and identifies the specific radionuclides found in each building. Generally, the report provides an overall picture of the relative degrees of contamination in and between buildings and equipment.

Although the RETA report compares measurement results in the buildings to U.S. Department of Energy (DOE) guidelines for unrestricted use, the data are not comprehensive enough to release materials from the site for unrestricted use. If releasing materials from buildings characterized by RETA from the site is determined to be practical, more thorough radiation surveys will be performed.

3.1.1.3 Bechtel National, Inc. - 1986. From March to May 1986, BNI began detailed radiological characterizations of the structures at the chemical plant. The principal objectives of BNI's efforts were to determine the radiological status of each chemical plant structure and to describe the location and magnitude of contamination on the structure itself, as well as on equipment within the structure. A minor objective was to gather data to chemically characterize the chemical plant structures. The usefulness of the chemical data acquired during BNI's characterization efforts is extremely limited because only pH and combustible gas measurements were taken, and in only a few locations (BNI 1986d).

The BNI survey included measurements of total and removable alpha radiation, total and removable beta-gamma radiation, and gamma ray exposure rates. BNI also collected residues from floors and equipment to identify the radionuclides present.

Samples of airborne particulates were collected with a high-volume air sampler at several grid locations within each building. Individual breathing zone samples were collected using low-volume personal sampling pumps.

The BNI report provides a breakdown of the number of surface radioactivity measurements that exceed DOE unrestricted use guidelines. The BNI report also discusses the rationale used for determining which guideline applied to a specific building.

The BNI survey was terminated in May 1986. At that time, only buildings 201, 301, 403, 404, 405A, and 405B had been surveyed. The survey reports are in various degrees of completeness, depending on how far the survey had progressed before BNI's activities were halted. The data collected by BNI revealed significant contamination of all buildings, which is not surprising since all these buildings were used for processing uranium and/or thorium.

3.1.1.4 Project Management Contractor - Various Dates. Beginning in 1986, the PMC began several radiological and chemical investigations of individual buildings, facilities, and equipment.

From October 1988 to March 1989, the PMC collected data in support of a radiological characterization of the buildings where uranium had not been processed. The characterization efforts included radiation measurements on all building surfaces, such as walls (interior and exterior), exterior roofs, interior ceilings, floors, interior beams, and interior columns, as well as radiation measurements on pieces of equipment.

The purpose of this characterization was to determine which building components or equipment could potentially be released for unrestricted use. Key criteria were established in the *Buildings Characterization Sampling Plan* (MKF and JEG 1988o) for determining whether a material could be released for unrestricted use. The criteria that had to be met before release could occur were:

1. No single surface measurement could be greater than the DOE unrestricted use guidelines.
2. The measurement data on a material must be normally distributed.
3. The true mean surface radiation level must be estimated to within ±20% with 90% confidence.
4. The estimated probability of exceeding surface contamination guidelines for any single measurement taken from any location on a surface must be less than 0.02%.
5. The contamination must be surficial only.
6. The identity of the radionuclides must be known.

The PMC survey found that horizontal surfaces were usually more contaminated than vertical surfaces. This is true for both interior and exterior surfaces and agrees with RETA's findings. Areas such as hallways, which were more heavily traveled than surrounding areas, were usually more contaminated. Core samples showed that most, although not all, of the floors had surficial contamination only.

Process buildings were in general more heavily contaminated than non-process buildings. Uranium was found to be the principal contaminant, although some natural thorium and radium were also found, as well as some thorium-230 and thorium-228.

Most of the air samples collected were below DOE Derived Air Concentration guidelines. Only a few air samples exceeded the guidelines; however, additional air samples will be collected in each building before dismantling is begun to ensure proper worker protection.

Surveys were also conducted to determine the amount of asbestos-containing material (ACM) in the outdoor overhead utilities and buildings. A survey to characterize the asbestos content of insulation on outdoor overhead utilities was conducted in November 1986. Exterior bulk sampling was used for this characterization. Samples were collected from 10 locations within the chemical plant complex (Figure 3.1-2). The sampling locations were selected so that insulation on all types of pipe (steam, raffinate, ethylene glycol, and process) and all sizes of each type of pipe could be sampled. (MKF and JEG 1987s)

Sampling for preliminary identification of interior ACM was conducted in August 1986 and May 1987. The objective of the interior bulk sampling was to identify typical building materials, such as equipment insulation, which contain asbestos rather than to conduct a comprehensive survey of the site for ACM.

In late 1988 and early 1989, the PMC conducted a chemical sampling program in the non-process buildings. This program was designed to sample for asbestos and polychlorinated biphenyls (PCBs). No pipe insulation was sampled for asbestos, since previous surveys indicated all pipe insulation could be assumed to contain asbestos. Materials such as vinyl asbestos-containing floor tiles and Transite board were sampled (MKF and JEG 1989d).

Two types of samples for PCBs were collected: bulk and swipe samples. Bulk samples included sediment, floor and ceiling tiles, and electrical lighting fixture ballast (MKF and JEG 1989d). Swipe samples were taken from the floor areas of the various buildings.

The contents of numerous tanks, drums, and miscellaneous containers were sampled as part of the containerized chemical inventory. These materials are being managed as part of Interim Response Action 7 (Table 1.2-2).

Figure 3.1-3 shows potential nitroaromatic source areas on the site. A small surface impoundment located northwest of the Missouri Highway Department facility and 76.2 m (250 ft) north of the site was used as a wastewater retention basin for the Weldon Spring ordnance works prior to the completion of the wastewater treatment plant in 1943. Overflow from disposal lines and direct discharge of wastewater from certain buildings to surface drainageways was observed prior to completion of the treatment plant. The portion of the ordnance works underlying the chemical plant and raffinate pits is shown on Plate 1. Affected media were sampled for nitroaromatic compounds during soil, surface water, and groundwater investigations conducted by the PMC.

3.1.2 Raffinate Pits

The raffinate pit sludges have been analyzed for physical, radiological, and chemical properties by the U.S. Geological Survey (USGS), BNI, and the PMC. Surface water samples have been collected and analyzed for contaminants by the USGS, BNI, and the PMC.

3.1.2.1 Bechtel National, Inc. - 1983 (with Eberline Instrument Corporation). BNI contracted with Eberline Instrument Corporation in 1983 to sample the wastes in the raffinate pits and to analyze them for metals and radioisotopes. The analyses were performed on a single composite sample from each pit.

3.1.2.2 Bechtel National, Inc. - 1983 (with Environmental Science and Engineering, Inc.). In 1983, BNI contracted Environmental Science and Engineering, Inc., to sample and test the raffinate pit sludges to define the physical properties of the sludges. Sampling was performed by Monteagle, Inc., with Environmental and Energy Consultants and Reitz & Jens, Inc., performing the tests.

The initial intent of this study was to select on the basis of test results the type and size of mechanical dewatering equipment best suited to dewater the raffinate pit sludges. Early test results indicated the sludges had a considerably higher solids content than expected. For this reason, all further tests related to mechanical dewatering were stopped and replaced with a series of tests useful for the development of other treatment options.

3.1.2.3 Bechtel National, Inc. - 1986 (with Thermoanalytic/Eberline Laboratory). BNI conducted an initial Resource Conservation and Recovery Act (RCRA) characteristic sampling program for the raffinate pit sludges in 1986. Twenty-eight sample locations were chosen using a random number generation method. At each location, up to three samples were obtained and sent to the Thermoanalytic/Eberline Laboratory in Albuquerque, New Mexico, for radiological analysis. Eighteen samples were analyzed for extraction procedure (EP) toxicity, reactivity, ignitability, PCBs, and pH (BNI 1986b).

3.1.2.4 Project Management Contractor - 1987. Surface water samples were collected from the four raffinate pits as a part of the Phase I water quality assessment conducted by the PMC in April 1987. Samples were collected from at least four locations from the shore of each pit and composited to achieve representative samples from each pit for analysis (MKF and JEG 1987o).

3.1.2.5 Project Management Contractor - 1988. Characterization of the raffinate pits was undertaken by the PMC in 1988. The results of previous radiological and chemical characterizations identified the types of radionuclides and chemicals in the raffinate pit water and sludges. Additional testing was necessary to define the radioactive and chemical sources in the raffinate pits and to further characterize substances which may have been dumped during operation of the chemical plant and subsequent cleanup activities.

More in-depth radiological characterization of the raffinate pit sludges was necessary to accurately determine the concentrations of radionuclides in the sludges. The importance of accurately determining these concentrations is twofold. First, the radium-226 source term must be estimated to allow design of a radon-222 barrier as part of a remediation alternative engineered cover. And second, to assess the feasibility of recovering constituents (radionuclides or metals) from the sludges (MKF and JEG 1989e).

The purpose of the chemical characterization of the raffinate pit sludge material was to define the degree of contamination so that an appropriate treatment process and the magnitude of the effort required to ultimately dispose of the wastes could be quantified. The nature and variability of contaminants within the sludges will determine the disposal alternatives to be evaluated. Knowledge of these contaminants is necessary to establish the requirements for engineering design and treatability testing (MKF and JEG 1989c).

Physical characterization was undertaken to determine the degree of heterogeneity of the sludge, both horizontally and vertically, within each pit. Because previous studies had indicated a random pattern of varying physical characteristics, sample locations were based on an even distribution across each pit. Characterization performed was adequate to conclude that the sludges are highly heterogeneous and that the solids content may be sufficiently high to preclude the effective use of solely mechanical dewatering techniques. In addition, selected physical parameters were examined to determine the feasibility of various methods of stabilization.

3.1.2.6 U.S. Geological Survey - 1989, 1990. The USGS conducted an investigation of geochemical aspects of contaminant transport in the vicinity of the raffinate pits (USGS 1990). Samples of surface water were obtained from pits 3 and 4, and samples of sludge were obtained from pit 3. Additionally, experimental in situ dialysis cells, referred to as passive interstitial geochemical samplers, were placed at various depths in the sludge in raffinate pit 3 (Skelton 1990). Soil moisture samples from lysimeters and groundwater samples from monitoring wells located near the raffinate pits were also obtained for the purpose of equilibrium geochemical modeling.

In addition to investigating conditions in the vicinity of the raffinate pits, the USGS analyzed samples of unconsolidated overburden material, surface water, and groundwater as part of its hydrological and geochemical investigation in the Weldon Spring area.

3.1.3 Ash Pond

Surface water runoff from the north and west sides of the chemical plant area flows to Ash Pond. A significant portion of this runoff flows through the south dump area, picking up a major portion of its contamination before entering Ash Pond. The south dump was used as a burn area for combustible material, including trash and contaminated personal protective equipment. Some of this material was covered with dirt as the dump was continually graded to allow truck access. The south dump also served as a surface storage area for drums, hoppers, rubble, and other debris. Some of the drums and debris are still present in the area; the drums contain yellowcake, a uranium concentrate.

Four investigations have been conducted at Ash Pond. BNI sampled the Ash Pond outfall in February and March of 1985 (Coxon 1985). In 1987, the USGS and the PMC conducted studies which included sampling and analysis of Ash Pond water (Kleeschulte and Emmett 1987; MKF and JEG 1987o), and the PMC characterized the radiological and chemical constituents of the soil in the Ash Pond area to prepare for the construction of the Ash Pond isolation dike. This construction was completed in April 1989.

3.1.4 North Dump

The north dump area is located along the northern perimeter of the site and was used to store barrels containing radioactive material. Radiological soil surveys of this area were conducted as part of the RETA (1977) study and by the PMC in 1988 (MKF and JEG 1988q).

3.1.5 Frog Pond

Surface water from Frog Pond flows into Lake 36 in the Busch Wildlife Area. The 1987 USGS water resources investigation (Kleeschulte and Emmett 1987); the Phase I water quality assessment by the PMC in 1987 (MKF and JEG 1987o); and the annual environmental monitoring, also by the PMC in 1987 (MKF and JEG 1988s); included sample acquisition from Frog Pond surface water.

3.1.6 Southeast Drainage Area

The southeast drainage area receives surface water runoff from the southern and southeastern portions of the chemical plant area and flows to the Missouri River. During past operations at the chemical plant, the southeast drainage also received infiltration and inflow from the sanitary and process sewers. This area was surveyed for radiological soil contamination by Oak Ridge Associated Universities (ORAU) (1986a, 1986b). Sampling and analysis of surface water was performed by RETA (1977), ORAU (1986a, 1986b), and the PMC (MKF and JEG 1989h).

The southeast drainage area is preliminarily defined as the area of the drainage downgradient from the chemical plant boundary. Contamination may continue to enter the southeast drainage until cleanup activities at the chemical plant site are complete. The southeast drainage area will therefore be further characterized and, after the chemical plant site cleanup is complete, will be the subject of a separate decision-making process regarding any future actions.

3.2 Soil Investigations

Several soil investigations have been conducted to determine the nature and extent of radiological and chemical contamination of the soils at the site and vicinity properties. These investigations were designed based on knowledge of past operations at both the ordnance works and the uranium feed materials plant and the various chemicals used during processing.

3.2.1 Chemical Soil Contamination

Chemical soil investigations have focused on determining the level of contamination from nitroaromatic compounds produced during ordnance works operation. In addition, numerous anions and metals have been identified which are the result of uranium processing activities at the feed materials plant.

3.2.1.1 Department of the Army - 1975. Twenty surface soil samples were collected in 1975 by the U.S. Army Chemical Demilitarization and Installation Restoration (DACDIR) team to provide a general assessment of the residual explosives present on site from previous ordnance works operations (DA 1976). Most of the surface and subsurface sampling points were located in areas suspected of containing the highest level of nitroaromatic contamination on site, including building foundations, wastewater lines, and the area in and around the burning ground. Eight subsurface soil samples were also collected at this time by the U.S. Army Corps of Engineers (COE) - St. Louis District.

Soil samples collected by both DACDIR and the COE were analyzed for the quantitative determination of 2,6-DNT, 2,4-DNT, and TNT. The analytical results indicated low-level contamination (< 1 mg/kg) of the soil by all three nitroaromatic compounds.

3.2.1.2 PMC Phase I Chemical Soil Investigation - 1987-1988. The Phase I chemical soil investigation (MKF and JEG 1988l) was designed to provide baseline data regarding chemical soil contamination and to develop information on the on-site background metal concentrations at the site. Sampling locations were selected to investigate potential chemical soil contamination source areas from both TNT production and uranium processing, concurrently with a radiological soil contamination characterization performed by UNC Geotech (see Section 3.2.2).

The Phase I effort consisted of the collection of 135 samples from 32 boreholes within the 88 ha (217 ac) of the chemical plant and raffinate pit sites. Five other boreholes were drilled immediately adjacent to the chemical plant, four of which were drilled into the ordnance works waste lagoon 1, which is located just northeast of Frog Pond. One borehole was located between the chemical plant boundary and the ordnance works waste lagoon 1. Borehole locations are shown in Figure 3.2-1.

The selection of analytical parameters was based on results of the Phase I water quality assessment (MKF and JEG 1987o) which identified elevated levels of nitroaromatics, nitrate, sulfate, fluoride, and metals in the groundwater beneath the chemical plant and raffinate pits. The Phase I water quality assessment is discussed in Section 3.3.3. The Phase I soil samples were analyzed for these parameters as well as for chloride and percentage moisture.

3.2.1.3 PMC Phase II Chemical Soil Investigation - 1989. The Phase II chemical soil investigation was designed to fill data needs identified from the review of previous studies. Information obtained from the Phase II investigation, applied in concert with the previously existing soil data, was used to identify contamination source areas, determine the extent and magnitude of contamination, evaluate migration pathways, document uncontaminated areas, and provide a database for the preparation of the baseline assessment.

Because of the size of the site and the diversity of activities that occurred, two sampling approaches—biased and unbiased—were used to provide comprehensive soil contamination characterization. The biased sampling locations were selected based on historical documentation relative to ordnance works and feed materials plant operations and the results of the more recent site investigations. Cut and fill activities were also evaluated in determining sampling locations and depths. Unbiased sampling was conducted across the site to provide a statistically valid database for soil characterizations and to document uncontaminated areas.

Soil samples were collected from 245 locations within the chemical plant and raffinate pit areas. Sampling locations were surveyed to establish horizontal and vertical control prior to sampling. Soil samples were collected using continuous sampling equipment driven through conventional hollow-stem augers. This sampling method provided relatively undisturbed samples for chemical analysis and lithologic logging (MKF and JEG 1989a).

3.2.2 Radiological Soil Contamination

Investigations of radiological soil contamination have been conducted at the site and at vicinity properties near the site. The purpose of these studies was to assist in determining the volume of soil requiring remediation and to identify potential remedial technologies as part of the feasibility study.

3.2.2.1 Site Radiological Soil Surveys

3.2.2.1.1 U.S. Army Radiation Control Survey - 1975. A radiological survey was conducted in September 1975 by the U.S. Army Radiation Control (RADCON) team to determine outdoor areas of contamination, identify contaminants, and assess the potential radiological hazard to the properties surrounding the site (DA 1976).

Initially, the RADCON team surveyed the perimeter of the site at the boundary fence and 10 m (32.8 ft) inside the fence. Measurements were taken on the ground surface at 76-m (250-ft) intervals. The radiological survey also included the area covered in transit between survey points. This approach was employed throughout the survey making it possible to locate contaminated areas that were not on the formal survey plan. The survey was supplemented with readings from around exterior walls of buildings. Additionally, areas adjacent to surface drainages were surveyed, and water samples were collected at 10 locations where the survey indicated excessive radiological contamination or where surface water left the site.

3.2.2.1.2 Ryckman/Edgerley/Tomlinson & Associates - 1977. In 1977, another radiological survey was performed by RETA under contract to the DA. This radiological survey of soils and sediments was designed to define the extent and degree of contamination at the chemical plant. The plant site perimeter was surveyed using hand-held beta and gamma survey meters. Measurements were taken every 3 m (10 ft) along the fence line and approximately 1.5 m (5 ft) to either side of the fence. Dump areas on the north and south sides of the site between Ash Pond and the raffinate pits were also surveyed. At all sites where surface radiation levels significantly exceeded background levels, sample holes were bored and soil samples were taken. The holes were then logged with a sodium iodine (NaI) probe, and a vertical radiation profile was obtained. This information was used to determine the depth and extent of soil contamination (RETA 1977).

3.2.2.1.3 Bechtel National, Incorporated - 1983. In support of construction work and technical evaluation of site geology, a radiological survey of the raffinate pits was performed by BNI in June 1982, with a follow-up survey during the winter of 1982-1983. BNI used direct monitoring instruments in the collection of the gamma exposure rate measurements. These exposure rates were measured in 45 of a possible 64 grid center locations at the raffinate pit site. The measurements were taken one meter above ground with results reported in μR/h (BNI 1984b).

BNI also collected 70 surface and trench sidewall soil samples. The samples were analyzed wet and then dried and pulverized in a ball mill. The dried samples were analyzed by gamma spectrometry for uranium-238, radium-226, and thorium-232. The trench sidewall samples were collected from the sidewalls of 11 trenches located in the raffinate pit area. The sidewall samples were also analyzed for thorium-230.

3.2.2.1.4 UNC Geotech - 1987. In response to the need for additional data to complete an environmental impact statement in compliance with the National Environmental Policy Act and because there had been no broad data collection effort to identify radiological contamination in the chemical plant area, a focused sampling effort was conducted by UNC Geotech (UNC) from April through July, 1987 (UNC 1988). The UNC study report included descriptions of radiometric measurement methods, data reduction, sampling techniques, and sample analytical methods, as well as data summaries. UNC did not analyze the information derived from the characterization effort. The report presented the scope of the field activity, a description of the measurement methods, and a compendium of the results of sample analyses.

A combination of surface and subsurface radiometric measurements and surface and subsurface soil samples was collected. An on-site physical survey, which included the AEC coordinate system, was used to positively locate sampling locations.

Radiological data collected included:

- Near-surface soil sampling
- Borehole drilling, sampling, and logging
- Spectrometer measurements
- Delta-gamma radium measurements
- Exposure rate measurements

A description of each measurement technique is provided in the UNC study report (UNC 1988).

3.2.2.2 Vicinity Properties Radiological Soil Surveys. Vicinity properties are defined as radiologically contaminated areas outside the perimeter of the chemical plant, raffinate pits, and quarry. These off-site areas of contamination resulted from previous AEC operations and continuing on-site waste storage.

Vicinity properties are located in the August A. Busch Wildlife Area, Weldon Spring Wildlife Area, and Army Reserve property. These areas are shown on Figure 3.2-2, along with radiologically contaminated areas that have been cleaned up.

The U.S. Army Reserve property is a fenced area located to the west of the chemical plant occupying approximately 670 ha (1,660 ac). The land is level to rolling. Portions of the property are cleared and easily accessible, while other sections are wooded or overgrown with heavy brush. An extensive system of drainage ditches controls surface runoff. The site contains numerous paved and unpaved roads, several inactive railroad tracks, a few small lakes and ponds, and many small buildings including remnants of buildings that were associated with ordnance manufacturing operations.

The Busch Wildlife Area, north of the DA and DOE properties, is primarily composed of gently rolling terrain, varying from cleared recreational areas and leased farm lands to heavily overgrown and wooded sections. The area contains numerous lakes that are fed by springs and small drainage streams. Two larger streams, Dardenne Creek and Kraut Run, are located on the northern portion of the area. The central portion of the Busch Wildlife Area is readily accessible by many paved and gravel roads. The northern, eastern, and western sections of the area contain fewer roads and trails, and some locations are relatively inaccessible. Structures on the area include the site management headquarters and several residences which are occupied by Missouri Department of Conservation (MDOC) employees. Bunkers, originally constructed for ordnance storage, are also located along roads throughout the property.

The Weldon Spring Wildlife Area is located south and east of the DA and DOE properties. In contrast to the Busch Wildlife Area, the Weldon Spring Wildlife Area is primarily rugged, rocky terrain with ravines and bluffs. This area is largely undisturbed, heavily wooded, and contains regions of heavy underbrush. This area also contains several small lakes and ponds. Two abandoned quarries are located in the Weldon Spring Wildlife Area, the Hamburg quarry and the Weldon Spring quarry. There are a few interior roads, and this wildlife area is traversed by State Route 94. A railroad track once crossed the southern portion of the area between a bluff and the Missouri River. This track has been removed. Also, in the southern portion of the area between the chemical plant and the Weldon Spring quarry, there are several sections of out-of-service rail spurs. Surface water in this southern area includes the Little Femme Osage Creek, the Femme Osage Creek, and the Femme Osage Slough. A well field south of the area is the source of water for the St. Charles County Water Treatment Plant. Numerous drainages exist in the Weldon Spring Wildlife Area. One of these drainages, the southeast drainage area, serves as the main drainage pathway from the chemical plant to the Missouri River.

Radiological characterization of vicinity properties has been performed by ORAU and the PMC. ORAU characterized the U.S. Army Reserve Property from March through July 1985 (ORAU 1986a) and the two wildlife areas from July 1984 to September 1985 (ORAU 1986b). The PMC reviewed the ORAU characterization reports and collected additional data on all vicinity properties from May 1987 through April 1988 (MKF and JEG 1987c, f, g, and j, 1988k). Results of the radiological characterization program and an interpretation of those results are provided in Section 5.2.3.

3.2.2.2.1 Oak Ridge Associated Universities. The objective of the ORAU surveys was to provide an assessment of the radiological conditions present in the areas surrounding the chemical plant, raffinate pits, and quarry. Radiological information collected to accomplish this objective included:

- Direct radiation exposure rates and surface beta-gamma dose rates.
- Locations of surface residues emitting elevated levels of radiation.
- Concentrations of radionuclides in surface and subsurface soils.
- Concentrations of radionuclides in surface water and groundwater.
- Concentrations of radionuclides in stream, ditch, and lake sediments.

Descriptions of data collection and analysis methods are provided in the ORAU characterization reports (ORAU 1986a and 1986b). In general, ORAU was concerned with locating areas of radioactive contamination on vicinity properties; hence, data was collected to identify all locations with elevated radionuclide concentrations. The PMC characterization focused on determining the horizontal and vertical extents of contamination to estimate the volume of contaminated material associated with those areas identified by ORAU.

3.2.2.2.2 Project Management Contractor. Using the ORAU survey as a guide, the PMC resurveyed the non-drainage vicinity properties in 1987 to define more accurately the horizontal extent of contamination and to estimate contamination depths and volumes as well as to determine average radionuclide concentrations. The drainage areas were not resurveyed at this time because they will continue to be affected by runoff from the chemical plant.

The ORAU surveys were of a reconnaissance nature and provided information concerning locations of and maximum radionuclide concentrations found on vicinity properties. The purpose of the ORAU surveys was not to determine the estimated depths and/or horizontal extents of contamination. Instead, these surveys demonstrated the need for further characterization of vicinity properties.

To define the horizontal extent of contamination, the PMC reproduced the grid system that ORAU had defined and tied the grids to the permanent survey markers at each site. The PMC either expanded the grid system or decreased the grid intervals where greater concentrations of radioactivity were present.

Gamma radiation walkover scans were performed in the contaminated areas identified by ORAU, using NaI gamma scintillation probes coupled to portable ratemeters/scalers. The areas were surveyed by swinging the probe in a sinusoidal pattern close to the ground. Walking over the survey area in this manner provided essentially a 100% scan of the surface. In areas consisting primarily of soil, instrument count rates were used for preliminary delineation of surface areas of radiological contamination. Count rates indicative of contamination were based on a correlation of the gamma scintillation count rate with analytical results of soil samples obtained in contaminated areas. Soil samples were collected at various grid intersections and areas of elevated activity. To estimate the depth of contamination at each location, a hand-auger sampling tool was used to collect soil samples. Sampling was performed in 15-cm (6-in) increments until a background gross gamma scintillation count rate was obtained at the bottom of the sampling hole. These measurements were obtained with the same type of instrumentation used in the walkover survey.

Soil analysis was performed by the PMC on a high purity germanium gamma spectrometry system for uranium-238, radium-226, thorium-232 and thorium-230. Even though this system is typically used only for uranium, radium, and thorium-232, it has also been developed for screening for thorium-230. In addition to the above analyses, selected samples were analyzed for thorium-230 by a subcontractor laboratory using U.S. Environmental Protection Agency (EPA) procedures.

In November 1988 a low bias was discovered in all uranium-238 analyses performed by the PMC on soil samples collected on vicinity properties. The bias was introduced through use of an inappropriate detector calibration source. The bias was compounded for all analyses of samples collected on DA Vicinity Property No. 1 because these samples were not dried or pulverized prior to analysis.

After acquisition of a better calibration source, selected samples previously analyzed were reanalyzed. When a simple linear regression was performed on reanalysis results versus original results, the following equations were generated which correct the biased original results to the corrected values for samples from DA Vicinity Property No. 1 and for samples from all other vicinity properties on both DA and wildlife area properties.

(DA Vicinity Property No. 1): $y = 2.13\,x - 1.62$

(All other vicinity properties): $y = 1.62\,x - 2.1$

where y is the corrected uranium-238 concentration and x is the original uranium-238 concentration.

The overall impact of this bias is slight. Uranium-238 concentrations in soil were used mainly to define depths and boundaries of contaminated material based on a comparison to the uranium-238 reference-level of 15 pCi/g. Accordingly, only those original sample results having uranium-238 concentrations between 8 and 15 pCi/g on DA Vicinity Property No. 1 and between 11 and 15 pCi/g on all other vicinity properties would have an impact on the estimated depths or boundaries of contaminated material.

Original sample concentrations of less than either 8 or 11 pCi/g, when corrected for the bias, would have resulted in concentration levels that were still less than the 15 pCi/g reference-level. Original concentrations that were greater than the 15 pCi/g reference-level would already have been used to define contaminated areas. Since only 10% of all samples from DA Vicinity Property No. 1 fell within the range of 8 to 15 pCi/g and only 2.7% of all samples from all other vicinity properties fell within the range from 11 to 15 pCi/g, little change to the areas identified as contaminated results from the low analytical bias. All uranium-238 concentrations reported in Section 5.2.3 reflect the original results, not corrected values.

3.2.3 Background Sampling

In order to allow a valid assessment of chemical contaminant concentration values, the PMC conducted an off-site sampling campaign in 1988 to establish a baseline data set of background values. Background samples were collected from an area within 5 mi of the Weldon Spring site that was unaffected by ordnance works or uranium processing operations. Figure 3.2-3 shows the location of the background sampling area in relation to the chemical plant site. Two samples were collected from each of the 25 boreholes and were analyzed for selected metals and inorganic ions (MKF and JEG 1988b).

Normal background radiation levels and concentrations were measured near the site for comparison purposes. Subsurface soil samples and gross gamma radiation measurements were also taken in boreholes drilled by the PMC. Exposure rates at 1 meter (3.28 feet) above the surface ranged from 8.9 to 11.0 μR/h with an average of 9.8 μR/h. Concentrations of radionuclides in soil were radium-226, 0.8 to 1.3 pCi/g; uranium-238, 0.7 to 1.7 pCi/g; and thorium-232, 0.8 to 1.5 pCi/g. These concentrations are typical of the radionuclide levels normally encountered in surface soils unaffected by site operations and within a 8-km (5-mi) radius of the site.

Additional information concerning background data, sampling, equipment, and analytical procedures is provided in the PMC characterization reports of the various vicinity properties (MKF and JEG 1987c, f, g, and j; 1988k).

3.3 Surface Water and Sediment Investigations

Surface water and sediment investigations have been conducted to determine the nature and extent of chemical and radiological contamination in lakes and streams affected by the site. Four independent studies have been conducted on vicinity properties relative to potential accumulations of contaminants in lake and stream sediments.

3.3.1 Ryckman/Edgerley/Tomlinson & Associates - 1978

RETA was contracted by the DA to determine the extent of radiological contamination on the Weldon Spring site and surrounding properties. The data of interest to this study came from the samples of sediment in Busch Wildlife Lakes 35 and 36, the lake drainages, and Dardenne Creek (RETA 1978). The data obtained from Dardenne Creek were used to determine background conditions.

The study was designed to provide information on the presence or absence of contamination in the sediments, but no effort was made to completely characterize the extent of the contamination. Therefore, the report was of use in determining areas of concern for later studies, but could not be used for full characterization of sediment contamination. RETA determined that all sediments except those in Dardenne Creek contained amounts of uranium that were slightly above normal background levels.

3.3.2 Oak Ridge Associated University - 1984-1985

The ORAU study was conducted in 1984 and 1985 at the request of the DOE. Its purpose was to assess the extent and levels of off-site radiological contamination resulting from the operation of the uranium feed materials plant. The study examined surface and subsurface soils, water, and sediment on properties adjacent to the site (ORAU 1986a; 1986b).

ORAU documented elevated levels of uranium in Busch Wildlife Lakes 34, 35, and 36, Dardenne Creek, the stream leading from Burgermeister Spring, and the Frog and Ash Pond drainages. Because the ORAU report was strictly a data report, there was no interpretation of the processes of contaminant transport and contaminant deposition. No comments were made about the implications of the contaminated sediment.

3.3.3 Project Management Contractor Phase I Water Quality Assessment - 1987

The Phase I water quality assessment was designed to supply baseline groundwater and surface water quality information. The study consisted of sampling 50 monitoring wells (filtered) and 23 surface water locations (both filtered and unfiltered). In the Busch Wildlife Area, surface water samples were collected from Lakes 10, 34, 35, and 36, Burgermeister Spring, and Dardenne Creek. Samples were taken only from locations where measurable impacts could be attributed to the chemical plant. The samples were analyzed for total and dissolved uranium, radium-226, radium-228, thorium-230, thorium-232, gross alpha and beta, and total nitrate, sulfate, chloride, and fluoride (MKF and JEG 1987o).

3.3.4 Project Management Contractor - 1988

A survey of lake and stream sediments near the Weldon Spring site was conducted in 1988 (MKF and JEG 1989h). Sampling areas were selected by first reviewing the RETA and ORAU reports. The purpose of this review was to help identify areas of concern. The drainage basins in the area were analyzed following the review. Any drainage system receiving flows from the site was assumed to be subject to contamination.

Individual stream and lake sediment sampling locations were biased with respect to areas of sediment deposition. Zones of streambed erosion or scour were not sampled. In lakes, the distribution of sampling locations was biased toward upbasin areas of sediment deposition, based on data from ORAU. Samples were also obtained from the middle and downbasin lake areas to ensure that contamination was not overlooked.

The first stream sediment sampling locations below the lakes were sampled for nitroaromatics, PCBs, semivolatile compounds, and metals to verify that contaminated sediments had settled in the lakes.

Two phases of sampling were involved. The first phase, in June and July 1988, was designed to measure the nature and extent of both radiological and chemical contamination in the sediments themselves. These data indicated an overall lack of elevated chemical contamination which could be attributed to the site, but demonstrated that uranium contamination could be found at numerous locations. This led to the second phase of sampling in November 1988. This phase was based only on uranium contamination, and its purpose was to determine more accurately the boundaries of elevated radiological levels in the Busch Wildlife Area lakes.

3.4 Groundwater Investigations

A number of investigations have been conducted by the PMC and prior investigators to characterize physical and chemical groundwater properties at the Weldon Spring site.

3.4.1 Groundwater Monitoring Network

The current monitoring well network at the site includes 26 pre-1987 wells and 33 wells constructed to support the current RI/FS-EIS studies. Figure 3.4-1 shows the locations of both the pre-1987 monitoring wells and the new wells which have been installed at the site.

The 26 pre-1987 wells include only those that are suitable for water level measurements and groundwater sampling. Dry, damaged, and destroyed wells have been excluded from the monitoring program. Significant data also exist for other pre-1987 wells not included in the current monitoring well program. The pre-1987 wells were installed in 1983 and 1986 during hydrogeological studies by BNI (1984c; 1987). The technical information for these monitoring wells is presented in more detail in Section 4.6.

The following well designations are currently used at the site. Monitoring wells with a 2000 series number are located within the chemical plant area, wells with a 3000 series number are located in the raffinate pit area, and wells with a 4000 series number are located outside the site boundaries.

In addition to the extended monitoring-well network described above, two deep well clusters have been installed near the site as part of the U.S. Geological Survey (USGS) regional groundwater flow study. The clusters of deep monitoring wells have been installed at the locations shown on Figure 3.4-2 to determine vertical gradients between the shallow (Mississipian-Devonian) and deep (Ordovician-Cambrian) aquifers underlying the site.

The 33 monitoring wells constructed during the RI/FS-EIS studies were drilled, installed, and developed generally in accordance with accepted techniques as discussed in the EPA RCRA groundwater monitoring technical enforcement guidance document (EPA 1986a).

3.4.2 Aquifer Testing

The earliest aquifer testing of the shallow bedrock aquifer in the Weldon Spring vicinity was conducted in 1986 by BNI (1987) as part of its hydrogeological characterization report. Additional aquifer testing has been conducted as part of the field studies to support the RI/FS-EIS. Aquifer testing has included single-well hydraulic conductivity (permeability) tests and long-term pumping tests to define the hydraulic characteristics of the aquifer. The purpose of these tests is to aid in the prediction of contaminant migration and the assessment of groundwater remediation alternatives.

Single-well hydraulic conductivity tests (slug tests) have been used to provide information on areal variations in hydraulic conductivity within the Burlington-Keokuk Limestone. Each new monitoring well installed as part of the RI studies has had a slug test. These tests have also been performed in selected pre-1987 monitoring wells for comparison with the results of packer tests performed by BNI during well installation.

Long-term pumping tests were performed by Earth Scientists, Inc., for the PMC. These tests were performed at three locations on site to determine aquifer properties such as transmissivity, specific yield, and areal anisotropy. Locations for pumping and observation wells are shown on Figure 3.4-3. The locations were selected to determine aquifer conditions in areas where contaminants have been detected in the groundwater and could potentially migrate off site. Tests were also performed at a location adjacent to an area which might serve as an on-site disposal facility.

3.4.3 Groundwater Levels, Sampling, and Analysis

Static water levels are measured monthly in all of the wells in the extended monitoring well network. The water level is measured in accordance with Standard Operating Procedure (SOP) No. 4.4.2 in the WSSRAP procedures manual. Potentiometric surface elevations are calculated from the static water-level measurements.

The groundwater sampling conducted in support of the RI/FS-EIS effort was performed in conjunction with the 1987, 1988, 1989, and 1990 environmental monitoring programs for the Weldon Spring site (MKF and JEG 1988s, 1989p, 1990b, and 1991c). Groundwater sampling includes the entire extended monitoring well network as described above. The purpose of the sampling was to further define (1) types and concentrations of contaminants, (2) nature of contamination, (3) the horizontal and vertical extent of contamination, (4) potential contaminant sources, (5) contaminant migration pathways, and (6) potential future contaminant migration. Detailed procedures for groundwater sampling and sample handling have been developed to ensure that samples are representative and analytical results are accurate and defensible. Groundwater sampling equipment and procedures are described in WSSRAP environmental, safety, and health SOP No. 4.4.1.

Groundwater samples are filtered, preserved, and shipped on a daily basis to analytical laboratories under contract to the PMC. Table 3.4-1 lists the analytical parameters, sample containers, and preservation methods used for the groundwater samples. The analytical parameters are either present at elevated concentrations in groundwater samples from the Phase I water quality assessment, or have been identified as contaminants of concern.

3.4.4 Missouri Department of Natural Resources-Department of Geology and Land Survey Dye Trace Studies

The Missouri Department of Natural Resources-Division of Geology and Land Survey (MDNR-DGLS) conducted subsurface dye trace studies in 1983, 1984, and 1985 (Dean 1983a, b and c; 1984a and b; and 1985). Rhodamine WT and fluorescein dyes were injected into two boreholes (MW-2020 and MW-3007) in February and March 1983. Charcoal "bugs" (dye detector packets) were placed in stream channels north and south of the site, but no dyes were positively identified.

Dye was placed in a surface drainage west of raffinate pit 4 in February 1984 and west of Ash Pond in March 1985. These drainages are unnamed tributaries to the Schote Creek drainage to Lake 35. In November 1984, MDNR-DGLS also released dye at the sewer outfall at the head of the southeast drainage. The summary of the dye trace results can be found in the MDNR-DGLS Shallow Groundwater Investigation Phase 1 Report (MDNR 1989b).

The MDNR-DGLS conducted both borehole and surface stream injections of phosphorescent dyes both on and off at the WSCP/RP area. None of the borehole injections resulted in any positive traces to surface discharge points. The surface injections confirmed previous traces connecting Schote Creek and its tributaries to Burgermeister Spring and its associated drainageway.

Traces were also conducted in the Missouri River drainages, indicating the 5300 drainage (southeast drainage) was a self contained or gaining basin and that the nitroaromatically contaminated 5200 drainage does not source nitroaromatic contamination in 5300 drainage. The DGLS dye studies also confirmed the losing and gaining reach to understand the potential flow paths for spills which could occur during waste haulage.

MDNR conducted additional dye trace studies during the RI/FS-EIS monitoring well installation program. Only 4 of the 33 new monitoring well boreholes could be subjected to dye injection during a first round of tracing. The subject wells were those with a high potential for connection to conduit flow, based on a review of drilling logs, examination of rock cores, and downhole video camera examination of the boreholes. The boreholes dyed during the first round of tracing included MW-4014, MW-4016, MW-4018, and MW-4023. Charcoal bugs were placed in the perennial springs and some of the more significant wet weather springs in all the drainage basins surrounding the site. In some locations, charcoal bugs were also placed in gaining stream segments. The locations of these dye detector packets are shown on Figure 3.4-4.

3.4.5 Domestic Well Sampling

A number of domestic wells are used in the vicinity of the site. On June 5, 1984, the St. Charles Countians Against Hazardous Waste (SCCAHW) conducted a groundwater inventory of wells and springs in St. Charles, Defiance, Weldon Spring, St. Peters, Wentzville, O'Fallon, Augusta, and New Melle. This information, and well location data provided by the USGS, was included in a Groundwater Classification Study conducted by the PMC. The study was representative of the combined efforts of the St. Charles County Administrative Court, the Missouri Division of Health (MDOH), the Missouri Department of Natural Resources (MDNR), the MDOC, and the SCCAHW.

The overall groundwater classification study area is shown on Figure 3.4-5. The figure represents a compilation of private well information including information received from the SCCAHW and the USGS private well surveys. The well numbers shown on the map are the same as those used in listings of private wells by the USGS and SCCAHW. Many private wells are no longer used. Wells located within the present boundaries of the Busch and Weldon Spring Wildlife Areas are assumed to have been abandoned around 1941, when private properties were acquired by the United States for the ordnance works. These wells have recorded locations but no record of water samples or water-level measurements.

Extensive sampling of private wells in the vicinity of the Weldon Spring site has been performed since 1982 by the MDOH. Preliminary data received from the MDOH for the period from 1982 to 1989 indicate that private wells in the vicinity are not being affected by the former uranium processing operations at the Weldon Spring site. Evaluation of MDOH private well data will continue in conjunction with interpretation of the site monitoring well data.

3.5 Ecological Investigations

Beginning in 1987, the PMC conducted a series of biological investigations to assess environmental conditions at the Weldon Spring site. These investigations included census surveys and biouptake sampling programs to characterize the Weldon Spring chemical plant area and surrounding wildlife complex. Census surveys involve documenting the various species of flora and fauna observed within a specified area. Biouptake studies involve collecting various plant and animal specimens and analyzing tissue samples to calculate bioaccumulation of radionuclides in biota and potential dose to humans from ingestion of fish and game.

These studies are not comprehensive evaluations of all habitats and levels of the food chain. Species and study locations were selected upon endpoints of particular concern to humans and conducted in support of RI/FS risk assessment requirements to review the potential impacts on primary ecological receptor populations. The populations of game animals on site are relatively low and would have been severely impacted if the number of animal specimens required to obtain statistically valid data were collected. Only limited numbers of specimens were collected and select species examined. The data effort concentrated on species which could be consumed by human beings. Some data were also gathered as the result of opportunistic sampling, particularly where the accidental deaths of large mammals provided biouptake specimens.

In 1978, RETA conducted a study commissioned by the DA. The data collected during that study has been included in the ecological characterization of the site. The objective of the RETA study was to establish the fate of contaminants in the local ecosystem and to document the transfer of contaminants through the food web (RETA 1978). The MDOC conducted a small-scale investigation of fish, water, and sediments in 1983 and 1984 at the Busch Wildlife Area to determine the potential for radiological uptake in game species.

In addition to the data generated during site-specific studies, information from the MDOC regarding the surrounding wildlife complex is available. The MDOC owns most of land immediately surrounding the Weldon Spring site, including the Busch and Weldon Spring Wildlife Areas. The MDOC actively manages these areas for hunting and fishing and as nature preserves. The habitats and fauna found within the northwest corner of the Weldon Spring site are similar to the environments found within the MDOC wildlife areas. Information provided by the MDOC has been used as an additional source for identifying ecological systems at the Weldon Spring site.

3.5.1 Terrestrial Investigations

The Weldon Spring site is located within the temperate deciduous forest biome which covers the majority of the eastern and midwestern United States. In terrestrial communities, plants are the major species, and land communities are, in turn, named for the dominant species. The forests of Missouri are designated as the oak-hickory community. Herbaceous and shrub layers tend to be a developed part of the community. Characteristic grassland or "old field" vegetation constitutes early disturbance or developmental stages. The plants in terrestrial communities also provide food and shelter for many other species. The presence of large mammalian herbivores and birds is characteristic of forested areas. Grazing or burrowing animals typically inhabit the grassland communities.

To assess the terrestrial communities at the Weldon Spring site, major and minor communities were identified, and the food chain and non-human receptor species were reviewed. Various terrestrial studies were conducted as part of the biological investigation of the chemical plant area including biouptake studies of small mammals and ecological surveys of birds, reptiles, amphibians, and plant communities.

3.5.1.1 Flora. Vegetation surveys were conducted during the summer of 1991. The surveys focused primarily on distinguishing wetland habitats within the chemical plant area. However, information was also collected to other vegetation habitats and the presence of threatened and endangered plants on site. Information on area flora was also gathered by documenting observations during other on-site ecological activities, such as the bird survey. Quantitative surveys were conducted at Ash Pond, the south dump, and four raffinate pits. Qualitative observations were made for Frog Pond, the northwest forest, and the area around the chemical plant buildings.

Quantitative vegetation surveys were conducted using both line transect and quadrat vegetation sampling methods. One-square-meter (1.307-square-yard) quadrats were used to document the understory of herbaceous species, shrubs, and tree saplings. Quadrats were placed both randomly and along a transect, and a percent cover was estimated for each species found within the quadrat. Line transects were used to document tree species found in each quadrat and used to estimate percent cover. A 100 m^2 quadrat was used to quantify tree species. Qualitative observations were made to identify and document the presence of species nearby but not occurring within quadrat or transect samples. Other observations of on-site vegetation was limited to species identification and relative abundance.

3.5.1.2 Fauna. Small mammals were collected and sampled in 1987 as part of the original biouptake program initiated by the PMC. This biouptake program was designed to investigate the possible exposure pathways of chemical and radiological contamination to humans by ingestion of the on-site game species that may migrate off site (MKF and JEG 19891). Game animals such as rabbits, squirrels, deer, and turkeys are found within the chemical plant area and presumably are exposed to contaminated soils and water.

Small mammal specimens were collected by using live traps and hunting. Trapping was concentrated in three areas of known uranium contamination: the south dump, Ash Pond, and Frog Pond. Hunting was used to obtain samples from areas around the chemical plant buildings. No trapping was conducted at other areas of the site, namely the northwest forest. A total of 13 rabbits and six squirrels were collected from the Weldon Spring site. Each small mammal sample was a composite of three individuals collected from the location. Each sample was separated into bone and tissue samples, and analyzed for total uranium, thorium-230, thorium-232, and radium-226.

Large animals such as white-tailed deer were not sampled as part of the 1987 biouptake study; however, a male deer specimen became available in 1991 because of an accidental death within the material storage area. Samples of bone, tissue, and organs were separated and analyzed for total uranium, thorium-230, thorium-232, and radium-226. White-tailed deer are frequently sighted within the chemical plant area, primarily around the Ash Pond and north dump area.

Waterfowl surveys were conducted within the chemical plant area twice a week during the late spring and summer of 1991. Specific locations were selected as observation points, but other bird species observed outside the designated points were also noted. The survey locations were primarily selected to identify presence of waterfowl and usage of aquatic habitats on site. The survey locations included Frog Pond, the four raffinate pits, and Ash Pond. A 15-minute observational period was used at each location to document presence of species by visual or audio identifications. Typically, the surveys were conducted in the early morning period (6:30 am to 9:00 am), but afternoon sessions were also conducted. Birds were also documented from other habitats on site when traveling between on-site locations or during other ecological activities.

During the 1978 RETA study, 118 samples were collected from 31 sites within the chemical plant area and also included background sites. Study areas identified by gross gamma scanning in the field. Samples included earthworms, plants, small mammals, birds, and terrestrial reptiles. Samples were identified, measured, and dissected or combined in preparation for analysis of the uranium and thorium series.

3.5.2 Aquatic Investigations

Aquatic habitats under study at the WSS exist either as standing water (ponds) or running water (drainageways, creeks, and springs). The nature of these systems is dynamic in the midwestern region due to seasonal changes in temperature and precipitation. Aquatic habitats change much more rapidly than other communities. Unlike the terrestrial communities, which provide shelter, food, and breeding habitats, plants do not play a predominant role in the dynamics of the aquatic ecosystem but still remain important at the base of the food chain. The organisms of the aquatic habitats range from bacteria to fish.

Six aquatic habitats exist at the Weldon Spring site: Ash Pond, Frog Pond, and raffinate pits 1, 2, 3, and 4. All six habitats are man-made impoundments or dammed ponds created during chemical plant operations. The drainages from Ash Pond and Frog Pond lead into the Busch Wildlife areas located to the northwest and empty into Lakes 34, 35, and 36. RETA collected fish samples from the Busch lakes and aquatic vegetation and invertebrate samples from the on-site ponds and pits (RETA 1977). The PMC conducted biouptake studies of fish and waterfowl and performed ecological surveys of vegetation within these on-site aquatic habitats. In 1991, benthic invertebrates and zooplankton were examined in Frog Pond. Data is currently being reviewed and will be available in 1993.

3.5.2.1 Fish. Population surveys and biouptake studies of fish were first conducted in 1987. Sampling locations included Frog Pond, raffinate pits 3 and 4, and Lakes 34, 35, and 36 at the Busch Wildlife area. Lakes 33 and 37 were sampled to establish background data. The PMC collected fish specimens from Frog Pond; no fish were found in raffinate pits 3 and 4. Fishing was not conducted in raffinate pits 1 and 2 or Ash Pond. Ash Pond is periodically dry during the late summer months and could not be sampled. Fish samples were collected from Busch Lakes 33, 36, and 37 in 1989 and 1991, and from Lakes 34 and 35 in 1990 and 1991.

Fish samples were collected by electroshocking methods in which a gas-powered generator is used to introduce an electric current into the water. Fish are temporarily stunned and collected by dip netting. Specific game species were selected from each lake and composited into whole, fillets, and fishcake (beheaded, scaled, and eviscerated) samples. PMC samples were routinely analyzed for isotopic uranium. In the 1987 study, fillet composite samples of various fish species were analyzed for PCBs and metals. RETA analyzed fish samples in 1977 for total uranium, uranium-238, uranium-235, thorium-230, thorium-232, and radium-226.

The MDOC periodically samples fish from the Busch lakes. In 1983 and 1984 the MDOC collected fish samples from Lakes 34, 35, and 36; samples collected from Lakes 9 and 10 served to establish background levels. Each sample consisted of a composite of the edible portions of 10 fish.

Characterization data on fish species of the Missouri River is available for 1984-1990 (Union Electric 1988, 1989, 1990). Union Electric of St. Louis, Missouri, sampled the river as part of their NPDES program. Approximately 16 km (10 miles) upstream of the Weldon Spring site is Union Electric's Labadie plant. Electrofishing was conducted at this location from 1984-1990. No current data is available for Missouri River locations at or downstream of the WSS.

3.5.2.2 Benthic Invertebrates and Zooplankton. Benthic invertebrates are organisms (such as immature forms of aquatic insects and worms) that live in the sediments of lakes and streams; zooplankton are typically found within the water column. In 1991, a preliminary investigation was conducted to characterize the lakes and examine concentrations of uranium and metals in the lake water and sediments. Benthic invertebrates and zooplankton were sampled in Busch Lakes 34, 35, and 36 and Frog Pond at the Weldon Spring site. Quantitative samples were collected to estimate population densities and species diversities in the lakes and springs. Biotic data was collected to determine if uranium concentrations in sediment and water may effect biota populations.

Benthic invertebrates were collected from eight locations in the Busch lakes, three at Frog Pond, and two pools and one riffle at Burgermeister Spring and its resulting stream. Three composite dredge samples were taken for each lake or pool location, and three composite Surber samples were taken for each riffle location. Zooplankton samples were collected from the deepest location in each lake or pond. A Patalas trap was used to sample zooplankton at 1-meter intervals from the surface to the bottom. All samples were identified to species and counted (MKF and JEG 1991b).

Biomass samples of benthic invertebrates were collected from each lake. Each sample was collected using a dredge sampler and then separated from sediment and debris into taxonomic family (mayflies, worms, etc.). Each taxonomic family was analyzed as a separate sample if a sufficient mass of invertebrates was obtained. Otherwise, the samples were composited. Sediment and surface water samples were taken from each location. All sediment, water, and biomass samples were analyzed for total uranium. Sediments and water samples were analyzed for metals; water samples were analyzed for physical and chemical parameters to further characterize the lake ecosystem. Currently, only preliminary biomass data are available for the benthic invertebrate study. A report summarizing the study results will be available in 1993.

3.5.2.3 Waterfowl. The aquatic habitats found within the Weldon Spring site support a diverse group of waterfowl. These areas routinely attract waterfowl and shorebirds, some of which utilize the areas year-round, and therefore, these birds have a greater potential for uptaking radionuclides from contaminated sediments and water. Again, like mammals that use the site, waterfowl have the capability to migrate on and off site and may be consumed by humans.

In 1990, five migratory fowl, including three wood ducks, one Canada goose, and one mallard, were sampled from raffinate pit 4. Specimens were separated into tissue and internal organ samples and analyzed for isotopic uranium, thorium,-230, thorium-232, and radium-226.

In 1991, a census survey was conducted of the aquatic habitats during the summer months from June to September. Waterfowl were observed at all on-site aquatic habitats, primarily in the early morning. Species were identified and observations regarding location, sex, and activity of each individual were recorded. Biouptake sampling will be conducted if census surveys indicated that individuals could be documented as summer residents.

3.5.3 Wetlands Survey

The six aquatic habitats on site are identified as wetlands on the U.S. Fish and Wildlife Service National Wetlands Inventory Map. According to Federal guidance, three conditions must be met to confirm a wetland designation; (1) the presence of hydric soils, (2) saturated soil conditions for at least seven days during the growing season, and (3) presence of hydrophytic vegetation. Although all of the ponds and pits are man-made, Federal guidelines indicate a determination or delineation of wetlands must be conducted (COE 1987).

A preliminary survey of vegetation was conducted in August 1991 at Ash Pond and raffinate pits 3 and 4. Four transects were selected at each location, and quadrats were placed at 20-foot intervals along each transect. Herbaceous species, as well as shrubs, vines, and trees, were recorded in each quadrat for presence and percent cover. Qualitative data were recorded for species present in the transect area.

The study of the wetland areas will continue in 1992 and include Frog Pond, raffinate pits 1 and 2, and the drainage areas around the chemical plant area.

3.5.4 Food Chain Study

Approximately 60 aquatic samples were collected from 22 sites by RETA in 1977. The purpose of this study was to determine the extent to which the contaminants of concern may be distributed throughout the ecosystem. Samples from all levels of the aquatic food chain were selected and included algae, rooted aquatic macrophytes, macroinvertebrates, fish, amphibians, and muskrats (RETA 1978). Emphasis on selection of organisms for study was placed on the lower trophic level i.e., primary producers and consumers in direct contact with contamination (RETA 1977). A smaller number of samples were collected from upper trophic level organisms as indicators of biomagnification. Samples were analyzed for uranium, thorium, and radium. Locations were selected based upon soil and water contamination and included Frog Pond, Ash Pond (on and off site), Busch Lakes 35 and 36. Background locations selected were New Melle farm, situated 11 miles northeast of the WSCP; a site along Highway D, 5 miles northeast of the site; as well as other locations.

3.6 Meteorological Investigations

National Oceanic and Atmospheric Administration (NOAA) records have been reviewed for establishing local and regional climatic and weather patterns relative to the site (NOAA 1981-1986).

3.6.1 Bechtel National, Incorporated - 1983-1985

In 1983, BNI retained Shell Engineering and Associates to furnish, install, and operate a meteorological monitoring system and water gauging system at the raffinate pits. Two monitoring stations were installed at the raffinate pits site. Station No. 1 was activated on April 7, 1983. Station No. 2 was installed and activated in July 1984. The monitoring systems recorded wind direction, sigma theta (standard deviation of hourly wind direction fluctuations), wind speed, air temperature, dew point, radiation, precipitation, evaporation, water temperature, and wind run. In addition, water levels were recorded at each of the four raffinate pits.

Meteorological data were collected from a single gauge for each parameter, except for precipitation, evaporation, and wind run. The meteorological station installed July 1984 was added to verify data collected for precipitation and evaporation. This investigation was conducted in support of a water balance study of the raffinate pits (BNI 1986a).

3.6.2 PMC Studies

A site-specific meteorological study at the Weldon Spring site as part of the RI/FS has not been undertaken, although rainfall data have been recorded at the chemical plant since February 1987.

3.7 Geotechnical and Geophysical Investigations

3.7.1 Geotechnical Investigations

Geotechnical investigations at the site have included drilling, trenching, and geotechnical laboratory testing. More than 100 borings were drilled in the chemical plant and raffinate pit area (Table 3.7-1). These borings included test borings for construction of buildings and borings for installation of monitoring wells. In addition, 21 trenches were excavated in the raffinate pit and chemical plant areas. The types and numbers of geotechnical laboratory tests performed on samples collected during each investigation are listed in Table 3.7-2.

3.7.1.1 U.S. Army Corps of Engineers - 1954. Subsurface explorations were initiated by the St. Louis District, COE, at Weldon Spring under the direction of the AEC in November 1954. The purpose of the investigation was to gather geotechnical data for foundation design work. Eight boreholes were advanced into limestone bedrock. Rock cores were obtained with NX diamond bits. Undisturbed soil samples were taken from two boreholes. At one borehole, disturbed samples were taken with a split-spoon sampler using standard penetration tests (COE 1955).

3.7.1.2 Henry M. Reitz Consulting Engineers - 1963. In 1963, Henry M. Reitz Consulting Engineers investigated characteristics of the soils underlying the proposed raffinate pit (pit 4). Twelve boreholes were advanced using both mechanical and hand augering equipment. Five mechanical auger borings were extended to rock. Seven hand auger borings, with depths ranging from 1.5 to 6.1 m (5 to 20 ft), were terminated within the soil. Undisturbed soil samples were taken from three of the auger holes, and disturbed samples were taken from one (Henry M. Reitz 1964).

3.7.1.3 Bechtel National, Incorporated - 1982-1983. BNI conducted a geologic site characterization study of the raffinate pit area between December 1982 and April 1983. The study was designed to define the site stratigraphy, describe the lithology and general conditions of each geologic unit, and determine the existence of groundwater and its relationship with the geology (BNI 1983d).

A total of 26 holes, with depths ranging from approximately 4.6 to 45.7 m (15 to 150 ft), and 15 test pits, with depths ranging from 4.6 to 8.3 m (15 to 27 ft), were advanced into the overburden in the raffinate pit area. To drill the holes, 20-cm (8-in) hollow-stem augers and NX core drilling equipment were used. A backhoe was used to excavate the test pits.

3.7.1.4 Bechtel National, Incorporated - 1986. BNI also conducted a hydrogeological characterization study. Field work was conducted between January and August 1986. The study was designed to provide a groundwater monitoring system to determine if contaminants from the site had degraded groundwater quality and to evaluate the site geology and hydrogeology for utilization of the site as a waste disposal facility. A total of 35 boreholes with depths ranging from 16.4 to 28.7 m (54 to 94 ft) and five test pits about 4.8 m (15 ft) deep were located around the chemical plant area and north of the raffinate pits. The drilling was performed using 15.2-cm (6-in) outer diameter hollow-stem augers and both NQ and NXB wireline core drilling equipment. A backhoe was used to excavate the test pits. Generally, boreholes were sampled at 1.5-m (5-ft) intervals with split-spoon samplers. One or two undisturbed Shelby tube samples per borehole were collected from 24 borings. Samples were not obtained from the test pits (BNI 1987).

3.7.1.5 Project Management Contractor - 1988. Chemical Plant Area. As part of the 1988 remedial investigation (RI) field program, 16 vertical and two angled exploratory borings were drilled and sampled at the location of the proposed disposal cell. The investigation provided geotechnical design parameters and information for the evaluation of the suitability of the site for construction of a waste disposal facility. Soil sampling was performed at 0.76-m (2.5-ft) centers to auger refusal at the top of bedrock. Borings were then typically cored 6 m (20 ft) into bedrock. Direction for the drilling program was provided by the Geophysical/Geotechnical Investigation Sampling Plan (MKF and JEG 1988n). The sampling plan discusses the purpose and scope of the investigation, including data requirements and data collection methods.

At the beginning of 1989, two angled borings were drilled 30.5 m (100 ft) into bedrock. The purpose of these angled borings was to obtain geotechnical data for the bedrock, with particular attention given to bedrock structure, weathering, and permeability. The borings were drilled at a 30-degree angle and at a bearing perpendicular to the average joint trends to intersect as many vertical joints and fractures as possible. The rock was continuously cored, and water pressure (permeability) tests were conducted in each boring. At the completion of drilling, a downhole geophysical survey was conducted in each hole.

Other Studies. Six borings were drilled along the west side of raffinate pit 4 to determine groundwater and soil conditions for a dike stability study. All six borings were completed as piezometers. In addition, five borings were drilled at the approximate four corners and the center of the administration building prior to construction to determine geotechnical engineering design parameters for the building foundation.

Geotechnical laboratory testing on the samples from the 1988 field program included:

- Index properties tests such as gradation, Atterberg limits, natural moisture contents, dry unit weight, shrinkage limit, and specific gravity.
- Capillary moisture tests for evaluation of long-term moisture contents for radon attenuation studies and for correlation of unsaturated hydraulic conductivities with soil saturation.

- One-dimensional consolidation tests for compressibility and analysis of time-dependent settlement behavior of fine-grained soils.

- Compaction tests for determination of maximum dry density and optimum water content.

- Falling head permeability (hydraulic conductivity) tests for classifying the relative soil permeability.

- Triaxial shear strength tests (consolidated-undrained or unconsolidated-undrained) for evaluation of effective or total strength parameters of the soils.

3.7.1.6 Project Management Contractor - 1988-1989. Drilling and trenching information from past and current hydrogeological and geotechnical exploration programs was used to build a geological database to interpret the site geology. The database includes geological data from 139 borehole logs and 32 trench logs. Table 3.7-2 summarizes the sources of geologic data used. Additional boreholes that lacked geological information were also included in the database, by coordinates or by digitizing, to spatially locate the water level measurements and the water chemistry data gathered from the boreholes. Descriptive information for the boreholes and trenches used in the database are presented in Section 4.3.

Other pertinent data were added to the database to aid in the geologic study. These included digitized current topography of the site and main drainages; digitized site topography as of 1954 and drainages; digitized major site features including raffinate pits, buildings, and ponds; borehole data including location, elevation, total depth, top of casing elevation, monitoring interval, stratigraphic units, and rock quality designation data; and hydrogeological data including water level measurements and permeability coefficients. These data were utilized in the interpretation of the site geology which is detailed in Section 4.3.

3.7.2 Geophysical Investigations

Geophysical surveys conducted on site prior to 1988 are summarized in the Geophysical/Geotechnical Investigation Sampling Plan (MKF and JEG 1988n) and briefly described below. These surveys were limited primarily to the area around the raffinate pits. In 1988 an extensive geophysical survey of the site was conducted. The purpose of the survey was to enhance the information obtained from the 1988 geotechnical investigation by correlating information between boreholes and to determine, if possible, if solution features are present in the bedrock.

3.7.2.1 Weston Geophysical Corporation - 1982 and 1984. Geophysical surveys by Weston Geophysical Corporation (WGC) in 1982 and 1984, including electromagnetic (EM), self potential, and seismic refraction studies, were primarily conducted in the vicinity of the raffinate pits. The surveys were not designed to define the bedrock surface with high precision. Magnetic and electrical resistivity surveys were also conducted by WGC at five tentative monitoring well locations to detect buried metal objects (WGC 1983).

3.7.2.2 Detection Science, Inc. - 1986. In 1986, Detection Science, Inc., performed seismic refraction and electromagnetic studies in the area north of raffinate pit 4 and east of raffinate pits 1 and 2 (Detection Science, Inc., 1987). EM surveys were conducted to identify contaminant plumes in the groundwater and to assist in establishing monitoring well locations. Conclusions based on the EM data were subject to interpretation and have not been verified (Detection Science, Inc. 1987).

3.7.2.3 Geotechnology Services, Inc. - 1988. In 1988, an extensive geophysical survey of the chemical plant site was conducted by Geotechnology Service, Inc. (Geotechnology 1988b). The purpose of the geophysical investigation was to provide a geological model of the subsurface at the proposed disposal cell (MKF and JEG 1988n). Geophysical data obtained from the investigation included shallow EM induction, deeper EM, gradient magnetometry, very low frequency EM, seismic refraction, spontaneous potential, vertical electric resistivity, and seismic reflection.

3.7.2.4 Missouri Department of Natural Resources - 1988-1989. Spontaneous potential surveys were conducted by the MDNR in the vicinity of Burgermeister Spring to detect possible sources of water and conduits leading to the spring. An array of 35 electrodes was installed around Burgermeister Spring and two sets of readings were taken. A potential conduit leading to the spring from the south has been located. A tracking array was also installed to the south to follow the conduit upstream (MDNR 1989b).

Electrode array 1 was centered approximately on Burgermeister Spring. Array 2 was directly south of array 1, and its southwest corner was adjacent to Busch Wildlife Area Road C. Four additional sets of spontaneous potential readings (making a total of six) were taken for the Burgermeister Spring array 1. The Burgermeister Spring array 2 was installed using 35 electrodes initially and later increased to 43 electrodes. Four sets of spontaneous potential readings were taken for array 2 (MDNR 1988b).

3.7.2.5 Other Geophysical Studies. Two angled boreholes drilled in 1989 were geophysically logged. The logging methods utilized included resistivity, spontaneous potential, natural gamma, neutron, density, sonic, caliper, temperature, and a directional survey. Data obtained from the logging include information on lithology, joints and fractures, solution features, porosity, and permeability. These data helped define a model of the subsurface conditions at the proposed disposal cell site. In addition to the two angled boreholes, four USGS monitoring wells and two existing site monitoring wells were also geophysically logged.

4 PHYSICAL CHARACTERISTICS OF THE STUDY AREA

4.1 Surface Features

The Weldon Spring site is located in the southwestern uplands of St. Charles County. The county, roughly triangular in shape, is bounded by the Mississippi River on the north and east and the Missouri River on the south. The site is situated at the southern edge of the dissected till plains of the Central Lowlands Physiographic Province (Peterson et al. 1988).

The site is located on the drainage divide between the Mississippi and Missouri River (Figure 4.1-1) (Peterson et al. 1988). Drainage from the northern and western portions of the site flows northward to tributaries of Schote Creek, a tributary to the Mississippi River. The southeastern portion of the site drains generally southward to unnamed tributaries which flow to the Missouri River. The Missouri River is approximately 2.4 km (1.5 mi) southeast of the site, and at its closest point, the Mississippi River is approximately 22 km (14 mi) north of the site (Peterson et al. 1988). Additional information on regional and site-specific surface water flow is provided in Section 4.4.

Elevations on the site range from approximately 185 m (608 ft) National Vertical Geodetic Datum (NVGD) near the northern edge to approximately 205 m (672 ft) NVGD near the southern edge (Figure 4.1-2) (Peterson et al. 1988). Land surface slopes are generally gentle except in the vicinity of embankments of levees for the raffinate pits and Ash Pond. There are no natural drainage channels transecting the site, though remnants of a channel through the Ash Pond area are present (MKF and JEG 1988t). The main drainage from Frog Pond to Lake 36 extends north-northwest of the site boundary with only a small portion of the channel actually present on site.

The major surface features at the site are man-made. Raffinate pits 1, 2, 3, and 4 were constructed in the late 1950s and early 1960s for receiving process wastewater. In addition to process wastes, the raffinate pits have received precipitation and runoff. The topography of the raffinate pits influences the direction and rate of surface runoff in the vicinity of the site. The man-made dikes for the Weldon Spring raffinate pits extend up to 10 m (30 ft) above the surrounding ground surface (MKF and JEG 1988t).

Ash Pond occupies a topographic depression which was filled with water after construction of a dike at its northwest end. Ash Pond receives runoff from the northern portion of the site. When sufficient runoff has accumulated in Ash Pond, overflow is discharged off the site through its spillway. The ash discharge line transported ash slurry from the steam-generating plant (building 401) to Ash Pond. Ash Pond is generally shown as a marshy area on maps, but usually contains some standing water.

Frog Pond is a settling basin located near the east edge of the site. Overflow from Frog Pond is discharged to the north to surface water bodies in the Busch Wildlife Area.

The southeast drainage area receives surface water runoff from the site and flows to the Missouri River. During past operation of the Weldon Spring uranium processing plant, the southeast drainage area also received inflow from the sanitary and process sewers.

Another major topographic feature is a slope to the north along the northern margin of the chemical plant. This slope was artificially exaggerated in the area of the steam plant to provide a level coal storage area and a depressed settling basin for the coal storage area runoff (BNI 1987).

Additional surface features at the site include buildings and associated structures. Numerous buildings and structures associated with former ordnance works activities have been demolished or removed from the chemical plant area. The remaining buildings, facilities, and structures supported the uranium processing plant operations. Some uranium processing plant structures were demolished and decontaminated after operations ceased. There are currently 13 major buildings, approximately 30 support structures, and other miscellaneous facilities and equipment in the chemical plant area. These structures include sewage treatment facilities, power lines, transformers, construction vehicles, and several office trailers. The major buildings, structures, and other facilities are listed in Table 4.1-1 and are shown graphically on Figure 4.1-3 (Peterson et al. 1988). The portion of the site not occupied by structures or ponds is generally covered with vegetation, gravel, or asphalt pavement.

The Busch Wildlife Area is north of the site, and the Weldon Spring Wildlife Area is south and east of the site. These areas are predominantly vegetated with trees, brush, and grasses. The U.S. Army Reserve property to the west of the site is predominantly vegetated with trees and grasses (MKF and JEG 1988t).

4.2 Meteorology

This subsection identifies and discusses the major climatic components in the site vicinity. Both regional and site-specific climate are discussed. Meteorological data were used to characterize the atmospheric transport of contaminants for risk assessment and to determine the effect of weather patterns on remedial actions.

4.2.1 Regional Climate

Meteorological data recorded at several stations in the vicinity of the site can be used to define general meteorological conditions. Long-term data are available from St. Charles County (station number 23027397) for the period 1951 to 1986 (NOAA 1981-1986; 1984). In those cases where long-term data are not available for St. Charles County, data recorded at St. Louis-

Lambert Field from 1941 to 1970 (Ruffner 1978) are presented. Data collected from locations closer to the site, such as Spirit of St. Louis Airport, Labadie Power Plant and the Busch Wildlife Area, will be included in site documents as it becomes available.

The climate in the area of the site is continental in nature, with moderately cold winters and warm summers. Alternating warm/cold, wet/dry air masses often converge and pass eastwardly through the area, resulting in frequent changes in weather (BNI 1983a, 1984a).

4.2.1.1 Precipitation. Precipitation data are presented in Tables 4.2-1 and 4.2-2. The average annual precipitation recorded in the area is approximately 94 cm (37 in), based on data recorded at St. Charles County from 1951 through 1986. Precipitation has ranged from 61 cm (24 in) to 130 cm (50 in) annually (NOAA 1981-1986; 1984). On the average, more than half of the precipitation falls between March and July. December, January, and February are generally the driest months. The heaviest rains generally occur in spring and summer, although intense storms can occur during any month (see Table 4.2-2). Summer rains are frequently in the form of thunderstorms, often associated with hail and high winds (DOE 1987). Based on St. Louis area records from 1941 through 1970, measurable precipitation of 0.03 cm (0.01 in) or more occurs on an average of 109 days a year, with thunderstorms occurring on about 40% of these days (Ruffner 1978).

Snow in the region has fallen as early as October and as late as May. However, most snowfall is from December through March. Snow rarely remains on the ground for more than two weeks. Conditions sometimes fluctuate between rain and snow, resulting in freezing drizzle or freezing rain (Ruffner 1978). Based on data recorded at St. Charles County between 1951 and 1986, the mean annual snowfall is 43.7 cm (17.2 in). The maximum monthly snowfall was 69 cm (27.2 in) in January 1977 (NOAA 1984).

4.2.1.2 Temperature. Missouri is subject to frequent changes in temperature. Winters are moderately cold and summers warm, and prolonged periods of very cold or very warm to hot weather are unusual. Occasional mild periods with temperatures above freezing occur almost every winter. Conversely, occasional periods of dry, cool weather interrupt periods of heat and humidity during the summer (Ruffner 1978).

Table 4.2-3 summarizes mean, maximum, and minimum temperatures recorded at St. Charles County. The variability of the temperature is shown by the record low and high temperatures which are −28°C (−19°F) recorded on January 11, 1982 and 48°C (115°F) on July 14, 1954. The monthly average temperature is 13°C (55°F), the average daily minimum temperature is 7°C (44°F), and the average daily maximum temperature is 19°C (66°F). The frequency of temperature extremes is presented in Table 4.2-4. On the average, there are about 49 days a year when maximum temperatures are above 32°C (90°F). Minimum temperatures below 0°C (32°F) occur on 111 days of the year, although temperatures below -18°C (0°F) are infrequent (only about five days per year) (NOAA 1981-1986).

Relative humidity data for the St. Louis area (1941 to 1970) are presented in Table 4.2-5. The table also lists a heat stress factor which indicates those months in which heat stress can be expected as a result of temperature and humidity. The summer months generally pose the highest risk for heat stress due to increased ambient temperature and relative humidity during those months. Relative humidity is a measure of the amount of water vapor in the air as the temperature varies. As the ambient temperature increases, the amount of water vapor the air can hold (before condensation occurs) also increases. As the water vapor in the air increases, the rate of evaporation decreases due to the increased partial vapor pressure that must be exceeded for evaporation to occur. Evaporation of sweat is the primary mechanism by which the body cools itself. Therefore, in the summer when the temperature and relative humidity are high, heat stress can occur due to inhibited evaporation.

4.2.1.3 Wind. Wind data recorded at St. Louis-Lambert Field are available for the period 1941 through 1970. Wind speeds and prevailing directions are presented in Table 4.2-6. Prevailing winds are from the south during the summer and fall and from the northwest and west-northwest during the winter and early spring. The average annual wind speed is about 15.3 km/h (9.5 mph). Average wind speeds are about 13.7 km/h (8.5 mph) for May through November and about 17.5 km/h (10 mph) for December through April. The fastest mile of wind was 96.6 km/h (60 mph) from the southeast (Ruffner 1978).

4.2.1.4 Evaporation/Evapotranspiration. Free water surface evaporation is the term used by the National Weather Service to represent evapotranspiration from a completely vegetated land surface or from standing water in a basin. It is obtained by adjusting Class A Pan Evaporation using coefficients developed by the National Weather Service. The coefficient for the area near the site is 0.73 (MDNR 1984).

Data compiled from 1956 through 1980 indicate that annual average free water surface evaporation in the region is close to annual average total precipitation, approximately 94 cm (37 in). Normal monthly free water surface evaporation is also close to the average monthly precipitation, with the highest values occurring during the summer and the lowest in the winter (MDNR 1984).

4.2.1.5 Other Climatic Information. Fog data for the St. Louis area are available for 1940 through 1971. Foggy conditions occur an average of 11 days a year, causing visibility to decrease to 0.4 km (0.25 mi) or less. Fog generally does not occur between May and August (Ruffner 1978).

Between 1916 and 1958, 446 tornados were reported in Missouri, an average of about 10 each year. About 70% of these storms occurred from March through June. About 82% occurred between noon and midnight, with the greatest activity between 4 p.m. and 6 p.m. (Ruffner 1978). Tornados may occur in the St. Louis area once or twice per year, but they usually have a narrow path and often dissipate after a few kilometers. During the most recent

40-year period of records for the St. Louis area, there have been only four tornados that produced extensive damage and loss of life (Science Applications 1979).

4.2.1.6 Air Quality. The Weldon Spring site is located in the St. Louis Air Quality Control Region; this region includes St. Charles County, St. Louis, St. Louis County, Franklin County, and Jefferson County. The National Ambient Air Quality Standards for six criteria air pollutants are used by the state of Missouri to assess regional air quality and designate nonattainment areas (i.e., those areas for which one or more of the standards is not met within the state). The criteria pollutants are sulfur oxides (as SO_2), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), PM_{10} (particulate matter with an aerodynamic diameter less than or equal to 10 μm), and lead (Pb).

Measurements taken from 1979 through 1988 at the closest state monitoring location (Queeny Park, 22 km [14 mi] southeast of the site) indicate that the area is in compliance with federal and state air quality standards for carbon monoxide, nitrogen dioxide, sulfur oxides, PM_{10} (formerly regulated as total suspended particulates), and lead. Measurements taken in 1984 at the state monitoring site in Weldon Spring also indicate attainment of the standard for sulfur oxides. Measurement taken in 1988 at the Clayton station (32 km [20 mi] west of the site) indicate compliance with the PM_{10} standard (MDNR undated-a, undated-b; Shissler 1990). Hence, St. Charles County is currently an attainment area for five of the six criteria pollutants (Cassin 1990). Violations of the ozone standard have been recorded at the Queeny Park location, as well as at most stations in the St. Louis area (MDNR undated-a, undated-b; Shissler 1990). As a result, all of St. Charles County—which includes the Weldon Spring site—has been designated a nonattainment area for ozone since 1979.

4.2.2 Site-specific Climate

Since 1983, various types of meteorological data have been collected at the site. No long-term data are available. Most of the data are sporadic. Between 1983 and 1985, meteorological data were collected near the raffinate pits by Shell Engineering and Associates, Inc. (1985a and 1985c; BNI 1986a). Rainfall data have been collected at the chemical plant since 1987 by the Project Management Contractor (PMC) (MKF and JEG 1989f). A meteorological station was established at the site early in 1990. Data will be tabulated and included in future site documents.

4.2.2.1 Precipitation. Site precipitation data are summarized in Table 4.2-7. Total annual precipitation for the three years with complete data was 128 cm (50.39 in.) in 1984, 121 cm (47.64 in.) in 1985, and 81.5 cm (32.07 in.) in 1988 (BNI 1986a; MKF and JEG 1989f). The years 1981 through 1985 were unusually wet with precipitation exceeding 114 cm (45 in.); the annual average precipitation recorded for St. Louis from 1871 to 1987 is 94 cm (37.1 in.). Plots in Figure 4.2-2 show that monthly precipitation recorded on site generally follows the same trend as precipitation recorded in St. Charles County. Differences can be attributed to topography and localized storm events. The plots also indicate that precipitation occurs year-round. Reportedly, local rains can be very heavy, with 25.4 cm (10 in) having been recorded for a 24 hour period (Ficker 1981; DOE 1987). The U.S. Geological Survey (USGS) is currently monitoring 19 rain gauges in the vicinity of the site.

4.2.2.2 Temperature. Temperature data from the site are limited. Data are only available from April 1983 through December 1985 and are summarized in Table 4.2-8. Temperatures were recorded near the raffinate pits by Shell Engineering and Associates, Inc. (1985a). The average annual temperatures for 1984 and 1985, the complete years of data, were 13.2°C (55.8°F) and 12.1°C (53.7°F), respectively. For comparison, the average 1984 and 1985 temperatures recorded at St. Charles County were 12.6°C (54.7°F).

4.2.2.3 Wind. Wind speeds and directions recorded at the site during 1985 are summarized in Figure 4.2-1. Prevailing winds are from the south during the summer and fall. Wind speeds during these months average 14.0 km/h (8.7 mph). Winds during the winter months are from the northwest and west-northwest, averaging 17.7 km/h (11 mph) (BNI 1986c).

4.2.2.4 Evaporation/Evapotranspiration. Site-specific evaporation/evapotranspiration data are limited to the years 1983 and 1984. Only data collected between April and October of those years were available or computed. Freezing conditions prevented the operation of monitoring equipment from November to March. Total evaporation ranged from 80 cm to 97.3 cm (31 in to 38.3 in) during the seven-month period. Corresponding precipitation was 68.5 cm and 70.8 cm (27.0 in and 27.9 in), respectively (BNI 1986a).

4.2.2.5 Climatological Monitoring. Currently, on-site climatological monitoring is limited to precipitation. A rainfall gauge was installed in February 1987 and is read daily.

In the immediate vicinity of the site, the USGS has installed 19 rain gauges within the Schote Creek and Burgermeister Spring watersheds. Rain gauge locations are shown on Figure 4.2-3. The rainfall data will be used to determine the amount of precipitation within these two basins for use in USGS water balance calculations and modeling efforts. Evapotranspiration will also be estimated by the USGS using measurements of soil saturation, precipitation, and runoff as part of the regional water balance study.

4.3 Geology

Following is a description of the generalized geology of the site vicinity and detailed geology beneath the site. Included is a description of regional and site stratigraphy and structure.

4.3.1 Stratigraphy

This subsection describes the stratigraphy of the Weldon Spring region and the specific stratigraphy of the chemical plant site. The description of stratigraphy is restricted to the aspects that affect the depth, location, and extent of water-bearing units and the fate and transport of contaminants. This information can be used to evaluate alternatives for remediation and disposal.

4.3.1.1 Regional Stratigraphy. The regional stratigraphy of the Weldon Spring site and vicinity has been determined from previously available information. Figure 4.3-1 shows a generalized stratigraphic column of this area. Detailed descriptions are provided in the literature (Kleeschulte and Emmett 1987; BNI 1987). Following are brief descriptions of the units present in the vicinity.

The oldest formations of interest are in the upper series of the Cambrian System. As defined by Kleeschulte and Emmett (1987), the deep bedrock aquifer extends from the Potosi Dolomite of the Upper Cambrian System to the St. Peter Sandstone of the Middle Ordovician System. The Potosi and Eminence Dolomites are medium- to fine-grained and medium- to coarse-grained, respectively. They are overlain by several dolomite and dolomite-sandstone formations of the lower and middle Ordovician System. The St. Peter Sandstone, which forms the top of the deep aquifer, is a widely recognized, massively bedded unit consisting of fine- to medium-grained, well sorted, well rounded frosted grains of quartz. This unit is also friable or weakly cemented.

The overlying units from the Joachim Dolomite to the top of the Maquoketa Shale Form a leaky confining layer that separates the shallow bedrock aquifer from the deeper aquifer. The Joachim Dolomite is a silty, thin- to thick-bedded unit which grades into siltstone. It has a thickness of approximately 18 to 24 m (60 to 80 ft) (Whitfield et al. 1989) in this area. The Plattin Limestone, a finely crystalline, thin-bedded unit, overlies the Joachim Dolomite. This unit has a total thickness of approximately 24 to 41 m (80 to 135 ft) (Whitfield et al. 1989) and is probably uniform throughout this area. The Decorah Formation conformably overlies the Plattin Limestone. It is a finely crystalline, thin-bedded unit that is thought to be approximately 9 m (30 ft) thick in the area (Whitfield et al. 1989). The Kimmswick Limestone unconformably overlies the Decorah Formation. This unit is medium- to coarsely-crystalline, cherty near the base, highly fossiliferous, medium- to thick-bedded, and is approximately 15- to 24-m- (50- to 80-ft-) thick in this area (Whitfield et al. 1989). The Kimmswick Limestone is susceptible to natural solution action and commonly contains stylolites (pressure-solution features) along bedding planes as an indicator of the solution phenomenon. The Maquoketa Shale of the Cincinnatian Series of the Ordovician System overlies the Kimmswick Limestone. This shale unit ranges from calcareous to dolomitic. This unit has been encountered in USGS boreholes north and south of the site and attains a thickness of approximately 3 to 9 m (10 to 30 ft) (MKF and JEG 1992c).

The Sulphur Spring Group overlies the Maquoketa Shale unit. The Glen Park Formation of the Sulphur Spring Group has been encountered in a USGS borehole located south of the site. The Glen Park Formation has a thickness of about 1.5 m (5 ft) and is an argillaceous, slightly calcareous to dolomitic, brown-gray siltstone.

The sequence from the Upper Devonian Bushberg Sandstone unit to the Burlington-Keokuk Limestone forms the shallow bedrock aquifer. The Bushberg is a fine- to medium-grained, thick-bedded unit with an average thickness of approximately 2.5 m (8 ft) in this area. Some sections of this sandstone are porous and friable, whereas others are very well cemented. Concretions and iron oxide nodules are common in the Bushberg unit. The Chouteau Formation Group unconformably overlies the Bushberg Sandstone unit. This formation is a fine-grained, thin- to medium-bedded dolomitic limestone and is fossiliferous throughout its entire thickness, which ranges from 30 cm to 5 m (1 to 15 ft).

The Fern Glen Formation conformably overlies the Chouteau unit. It is a thin- to thick-bedded, crystalline or argillaceous, highly fossiliferous limestone. Chert is common in this formation with minor calcareous shale interbeds. This limestone is relatively resistant to weathering and is estimated to be approximately 1.5 to 12 m (5 to 40 ft) thick at the site (Whitfield et al. 1989).

The Burlington and Keokuk Limestones conformably overlie the Fern Glen unit. The units are similar in lithology and have therefore been grouped together by most investigators into the Burlington-Keokuk Limestone. It is a fine- to coarsely crystalline, thin- to thick-bedded argillaceous, cherty, limestone unit containing solution features such as vugs and small cavities. The thickness of the Burlington-Keokuk Limestone is estimated to be approximately 12 to 56 m (40 to 185 ft) in this area (Whitfield et al. 1989). Erosional remnants of the Mississippian Warsaw and Salem Formation locally overlie the Burlington-Keokuk Limestone. The Warsaw Formation is a calcareous shale and interbedded shaley limestone which grades downward to a shaley dolomitic limestone with chert. In the vicinity of the Weldon Spring site, the Warsaw Formation ranges in thickness from 18.3 to 24.4 m (60 to 80 ft) (Whitfield et al. 1989).

In the vicinity of the Weldon Spring site, the Salem Formation ranges in thickness from 0 to 4.5 m (0 to 15 ft) (Whitfield et al. 1989). The Salem Formation is a light gray to white, fine to coarsely crystalline limestone which grades to shale, cross-bedded wackestone, dolomite, and limey siltstone.

Clay-rich soil units overlie the Mississippian carbonate rocks in the site vicinity. A residuum unit overlies the bedrock and is believed to be either a weathering product of remnant Warsaw or upper Burlington-Keokuk Limestone. It consists of clayey gravel to gravelly clay. The residuum unit is discussed in detail in Section 4.3.1.2, Site Stratigraphy.

Overlying the residuum and/or bedrock units is glacial drift and loess of the Pleistocene Series. These sediments consist of silty clay, clayey silt, gravelly clay, or clayey gravel. In some upland valleys, alluvium of the Holocene Series overlies the glacial drift and loess, or it lies directly upon the Paleozoic bedrock.

4.3.1.2 Site Stratigraphy. A detailed investigation of the site-specific geology was performed by drilling or excavating and sampling of numerous holes and trenches. The subsurface exploration generally extended from the ground surface to the unweathered section of the Burlington-Keokuk Limestone. This subsection describes the exploration and related data, analysis of the data, and the resultant site-specific stratigraphy.

Geological Data Correlation

The geological data obtained from boreholes and trenches were stratigraphically correlated. Geologic logs from past programs were interpreted and stratigraphic delineations were made using physical descriptions, field stratigraphic picks, drilling notations, and correlation with nearby boreholes. Core and sample logs were given more validity than logs of cuttings during correlation because core and sample logs provide a more representative sample of the strata.

Recent boreholes and wells were generally correlated by studying soil samples and/or rock cores in the field during or shortly after completion of the boreholes or wells. These boreholes were correlated using the same criteria as the older boreholes but with the advantage of having samples available for study. Results of laboratory tests on soils, such as grain size distribution and Atterberg limits, were used to define the overburden stratigraphic units. Auger refusal was assumed to indicate the top of bedrock in a given borehole. Table 4.3-1 lists the borehole and trench numbering conventions.

Table 4.3-2 also lists all boreholes and trenches used in the geologic database. Additional wells that lacked geologic information were also input into the database by coordinates or digitized to spatially locate the water level or chemistry data obtained from the wells. A borehole and trench location map for the site is presented in Figure 4.3-2.

Analysis of Site Stratigraphy

The drilling and trenching programs completed at the Weldon Spring site have allowed delineation of stratigraphic units in the overburden and upper bedrock. The overburden has been divided into six distinguishable soil units based on physical characteristics observed during sampling and the results of subsequent laboratory testing. The Burlington-Keokuk Limestone is the first bedrock unit underlying the unconsolidated overburden. This formation has been divided into two horizons determined by the degree of fracturing and weathering exhibited in the rock. The weathered and fractured upper horizon is designated as the weathered limestone.

The less fractured and weathered rock below this horizon is designated as the competent limestone. Figure 4.3-3 shows the site stratigraphy in a typical borehole where all the units are present. Figures 4.3-4 through 4.3-8 are computer-generated cross sections constructed with stratigraphic data from boreholes and trenches. These cross sections are located on the borehole map (Figure 4.3-2).

Overburden Stratigraphy

Figure 4.3-9 is an isopach map of the overburden at the Weldon Spring site. This map was generated by subtracting the top of bedrock surface from the site topography. This method ensures that site topography, overburden thickness, and bedrock topography maps are consistent. In certain locations, large quantities of construction fill materials have been placed. For example, the dikes for the raffinate pits are reflected in the overburden isopach map as areas of relatively great thickness and limited areal extent.

The thickness of the overburden generally ranges from 5 to 18 m (15 to 60 ft) and is controlled both by surface erosional features and bedrock topography. Figure 4.3-10 is an isometric view of the overburden thickness across the site. It shows relative thickness variations across the site. The overburden is generally thickest in the north-central portion of the site and thinnest in the eastern third of the site. This thickness can be correlated directly with topographic lows and highs, respectively, on the bedrock surface in these areas. The six soil units which comprise the overburden are discussed in descending order below.

Topsoil/Fill Unit. The uppermost overburden unit on site is the combined topsoil/fill unit. This unit ranges in thickness from 0 to 9 m (0 to 30 ft) (Figure 4.3-11). The topsoil fraction is widespread on site and ranges from 0 to 1 m (0 to 3.5 ft) thick. It is generally a black, organically rich clayey silt to silty clay. The fill portion of the unit varies greatly in thickness because of its use as construction material for the raffinate pit dikes, Ash Pond dike, and as fill for leveling low areas such as old drainages prior to construction of the site buildings. The fill composition varies but is primarily clayey silt believed to be excavated on or near the site, transported, and recompacted. Laboratory testing indicates the dike fill material to be unsaturated, with moisture contents ranging from 15% to 22% (BNI 1984c; MKF and JEG 1988j).

Loess Unit. Underlying the topsoil/fill unit is an upper Pleistocene loess unit that is distributed sporadically on site due to predepositional topography, post-depositional erosion, and the extensive reworking of the upper overburden soil during site preparation and construction. Loess thickness from borehole data ranges form 0 to 3 m (0 to 10.5 ft). The loess unit is primarily a silt to clayey silt with very minor amounts of sand and exhibits low plasticity. The sporadic distribution of loess on the site tends to minimize its effect on the total overburden hydrogeology and potential contaminant pathways at the site.

<u>**Ferrelview Formation.**</u> The Ferrelview Formation underlies the loess unit and is present across most of the site. Figure 4.3-12 is an isopach map of this unit derived from borehole and trenching data. The thickness of the unit ranges from 0 to 6.5 m (0 to 22 ft). The Ferrelview Formation is believed to be a mid-Pleistocene glacial till plain sediment. It consists of a mottled gray and dark yellowish-orange silty clay to clayey silt that is often quite stiff and plastic. Iron oxide nodules and pyrolusite (manganese oxide) fracture coating are common in this unit. Samples of the clay will sometimes fracture conchoidally and in many cases are slickensided due to consolidation and compaction after deposition. Laboratory tests for particle size distribution show a majority of silt and clay-sized particles (<0.063 mm or <0.002 in) in this unit with minor sand and fine gravel.

<u>**Clay Till Unit.**</u> The clay till unit underlies the Ferrelview Formation and is the most areally extensive overburden unit on the site. Figure 4.3-13 is an isopach map of this unit. The clay till ranges in thickness from 0 to 9 m (0 to 30 ft) and is found in almost all boreholes and trenches on site. This unit is a lower Pleistocene glacial till composed of yellowish-brown silty clay and clayey silt. This material is massive, very stiff, moderately to highly plastic, and contains some sand and rounded pebbles of chert, igneous, and metamorphic rock. Pyrolusite fracture coatings are abundant as are iron oxide nodules.

<u>**Basal Till Unit.**</u> The basal till unit is the lower member of the Pleistocene glacial till sediments found on site. It underlies the clay till unit and was deposited mainly on the western and north-central areas of the site. Figure 4.3-14 shows the distribution of this unit and its thickness. Deposition of the basal till appears to have been influenced by the bedrock topography since the unit is generally thin or absent in areas of higher bedrock elevations and is thicker where bedrock elevations are lower. The basal till unit ranges in thickness from 0 to 3 m (0 to 10 ft) and can generally be described as a yellowish-brown sandy, clayey, silty gravel or gravelly silt. The gravel fraction is usually angular chert which is loosely bound in the silty matrix.

<u>**Residuum Unit.**</u> The residuum unit is located beneath the basal till at the base of the unconsolidated overburden. It is interpreted to be a weathering product of the underlying argillaceous cherty limestone, probably formed prior to the Pleistocene. Figure 4.3-15 is an isopach map of the residuum. The thickness and areal extent of the unit appear to be somewhat affected by bedrock topography. Bedrock lows tend to have a thicker section of this unit as illustrated in the cross sections (Figures 4.3-4 through 4.3-8).

This unit ranges in thickness from 0 to 8 m (0 to 26 ft). The residuum is typically a distinctive red to minor yellow gravelly clay to gravelly silt. The gravel fraction is generally weathered chert fragment but contains minor weathered limestone. The interstitial clay is usually quite plastic and tends to form a tight matrix within the gravel fraction.

Overburden Properties

Selected geotechnical engineering properties of each of the site soil types were evaluated. Laboratory test results for soil evaluations conducted from 1988 to 1990 are summarized in Table 4.3-3. Except for the raffinate pit dike fill material, the engineering properties of each soil unit were evaluated based on the laboratory test results of combined samples from the chemical plant, raffinate pit, and administration building areas. Engineering properties of raffinate pit dike fill were evaluated separately and are also presented in Table 4.3-3.

Bechtel National, Inc. (BNI) (1987) also summarized soil testing data for samples from the various overburden units. These data are presented in Table 4.3-4. BNI measured the cation exchange ratio in samples from selected overburden units. The clay till exhibited the highest effective cation exchange ratio while the basal till had the lowest. This high ratio, in addition to its high unit weight, may make the clay till a suitable candidate for borrow material for construction of a clay liner and cap in a disposal cell. Additional cation exchange testing was conducted on soil samples from the geotechnical trenching in 1988 and 1989 on the site and in a clay borrow area off site. Testing of selected soil samples from the test pits showed that the Ferrelview Formation also has a high effective cation exchange ratio with some samples testing higher than the clay till.

BNI reported that quartz, limonite (iron oxide), and limestone (calcium carbonate) were noted in particle size analyses of the overburden (BNI 1987). These minerals are of interest as they influence the groundwater chemistry, and possibly the physical nature of the unsaturated zone and the aquifer. In addition, the mineralogical composition is useful in assessing the leaching and/or attenuation of contaminants. The data, however, are not quantitative (MKF and JEG 1988j).

The USGS collected and analyzed more than 60 samples of overburden materials for chemical and mineralogical constituents and grain size distribution. Mineralogical and grain size distribution analyses indicate that quartz is the predominant mineral in all size fractions. Clay minerals compose 1 to 10 weight percent of bulk mineralogy for the Ferrelview Formation, 3 to 11 weight percent for the clay till, and 1 to 8 percent for the basal till unit. Montmorillonite is the most abundant clay mineral followed by kaolinite and illite. Calcite is present at noticeably greater weight percent in samples from the middle and lower clay till, the basal till, and residuum than from the Ferrelview Formation and upper clay till (Schumacher 1990).

Composite samples of the Ferrelview Formation and clay till unit were used in laboratory sorption experiments (batch tests) using a simulated leachate constructed of raffinate pit water. The results of these experiments indicated that concentrations of most contaminants in the simulated leachate solution decrease when in contact with the Ferrelview Formation and clay till. However, concentrations of calcium in solution generally increase with reaction time, especially at lower pH values, in contact with the clay till material. For example, concentrations of calcium in solution in contact with the clay till increase from 530 mg/l in the initial solution to 1,400 mg/l after 480 hours (20 days) at pH 4.5. Magnesium concentrations in solution decrease with time at all pH values except in contact with the clay till at pH 4.5. Concentrations of sodium, sulfate, nitrite, nitrate, and lithium generally remain unchanged with time at all values of pH for both the Ferrelview Formation and clay till experiments. Aluminum concentrations in solution in contact with the Ferrelview Formation and clay till decrease with time at pH 7.0 and 9.0. At pH 4.5, however, aluminum concentrations increase with time, especially when in contact with the clay till material, 80 μg/l at time period 0 to 3,100 μg/l at time period 5 (480 hours). Concentrations of lead and vanadium decrease rapidly at all values of pH for both overburden units to less than the detection limits of 2 and 10 μg/l. Concentrations of molybdenum remaining in solution are significantly affected by pH. At pH 4.5, molybdenum decreases from 4,400 μg/l and 4,000 μg/l in the Ferrelview Formation and clay till experiments to less than the detection limit of 100 μg/l at the end of 480 hours. Lesser quantities of molybdenum were removed at pH 7.0, and no significant removal was observed at pH 9.0 (Schumacher 1990).

Generally, trends of increasing or decreasing constituent concentrations in solution with time were similar in both the Ferrelview Formation and clay till experiments. However, the magnitude of such changes usually were different. Concentrations of uranium in solution decreased at all pH conditions in the Ferrelview Formation and clay till experiments. At low pH values, uranium decreased from 3,400 μg/l and 3,100 μg/l in the initial Ferrelview and initial clay till solutions to 160 μg/l and 75 μg/l after 480 hours. Similarly to most other contaminants, larger quantities of uranium remained in solution with increasing values of pH except for the solution in contact with the clay till at pH 7. At this pH, nearly 50% of the initial quantity of uranium remained in solution after 480 hours (Skelton 1990).

Hydraulic conductivity testing of overburden samples indicates the loess unit has the highest values ranging from 2.0 x 10^{-7} to 3.8 x 10^{-9} m/sec (6.5 x 10^{-7} ft/sec to 1.2 x 10^{-9} ft/sec). BNI tested the topsoil/fill unit in samples from the raffinate pit 4 dike which exhibited a range of 1.4 x 10^{-9} m/sec to 1.6 x 10^{-11} m/sec (4.6 x 10^{-9} ft/sec to 5.2 x 10^{-11} ft/sec) (BNI 1984b). The Ferrelview Formation has hydraulic conductivity values ranging from 3.2 x 10^{-8} to 4.0 x 10^{-11} m/sec (1.0 x 10^{-7} ft/sec to 1.3 x 10^{-10} ft/sec) with an average of 4.6 x 10^{-10} m/sec (1.5 x 10^{-9} ft/sec). The clay till exhibits the lowest hydraulic conductivity of the overburden units, ranging from 3.0 x 10^{-8} m/sec to 3.2 x 10^{-11} m/sec (9.8 x 10^{-8} ft/sec to 1.0 x 10^{-10} ft/sec), averaging 2.6 x 10^{-10} m/sec (8.6 x 10^{-10} ft/sec). One sample at the basal till/clay till contact was tested and revealed a hydraulic conductivity of 3.9 x 10^{-10} m/sec (1.3 x 10^{-9} ft/sec) which is probably not indicative of the basal till unit. The hydraulic conductivity for this unit can be expected to be higher than other overburden units due to the high sand and gravel content.

In terms of hydraulic conductivity, the residuum is extremely heterogeneous. Due to its gravel content, collection of undisturbed samples of this unit for laboratory testing proved extremely difficult. Of the five samples successfully recovered, three consisted of noncohesive gravels which could not be tested. These samples represent high conductivity zones within the residuum. The two remaining samples were gravelly, but cohesive, and yielded hydraulic conductivity values of 5.0×10^{-10} m/sec (1.6×10^{-9} ft/sec) and 3.0×10^{-10} m/sec (9.8×10^{-10} ft/sec). These values should not be considered as representative of the entire residuum unit.

In situ hydraulic conductivity measured at the overburden/bedrock interface (base of residuum) ranges from 9.4×10^{-4} m/sec to 1.5×10^{-6} m/sec (3.1×10^{-3} ft/sec to 4.9×10^{-6} ft/sec) (BNI 1987). These results reflect hydraulic properties at the residuum/bedrock interface and may not represent the residuum unit. However, these results are much higher than other overburden units tested and may be of concern as a potential lateral migration pathway for contaminants. Migration is possible, particularly where the bedrock surface exhibits a linear channel morphology and the interface zone is saturated or directly below a contaminant source.

Bedrock Stratigraphy

The uppermost bedrock unit at the site is the Burlington-Keokuk Limestone. This is a fine- to coarse-grained, thinly to massively bedded argillaceous limestone that contains abundant chert as nodules and beds. From borehole stratigraphic data, the formation has been divided into two units based primarily on weathering characteristics. The upper division is referred to as the weathered limestone, and the lower division is referred to as the competent limestone.

Weathered Limestone.

The weathered limestone ranges in thickness from 3 to greater than 15 m (10 to greater than 50 ft). Figure 4.3-16 is an isopach of this unit showing the depth of significant weathering of the bedrock. Figure 4.3-17 is a top of bedrock contour map interpreted from borehole data. It shows possible paleodrainage features identified in earlier studies (BNI 1987). The longest linear paleodrainage feature is located in the north central area of the site and trends approximately N30°W, which is within the regional joint orientation range of N30°-65°W (BNI 1987). The limestone surface does not exhibit features indicative of karst geomorphology. Figure 4.3-18 is an isometric view of the weathered limestone surface with a vertical exaggeration of ten times to accentuate relief. It graphically shows the general dip of the limestone to the north, and the linear depressions inferred to represent pre-glacial drainages.

The weathered limestone is typically a grayish-orange to yellowish-gray, argillaceous limestone, commonly containing up to 60% chert as nodules and interbeds. The unit is finely crystalline, thin- to thick-bedded, fossiliferous, moderately to highly fractured, slightly to severely weathered, with abundant iron oxide staining and pyrolusite (manganese oxide) in the rock matrix and along fractures. Solution features are quite common in this unit, ranging from pinpoint vugs to small cavities up to 1.5 m (5 ft) (BNI 1987). Many of the smaller vugs are lined with calcite and drusy to euhedral quartz. In most cases the larger voids are filled with clay or silt/clay/chert gravel mixtures. These cavities are generally reported as core loss on the borehole logs due to the washing out of the clay and gravel during the coring operation. During the drilling of some holes, it was difficult to distinguish the top of bedrock due to alternating rock and clay zones at or near the bedrock surface. These zones may be interbeds of chert and argillaceous limestone. The solution-resistant chert beds remain, whereas only the insoluble fraction of the limestone (clay) remains as cavity fill. Solution features in this unit are typically oriented parallel to bedding.

Competent Limestone. Underlying the weathered limestone is the competent limestone which is thin- to massively bedded, gray to light gray, finely to coarsely crystalline, stylolitic and fossiliferous, slightly weathered to fresh, with 20 to 40% chert. This unit has very little iron oxide staining and exhibits fresh pyrite on some fracture surfaces. Figure 4.3-19 represents the top of this unit which shows a relatively planar surface dipping to the north. This indicates a somewhat even datum for the depth of weathering in the limestone. Figure 4.3-20 represents an isometric view of this weathering-controlled surface.

Bedrock Properties. Discontinuity in the rock was quantified by calculating the rock quality designation (RQD) for each length of core recovered during core drilling. The RQD equals the cumulative length of intact core pieces 10 cm (4 in) in length or greater, divided by the total length of the core run, expressed in percent form. Table 4.3-5 shows a summary of RQD values by bedrock unit. The table shows that 73% of the RQD values for the weathered limestone are very poor (0 to 25%) or poor (26 to 50%). Conversely, the competent limestone has only 21% very poor to poor RQD values. Lower RQD values for the weathered limestone unit result from a higher degree of fracturing and weathering that has occurred near the surface of the bedrock.

Core drilling results indicate that fracturing in the weathered limestone is predominantly horizontal and loosely spaced, typically occurring along less indurated interbeds, bedding planes, or cherty interbeds. Mineralization and clay deposition of fractures is common.

Two borings (AH-1 and AH-2) were cored at 60 degrees from horizontal along bearings of N42° and N39°W to intersect regional northwesterly and northeasterly vertical joint sets, respectively. The vertical joints near the bedrock surface were obscured by poor quality core and/or core loss caused by the highly weathered nature of portions of the rock. Below the bedrock surface, spacing between vertical joints was sporadic, ranging from approximately 1 m to 5.5 m (2.5 to 18 ft) and averaging 3 m (10 ft). Vertical joints near the bedrock surface have enlarged and filled with clay due to dissolution. The apertures of these fractures appear to narrow in short vertical distances and become relatively tight at depth. The ratio of horizontal to vertical fractures in these angled holes is approximately 20:1 or greater. The hydraulic conductivity of the bedrock is discussed in Section 4.6.2.

The competent limestone lacks significant horizontal and vertical fracturing. Table 4.3-5 shows that 79% of the RQD values are in the fair to excellent range. Large solution features are uncommon in this unit.

Geophysical Studies

Geophysical studies have also been conducted to characterize site stratigraphy. The investigation most applicable to site stratigraphy was conducted by Geotechnology Services, Inc. (GSI) (GSI 1988b). The results of the GSI investigation are summarized below.

Generally, three seismic layers were defined by seismic refraction. The surface seismic layer ranges in thickness from 0.5 to 4.6 m (1.5 to 15 ft), and the velocity ranges from 15.2 to 585.2 m/sec (500 to 1,920 ft/sec). This layer does not appear to correspond to a specific litho-stratigraphic unit. The second seismic layer ranges in thickness from 6.7 to 18.3 m (22 to 60 ft) and has a velocity between 677 and 1,792 m/sec (2,221 and 5,878 ft/sec). Seismic velocities in this range may correspond to the top of layers within the Ferrelview Formation or clay till unit. Velocities above 1,220 m/sec (4,002 ft/sec) probably correspond to basal till or residuum.

The deepest seismic horizon has a velocity of 3,535 to 5,547 m/sec (11,595 to 18,194 ft/sec) and may correspond to the top of moderately weathered to fresh limestone. The seismic horizon dips generally toward the north-northeast. The surface undulates, and local relief of 4.6 m (15 ft) is commonly observed along the seismic lines. The higher velocities are thought to indicate zones of denser, less weathered limestone.

Electromagnetic (EM) resistivity data generally indicated four layers. The surface layer ranges in thickness from 1.7 to 5.5 m (5.5 to 18 ft) and has resistivities ranging from 8 to 45 ohm/m. The surface layer represents fill, loess, or the Ferrelview Formation. The second layer ranges from 1.4 to 5.0 m (4.5 to 16.5 ft) thick and from 2 to 17 ohm/m resistivity. The layer usually corresponds to a zone in the clay till but may also indicate areas of increased clay content in the Ferrelview Formation. The bottom of the layer may correspond to a reduction in clay content.

The third EM layer ranges in thickness from 1.1 to 10.1 m (3.5 to 33 ft), and resistivity varies from 13 to 24 ohm/m. The layer may include highly weathered limestone, residuum, basal till, and lower portions of the clay till. This resistivity layer matches well with the surface at the deepest seismic horizon. Resistivities of the deeper EM layer generally range from 20 to 50 ohm/m. The resistivities are generally low, which may indicate shale and/or clay filled bedding planes in the dense bedrock.

Subsurface models derived from the four vertical electric resistivity surveys show five or six layers. The surface resistivity layer varies both in value and thickness due to the moisture content, type of soil, and the vegetation present at the surface. Below the surface layer, variations in resistivity are probably due to changes in clay or moisture content. The resistivity of the second and third layer range from 20 to 35 ohm/m and 3 to 20 ohm/m, respectively. Both of these layers may include clay till. The fourth layer ranges in resistivity from 22 to 120 ohm/m. This layer may correspond to basal till or highly weathered limestone. Moderately weathered limestone may be indicated by the fifth layer which ranges in resistivity from 480 to 1,000 ohm/m.

4.3.2 Structural Geology

The Weldon Spring site is situated in the southeast corner and on the very southern edge of the Dissected Till Plains, a subdivision of the Central Lowland Physiographic Province. The site lies on a subtle ridge which forms a surface drainage divide between the Missouri and Mississippi Rivers. South of the site, the topography changes dramatically as the gentle, rolling topography of the Dissected Till Plains gives way to narrow ridges and valleys which characterize the Salem Plateau, a subdivision of the Ozark uplift. Near the southern boundary of the site, the transition from the Dissected Till Plains to the Salem Plateau is evident where relatively steep and highly dissected bedrock slopes to the Missouri River 24 km (1.5 mi) south of the site. This physiographic transition nearly coincides with the line of demarcation of the southern edge of the Pleistocene glaciation that covered the northern half of Missouri over 10,000 years ago (Kleeschulte et al. 1986).

Due to vertical crustal movement during the Paleozoic Era, rocks of the Central Stable Region, of which Missouri is a part, were deformed into broad basins and arches (Eardley 1962). Located about 6 km (4 mi) southwest of the site is the northwest trending axis of the Eureka-House Springs anticline (BNI 1987). Rocks on the northeast limb of this gentle fold strike approximately N60°W and dip approximately 0.5° to 1° to the northeast.

4.3.2.1 Faulting. Geologic mapping of the Weldon Spring 7.5 minute quadrangle by the Missouri Department of Natural Resources-Division of Geology and Land Survey shows an unnamed east trending normal fault located approximately one mile north of the site. The concealed trace of the fault terminates at Lake 35. A 1.6 km (1 mi) westerly projection of the trace passes very close to Burgermeister Spring. The fault reportedly exhibits approximately 18 m (60 ft) of vertical displacement with the north block down. East of Highway 40/61, the Salem Formation is in fault contact with the Warsaw Formation. At a location north of the site, the Burlington-Keokuk Limestone may be faulted against the Warsaw Formation (Whitfield et al. 1989).

Figure 4.3-21 is a regional geologic structure map showing the elevations of the top of the Fern Glen Formation. This map in concert with other mapped horizons depicts the strike and dip in the region as well as the faulting, as evidenced by surface observation and subsurface data. Data density and quality is sufficient to demonstrate that no faults cross the Weldon Spring site. An unusually thick section of Plattin Limestone overlying the Decorah Formation on the western portion of the map is indicative of a thrust or reverse fault. The possible fault would track to the southeast as detected in the well which showed thick Chouteau Formation while the Fern Glen Formation was absent, apparently faulted out. This reverse or thrust fault may be present as a result of the uplift resulting in the formation of the Eureka House Spring Anticline.

The Weldon Spring site lies within the tectonically quiet, central stable seismic region. A few scattered seismic events have been recorded throughout Missouri and Illinois (Zoback and Zoback 1981; Johnston 1982; BNI 1984d), but these have been of small magnitude and do not define a currently active fault or faults. No evidence has been found of tectonic surface ruptures related to historic earthquakes in the area. The New Madrid seismic zone at the northern end of the Mississippi Embayment, located about 260 km (160 mi) south of the site, is the nearest zone of major seismic activity (BNI 1983c). Isoseismal maps compiled for the 1811, 1843, 1895, and 1968 earthquakes by Hopper et al. (1983) show that the Weldon Spring area has experienced Modified Mercalli earthquake intensities ranging from V to VII.

4.3.2.2 Bedrock Jointing. Roberts (1951) reported two major joint sets in the Weldon Spring area: one set trending between N30°W and N65°W and the other set oriented N30°E to N72°E. All joints have dips of vertical to nearly vertical. Joint mapping of the limestone bluffs near the Weldon Spring quarry site by Berkeley Geosciences Associates (1984) revealed a dominant joint trend of about N70°W and two minor orientations of approximately N60°E and northerly.

Project Management Contractor (PMC) personnel obtained 80 joint measurements from Ordovician bedrock exposures at quarries and exposures along the drainage flowing from the southeast edge of the site to the limestone bluffs bordering Femme Osage Slough. These results show a major joint set trending N70°W to N80°W. Two secondary sets are oriented N50°W to N60°W and N60° to N80°. Additional joints show a minor trend northerly. All joint surfaces dip nearly vertically (JEG 1987).

The regional joint system was evaluated from topographic features depicted on the Weldon Spring and Defiance 7.5 minute topographic quadrangles and the viewing and interpretation of stereoscopic infrared aerial photographs. Inspection of topographic quadrangle maps reveals many linear streams associated with the dissected slope (Salem Plateau) bordering the northwest side of the Missouri River. The extreme linearity of these streams suggests that these valley orientations may be structurally controlled along joints (Figure 4.3-22).

The predominant trend of the stream segments shows a strong orientation to the northwest at a mean bearing of N65°W. Another set of stream segments, nearly as prominent, trends N20°E to N58°E with a mean bearing of N38°E. A tertiary set bears approximately N10°W. Length measurements of all straight stream segments indicate the N65°W segments are of greater average length, suggesting this trend is dominant. Lineaments identified on air photos are also plotted on Figure 4.3-22 and show very similar trends to the linear streams. The lineaments are interpreted to represent joint directions.

A few northeast oriented linear streams are located on the till plain north and northwest of the site. These trends may reflect bedrock jointing at depth; however, surface drainage in this area appears to lack significant structural control compared to the tributaries of the Missouri River which are incised into bedrock.

Figure 4.3-17 displays the topography of the uppermost weathered limestone beneath the site. Although the surface displays considerable relief, in general the surface dips approximately 1° to the north-northwest. Etched upon the limestone surface are several linear depressions which appear to reflect pre-glacial drainages. Figure 4.3-23 presents the bedrock linear features and suggests that present day topography and surface drainages reflect subsurface structure.

In summary, all investigations of the Weldon Spring area have recognized joint orientations to the northwest and northeast with a minor northerly trend.

4.3.3 Soils

The predominant soil type in the chemical plant area is the Harvester-Urban Complex (U.S. Department of Agriculture 1982). This soil is primarily composed of silty loess materials that have a moderate permeability and high water content. The Harvester group has been transported and shaped by earthmoving equipment; the Urban group has been covered by roads, parking lots, buildings, and other structures. The Harvester-Urban soil exhibits moderate shrinking and swelling and is easily eroded. More than 20 m (64 ft) of alluvial deposits blanket the bedrock in the Missouri River valley.

4.4 Surface Water Hydrology

A primary factor influencing surface water hydrology in the vicinity of the Weldon Spring site, is the site location on the drainage divide between the Mississippi and Missouri River basins. The Missouri River is about 2.4 km (1.5 mi) southeast of the site, while the Mississippi River is approximately 22.4 km (14 mi) north of the site.

4.4.1 Surface Water Features and Drainage Patterns

Streams in the immediate vicinity of the site include Schote Creek, a tributary of Dardenne Creek north of the site, and the southeast drainage, an unnamed tributary of the Missouri River south of the site. Figure 4.4-1 shows the major tributaries and their drainage boundaries in the vicinity of the site. Surface runoff from approximately 68 ha (168 ac) of the chemical plant and raffinate pit areas ultimately flows to the Mississippi River, while 8.9 ha (22 ac) drain toward the Missouri River. The four raffinate pits, encompassing about 10.9 ha (27 ac), do not directly contribute to surface runoff (Figure 4.4-2).

Much of the original topography across the site prior to 1954 was changed by cuts and fills for the construction of the uranium processing plant and raffinate pit facilities, including several man-made ponds. The main surface water bodies within the site boundaries are the four raffinate pits, Ash Pond, and Frog Pond. The physical characteristics of the four raffinate pits are listed in Table 4.4-1 (Kleeschulte and Emmett 1987). The storage volume of Ash Pond is about 53,600 m^3 (1,892,080 ft^3) at its full pool level, 192.6 m (632 ft) NVGD, estimated from the available topographic maps (Surdex Corp. 1987). The corresponding surface water area is about 4.5 ha (11.1 ac). Frog Pond is relatively small. The surface water area at its full pool level, 192 m (630 ft) NVGD is about 0.3 ha (0.7 ac), estimated from the available topographic maps (Surdex Corp. 1987).

The U.S. Department of Housing and Urban Development (1978) has identified approximately 0.5 ha (1.3 ac) of the Weldon Spring property as lying within the area identified as the 100-year flood plain of Schote Creek. An existing roadway and a weir for measuring stream flow at the property fence line (elevation 610 ft) would affect floodwaters that could result from such an event.

Surface water bodies in the vicinity of the site potentially affected by surface runoff from the site include Lakes 34, 35, and 36 in the August Busch Wildlife Area (Figure 4.4-1). Lake 36 has a surface water area of about 6.3 ha (15.5 ac) when it is full. The average depth of Lake 36 is about 1.8 m (6 ft), and the deepest part of the lake is about 5.8 m (19 ft). The average depth of Lake 35 is about 2 m (6.5 ft) and the surface water area is about 25.3 ha (62.5 ac) when the lake is full. The deepest part of Lake 35 is about 8.2 m (27 ft). The surface water area of Lake 34 is about 14 ha (35 ac) with an average depth of about 2.8 m (9.3 ft) when it is full. The deepest part of Lake 34 is about 8.2 m (27 ft). Table 4.4-2 lists the drainage areas at various locations on Schote Creek and the unnamed tributary of Dardenne Creek flowing through Lake 34.

Several springs and seeps also exist in the vicinity of the site. Some of the springs, known as wet weather springs, flow only following moderate to heavy rainfall events (MKF and JEG 1988r). Burgermeister Spring, located immediately upstream of Lake 34, is a major spring with perennial flow (Figure 4.4-1).

Three major drainage areas within the Mississippi River basin exist at the site: Frog Pond area, the Ash Pond area, and the raffinate pit area. Figure 4.4-2 shows the site drainage area boundaries and illustrates the potential surface flow paths out of the site. As shown in Figures 4.4-1 and 4.4-2, runoff from the northeastern portion of the chemical plant and stormwater from most of the chemical plant area are collected at Frog Pond and released into Lake 36. Overflow from Lake 36 enters Schote Creek and flows into Lake 35. Surface runoff from the Ash Pond drainage area and the raffinate pit area drains to an unnamed tributary of Schote Creek. From there it flows into Schote Creek northward to Lake 35. Lake 35 has been losing water to the subsurface since its construction (MKF and JEG 1988t).

Overflow from Lake 35 enters Schote Creek, which joins Dardenne Creek just east of State Route K, and eventually enters the Mississippi River. Both Schote Creek and its unnamed tributary, which drains water from the Ash Pond and raffinate pit areas, lose water to the subsurface. Subsurface flow originating in the Ash Pond drainage and Schote Creek resurfaces at Burgermeister Spring (Dean 1985) and flows into Lake 34. Outflow from Lake 34 enters an unnamed tributary of Dardenne Creek and eventually flows into the Mississippi River.

Surface runoff from the 8.9 ha (22 ac) of land in the southeast portion of the chemical plant flows through the southeast drainage area, an approximately 2.4-km- (1.5-mi-) long intermittent stream channel, into the Missouri River (Figure 4.4-1). The drainage area of the southeast drainage is about 151 ha (373 ac) (Table 4.4-2). Some of the rainwater and snowmelt that enter several man-made drains in the chemical plant area flow into the process sewer and exit to the southeast drainage area (MKF and JEG 1988t).

4.4.2 Streamflow

4.4.2.1 Streamflow Characteristics. The small tributary streams in the vicinity of the site have highly variable flows and derive most of their water from direct runoff (Kleeschulte and Emmett 1986). Many streams, including Dardenne Creek and Schote Creek, in the dissected till plains north of the site, have minimal low-flow potential because of the minimal permeability of the underlying clay and shale. The streams are usually dry at some time during each year. The seven-day, two-year low flow for Dardenne Creek near Weldon Spring, estimated by the USGS, was about 0.003 m^3/sec (0.1 ft^3/sec), and the seven-day, ten-year low flow was 0 m^3/sec (0 ft^3/sec) (Missouri Geological Survey 1977). It is also possible for the streams to either gain or lose water if the streambed fully penetrates the underlying clay or shale (Kleeschulte and Emmett 1986; 1987). Streams can have sustained low flows (gaining streams) because of inflow of water from springs or lose water to the streambed (losing stream) through seepage. The unnamed tributary of Schote Creek, which drains water from Ash Pond and the raffinate pit area, is an example of a losing stream. Springs and losing streams are described in Section 4.4.4.

4.4.2.2 Streamflow Data. Streamflow data available on the small tributary streams near the site area are sporadic. Most of the stream flow data available were collected from 1984 through 1986 in conjunction with several water quality and seepage run studies (Kleeschulte and Emmett 1986; 1987; Kleeschulte et al. 1986). The USGS has installed several continuous recording stream gauges near the site, including Schote Creek downstream of Lake 35, an unnamed Dardenne Creek tributary at Twin Island Lake downstream of Lake 34, and Burgermeister Spring (Kleeschulte 1989). Two gauges have been installed in the Burgermeister Spring area since March 1984. Provisional daily flow data are available from these two gauges. The Schote Creek and Twin Island Lake gauges were both installed in August 1987. Three other stream gauges at the site have also been installed by the Missouri Department of Natural Resources (MDNR) and have been in operation since April 1988 (MDNR 1988a). The three MDNR gauging locations correspond to the National Pollutant Discharge Elimination System (NPDES) sampling points: NP-0002 on the Frog Pond tributary just inside the site boundary fence; NP-0003 on the Ash Pond tributary just inside the site boundary fence; and NP-0005 on the southeast drainage just outside the site boundary fence (Section 4.4.2.3).

4.4.2.3 National Pollutant Discharge Elimination System Program. Since 1987, discharge has been measured monthly for the NPDES surface water sampling locations NP-0002, NP-0003, and NP-0005 and quarterly for NP-0001 and NP-0004. Continuous gauging recorders at NP-0002, NP-0003, and NP-0005 were installed by the MDNR after April 1988 as mentioned in Section 4.4.2.2. A new NPDES sampling site, NP-0006, was established in January 1989. This discharge consists of treated effluent from the administration building wastewater treatment plant. The monthly surface water samples are usually collected following significant precipitation events causing consistent runoff. Figure 4.4-3 shows the locations and drainage boundaries of the six NPDES sampling points (NP-0001 through NP-0006).

As shown in Figure 4.4-3, NP-0003 and NP-0004 represent the off-site discharge points leaving the Ash Pond and raffinate pit drainage areas, respectively. Discharges from NP-0003 and NP-0004 flow through the unnamed tributaries to Schote Creek and into Lake 35. NP-0002 is the discharge point for the Frog Pond area which covers the northeastern portion of the site and most of the chemical plant area. Discharges from NP-0002 flow through Lake 36 to Schote Creek and into Lake 35. Water leaving the site as overland flow in the southeastern portion of the site is represented by NP-0005. Flow from precipitation events which is intercepted by the process sewer system at the chemical plant and flow from water which enters various building sumps and drains due to disrepair of some of the roofs of buildings are represented by NP-0001 (MKF and JEG 1988s). Discharges from NP-0001 and NP-0005 flow through the southeast drainage to the Missouri River. NP-0006 is located at the outfall from the wastewater treatment plant for the new administration building, which measures discharge directly from the treatment plant. Discharges from NP-0006 also flow through the southeast drainage to the Missouri River.

The average flow rates from the monthly measurements in 1987 at five sampling locations, NP-0001 through NP-0005, are presented in Table 4.4-3. Because samples were collected only after sufficient precipitation to cause consistent runoff, the actual annual average flow rate from these discharge points would be significantly less than the average of the measured flow rates. The average annual runoff volumes discharged from the five sampling points were estimated based on the size of the drainage area, annual precipitation, and runoff/precipitation ratio in each area (Table 4.4-3) (MKF and JEG 1988s). An average annual precipitation of about 91.4 cm (36 in) at the site was used for the above estimates.

At present, only water level data are available at the three MDNR gauges (NP-0002, -0003 and -0005). The stages and flows at NP-0002 and NP-0003 would be affected by storage in Frog Pond and Ash Pond. The stage hydrographs available in 1988 indicate that NP-0002 below Frog Pond has flow more frequently, while NP-0003 downstream of Ash Pond seldom has flow. NP-0005 has occasional flow from its small drainage area (MDNR 1989a). Flow from NP-0006 ranges from 4×10^{-5} to 3.2×10^{-4} m^3/sec (1.4×10^{-3} to 1.1×10^{-2} ft^3/sec).

In addition to the previously discussed method for determining surface runoff for the site, the USGS has completed a water budget study which may be a more efficient representation for determining a surface runoff coefficient. However, the results of the study are not yet available. Methodologies and results of the USGS study will be reviewed and compared with those used previously at the site to determine applicability and validity.

4.4.2.4 Streamflows of Mississippi River and Missouri River. The surface water from tributary streams near the site eventually reaches either the Missouri or Mississippi rivers. Flow characteristics of the Missouri and Mississippi rivers are completely different from the highly variable tributary stream flows. The flows of these two rivers near the site are perennial. Streamflows on the Missouri River are regulated by an extensive reservoir system in the headwater area, which provides flood control for downstream areas and adequate summer flows for navigation. Flows on the Mississippi River are controlled by a system of locks and dams above the confluence with the Missouri River. The lock and dam system maintains the depth for navigation, but has little effect on mean and high flows for flood control (Missouri Geological Survey 1977).

The 89-year (1897 through 1985) average annual discharge for the Missouri River at Herman, Missouri (USGS gauge 06934500), is about 2,300 m^3/sec (81,230 ft^3/sec) (USGS 1987c). Herman is about 80 km (50 mi) upstream of the site. The total drainage area at Herman is about 1.36 million km^2 (524,200 mi^2). The 59-year (1928 through 1986) average annual discharge for the Mississippi River at Alton, Illinois, near the junction with the Missouri River (USGS gauge 05587500), is about 2,900 m^3/sec (103,500 ft^3/sec) (USGS 1987d). The total drainage area at Alton is about 0.44 million km^2 (171,500 mi^2). The combined flow of the two rivers at St. Louis (USGS gauge 07010000) averages about 5,1000 m^3/sec (180,000 ft^3/sec) with a total drainage of 1.81 million km^2 (697,000 mi^2) (USGS 1987c).

4.4.3 Flooding Potential

Floods on the Missouri and Mississippi Rivers are most common in spring and summer between April and July. The maximum recorded flood discharge on the Missouri River at Hermann was 14,144 m^3/sec (676,000 ft^3/sec) with a stage elevation of 158 m (517 ft) NVGD, on June 6, 1903. The maximum recorded flood discharge on the Mississippi River at Alton was 15,200 m^3/sec (535,000 ft^3/sec) on April 29, 1973, and the corresponding river stage was elevation 131.8 m (432.1 ft) NVGD (USGS 1991). Since the elevation at the site ranges from approximately 185 m (608 ft) NVGD near the northern edge to about 205 m (672 ft) NVGD near the southern edge (MKF and JEG 1988t), the potential for site flooding as a result of floods on the Missouri and Mississippi Rivers is negligible.

Floods on the tributary streams in the vicinity of the site are most likely to occur during the summer months (May and June) as a result of intense local thunderstorms which cause flash-flooding (Missouri Geological Survey 1977). Preliminary estimates of peak flood discharges for

Schote Creek near the site have been developed by the U.S. Army Corps of Engineers (COE) (DOE 1987). The 100-year and 500-year flood peak discharges for the mainstem for Schote Creek are 59.5 m^3/sec (2,100 ft^3/sec) and 76.5 m^3/sec (2,700 ft^3/sec), respectively. The 500-year flood elevation near the raffinate pits was determined to be about 162 m (531 ft) NVGD, which is considerably lower than the elevation for the site.

4.4.4 Surface Water/Groundwater Interaction

In the past, spring and seep surveys, seepage runs, and dye trace and water trace studies have been conducted around the Weldon Spring site area by several agencies. The results of these studies were used to determine the interaction between surface water and groundwater in the site vicinity; to identify potential contaminant migration paths from the site; to identify the gaining versus losing-stream reaches; and to trace the interconnection between surface runoff from the site flowing through the losing-stream reaches and the flow from the contaminated springs.

4.4.4.1 Springs and Seeps. A complete reconnaissance survey of the area surrounding the site was performed in the summer and fall of 1987 to locate springs and seeps which may be affected by the site. The survey was performed by MDNR and PMC geologists (MKF and JEG 1988t).

Springs, seeps, and swallow holes were identified and located on USGS 7.5 minute topographic maps. Locations of known springs, seeps, and swallow holes in each tributary drainage basin are shown on Figure 4.4-4 (MDNR 1989a). A swallow hole is a point in a stream bed where a sinking stream loses its discharge to the subsurface (White 1988). The 5000 series numbers represent the springs and seeps located in the Missouri River drainage, and the 6000 series numbers represent those located in the Mississippi River drainage. The second digit (hundred) in the thousand series represents the subdrainage area from east to west. The last two digits represent the designated spring number.

The types of springs in the vicinity of the site vary from small seeps at bedrock and clay interfaces to solution-enlarged bedrock conduits and fractures that flow at rates of 0.01 m^3/sec (0.44 ft^3/sec) or more during precipitation events. Some of the springs, referred to as wet weather springs, flow only after significant rainfall events. Flows from wet weather springs are generally short in duration and sometimes quite heavy (Figure 4.4-5) (MKF and JEG 1988r).

Daily discharges of Burgermeister Spring (SP-6301) and a nearby wet weather spring (SP-6302) have been monitored by the USGS since March 1985. Tables 4.4-4 and 4.4-5 are the recorded spring flow data for a period from March 20, 1985 through April 30, 1986 (Kleeschulte et al. 1986). These measurements were used to determine the connection between the losing-stream reaches draining the Ash Pond and raffinate pit area and Burgermeister Spring. Figure 4.4-5 shows the daily flow hydrographs of Burgermeister Spring and spring SP-6302, and the corresponding rainfalls during the periods from March 1985 to April 1986. Figure 4.4-5 indicates that the discharges from both Burgermeister Spring and the wet weather spring responded quickly to rainfall. The daily discharge of Burgermeister Spring for the period of record ranged from 0.002 m^3/sec (0.07 ft^3/sec) during base flow to 0.02 m^3/sec (0.71 ft^3/sec) following an intense storm, while the daily discharge for the wet weather spring ranged from no flow to 0.1 m^3/sec (3.7 ft^3/sec) (Kleeschulte and Emmett 1987).

4.4.4.2 Losing Streams. Losing stream segments on several tributaries around the Weldon Spring area have been identified from seepage runs conducted by the USGS in 1984 and 1985 (Figure 4.4-9) (Kleeschulte and Emmett 1986; Kleeschulte et al. 1986). Results of the MDNR and USGS studies are presented in Figure 4.4-9. A seepage run is a series of discharge measurements along a stream reach made in a short time period to identify where gains or losses in flow occur (Kleeschulte and Emmett 1987). A gaining segment is identified by the consistent increase in flow in the downstream direction. A reduction of flow in the downstream direction indicates the segment is losing water to the subsurface and groundwater system.

On December 11, 1984, visual estimates of discharge were made at 20 different locations on Schote Creek and its tributaries in the Weldon Spring and Busch Wildlife areas, an unnamed tributary of Dardenne Creek containing Lake 34, and the southeast drainage area. The information provided by the USGS was supplemented and slightly modified by the MDNR (1989b). Figure 4.4-6 shows the discharge measurement locations and the estimated discharge values.

From April 1 through 4, 1985, streamflow was measured at 102 sites on six north-flowing Dardenne Creek tributaries from Kraut Run to Crooked Creek. Figures 4.4-7 and 4.4-8 show the USGS discharge measurement locations and estimated discharge values for subdrainages near the site. Figure 4.4-7 specifically addresses the tributary to Dardenne Creek above Lake 34, and Figure 4.4-8 shows locations and values for Schote Creek basin above Lake 35.

These studies found that Kraut Run gains flow along its entire length (Figure 4.4-9). The source of discharge in the upstream reach of the creek was groundwater seepage to the stream. The flow significantly increased in the downstream reach east of State Route DD, and the area in the vicinity of Lake 33 appears to be a groundwater discharge zone.

The unnamed tributary of Dardenne Creek to the east of Kraut Run was an interrupted stream at the time of the April 1985 seepage run. The stream reach downstream from Busch Wildlife Area Road C to the junction with the tributary that drains Lake 31 appears to be a losing stream (Figure 4.4-9). The flow decreased until the stream became dry. Downstream from the junction with the tributary from Lake 31, the streambed remained dry, but began flowing again about 366 m (1,200 ft) upstream from Busch Wildlife Area Road B. Flow gradually increased downstream to the confluence with Dardenne Creek.

The upstream reach of the unnamed tributary of Dardenne Creek receiving water from Lakes 6, 7, 8, and 23, above the junction with the stream draining Lake 23, appeared to be a losing stream based on the April 1985 seepage-run data (Figure 4.4-9). The remaining reach of the tributary became a gaining stream.

The December 1984 and April 1985 seepage-run data indicate the unnamed tributary of Dardenne Creek containing Lake 34 appeared to be gaining flow along its reach (Figures 4.4-6 and 4.4-7). Part of the increased discharge may be attributed to change in storage of Lake 34 and also from spring flow at Burgermeister Spring and two wet weather springs. During wet weather, flows from the three known springs enter the main stem of the tributary by a spring branch. The three springs are all believed to be hydrologically connected. However, only Burgermeister Spring is perennial.

Based on both December 1984 and April 1985 seepage-run results, Schote Creek was gaining discharge throughout its upstream reaches above Hampton Memorial Lake. Downstream from Hampton Memorial Lake, the creek was a losing stream to Lake 35 (Figures 4.4-6 and 4.4-8). The unnamed tributary of Schote Creek that drains the Ash Pond and raffinate pit areas was a losing stream and was dry between 183 m (600 ft) downstream of State Route D and the junction with Schote Creek. Schote Creek itself was dry above the junction with the tributary that drains Frog Pond and Lake 36. The tributary that drains the Frog Pond area did not appear to be losing flow. Schote Creek below Lake 35 gained flow downstream toward its confluence with Dardenne Creek.

Crooked Creek did not have any losing reaches throughout its length according to the April 1985 seepage run. This was verified again by measurements in June 1987 (Kleeschulte and Emmett 1987).

The southeast drainage area appeared to contain a perennial reach and gained flow to a point about 91 m (300 ft) downstream of State Route 94, based on December 1984 measurements. The streambed became dry about 183 m (600 ft) farther downstream and remained dry for about another 183 m (600 ft) (Figure 4.4-6). The seeps emerged at this point and caused flow to begin again in the tributary. A gaining-losing-gaining sequence occurred again within the next 0.8 km (0.5 mi).

4.4.4.3 Dye Trace and Water Trace Studies. Both the MDNR and the USGS have conducted dye trace studies on surface streams in the Weldon Spring site area. The locations of these dye trace studies are shown on Figure 4.4-10.

<u>Trace Studies on North-Flowing Tributary Basin</u>

On February 9, 1984, MDNR performed a dye trace test (Trace 1) on the surface drainage west of raffinate pit 4 in a losing stream reach of the unnamed tributary of Schote

Creek. The dye was detected in charcoal packets recovered on February 14 and February 17 at several springs in the Burgermeister Spring area (SP-6301 to SP-6303) and on the stream channel at the head of Lake 34 immediately west of SP-6301 (Dean 1984a).

The March 21, 1985, dye trace test (Trace 3) by the MDNR was in a losing stretch downstream from Ash Pond in the east fork of the unnamed tributary of Schote Creek. The dye was placed in a flowing reach of the tributary downstream from Ash Pond. The surface flow continued downstream for about 27 m (90 ft) where the entire flow was lost to the subsurface. Four days later, the charcoal packets were recovered and positive traces of dye were detected in those from Burgermeister Spring (SP-6301) and Overflow Spring (SP-6302) (Dean 1985).

The results of the two MDNR dye trace studies indicate a probable subsurface connection between the unnamed tributary of Schote Creek that drains the Ash Pond and raffinate pit areas and the Burgermeister Spring area. The straight line subsurface flow distance is about 1,980 m (6,494 ft). The time of travel is estimated to be 48 to 72 hours but is dependent on rainfall conditions (Dean 1984a).

On February 14, 1986, the USGS conducted a dye trace study (Trace 4) to determine where the water emerged from a losing stream reach in the unnamed tributary east of Kraut Run and west of Schote Creek in the Busch Wildlife Area. This stream does not drain the chemical plant property, but the information will be used to define whether there are any subsurface connections with other drainage basins. The time of travel is estimated to be 48 to 72 hours, indicating flow velocities of 0.76 to 1.1 cm/sec (1.5 to 2.2 ft/min), depending on rainfall conditions (Dean 1984a). The water that was lost appeared to be confined to its own drainage basin and did not have any subsurface connection with the Burgermeister Spring area (Kleeschulte and Emmett 1987).

In March 1987, a small swallow hole (SH-6201) opened near the headwaters of Lake 35 (Figure 4.4-4). The MDNR conducted a dye trace test (Trace 5) and determined that some of the lost water resurfaced in Lake 34 and at a spring (SP-6306) northeast of Lake 34 near Twin Island Lake (MKF and JEG 1988t).

Trace Studies on Southeast Drainage Basin

On June 28, 1984, the MDNR conducted a dye trace test (Trace 2) by placing the dye south of the outfall sewer discharge point from the chemical plant. All of the flow at this point was lost to the subsurface. The dye was detected in charcoal packets recovered on July 2 and 3, 1984, from two springs (SP-5301 and SP-5303) in the southeast drainage area. The dye was also detected in subsequent charcoal packet collections on July 9 and 10, August 1, and September 10, 1984. No dye was detected in charcoal packets placed in locations north of the site.

On October 28, 1987, the MDNR conducted a water trace study in the southeast drainage area by opening a fire hydrant at the upper end of the valley and allowing water to flow at a consistent rate of 0.01 m^3/sec (0.22 ft^3/sec) for eight days down the drainage way. The flow characteristics of the water were directly observed to determine gaining or losing stream conditions. Four losing stream segments were identified (Figure 4.4-11). A swallow hole was observed just south of the Army Reserve Training Area, where all flow disappeared. Water was then seen to alternately seep into and resurge from the streambed at four different points (SP-5301 through SP-5304) along the drainage. Each losing stream segment in the valley appears to be part of the recharge area for the next spring located further downstream. The 0.4 km (0.25 mi) reach downstream from SP-5304 appeared to be a gaining stream (Hoffman 1987).

The results of dye trace and water trace studies on the southeast drainage area indicated that a groundwater divide exists north of the area, and the water lost to the streambed stays within the drainage boundary (Hoffman 1987). The lower four springs (SP-5301 through SP-5304) in the southeast drainage area each receive some of their flow from the losing stream condition. However, SP-5303 may receive additional water from another uncertain source (Hoffman 1987). This assumption is supported by the fact that samples from SP-5303 consistently contain high levels of nitroaromatic contamination, which subsequently flows to SP-5304 (MKF and JEG 1988r).

4.5 Vadose Zone Hydrology

The geological profile extending from the ground surface to the phreatic surface is called the vadose zone. The term vadose zone is preferable to the term unsaturated zone because saturated conditions may be locally present in the form of perched groundwater and unsaturated flow due to infiltration, seepage, or percolation. Pore spaces in the vadose zone may contain water, air, or other gases. Water movement through the vadose zone is a function of gravity and tension forces. Both of these forces act in the vertical direction to cause percolation downward. Tension forces also act to divert water in other directions from larger pores to much smaller capillary pore spaces. Water movement is affected by a reduction in the extent or dimensions of the flow channels and the presence of impermeable layers. Because of local and seasonal variations in groundwater recharge and discharge, the vadose zone thickness at the site varies locally, seasonally, and from year to year. The vadose zone generally varies in thickness from less than 10.6 m (35 ft) to more than 19.7 m (65 ft) at different locations within the site (MKF and JEG 1988t). As shown on Figure 4.5-1, the vadose zone is thinnest in the northeast portion of the site near Frog Pond, the northwest portion of the site near Ash Pond and near the raffinate pits. The seasonal variation of groundwater levels is discussed in Section 4.6. The vadose zone below the site generally extends through the overburden and into the bedrock, although localized zones of saturated overburden do occur.

4.5.1 Overburden

Water infiltrates from the ground surface through the overburden materials at the site. Infiltration depends on precipitation intensity and type, the condition of the soil surface, the density and type of vegetation or ground cover, and the physical properties of the soil. The uppermost portion of the vadose zone extends from the ground surface through the major root zone. Water movement in the root zone is influenced by evapotranspiration (transpiration of water through uptake by plant roots and a smaller amount lost through evaporation) and by unsaturated flow.

Direct infiltration is possible in vegetated areas, such as those near Frog Pond, the western portion of the site near Ash Pond and the raffinate pits, and most of the area surrounding the site. The eastern portion of the site, however, is generally paved and covered with buildings which prevent direct infiltration. Recharge in this area is limited to discrete zones such as drainage ditches, deteriorated underground sewer lines, and any exposed areas. On-site storm sewer lines, which may act as underground infiltration galleries, are shown on Figure 4.5-2. Standing bodies of water, such as Ash Pond, Frog Pond, and the raffinate pits also act as recharge sources. The hydraulic conductivities of the underlying materials and the depth of ponded water affect the amount of recharge to the subsurface..

The thickness of the overburden at the site ranges from 4.6 to 18.3 m (15 to 60 ft) (see Figure 4.3-9). The overburden is comprised of fill/topsoil, loess, Ferrelview Formation, clay till, basal till, and residuum. The physical characteristics of these overburden units are discussed in Section 4.3. The overburden is generally unsaturated, although saturated conditions do occur locally, especially near the raffinate pits. In some areas, the upper few feet of overburden (mostly topsoil) are poorly drained, although the materials underlying the topsoil are unsaturated. This poor drainage indicates the presence of low hydraulic conductivity layers within the overburden (BNI 1984c). Root channels, desiccation cracks, or fractures in the overburden may help transmit water through the overburden material.

Hydraulic conductivities and moisture contents determined from laboratory testing for the various overburden units are summarized in Section 4.3 and Table 4.3-3. The saturated hydraulic conductivity values are generally very low. In March 1987, slug tests were performed at three overburden monitoring wells (MW-3011, MW-3004, and OW-3503). The results of these test indicate an average saturated hydraulic conductivity of 1.2×10^{-10} m/sec (3.9×10^{-10} ft/sec) for the clay till formation (MKF and JEG 1987u), which agrees well with the laboratory test results provided in Table 4.3-3. Hydraulic conductivity for unsaturated conditions, however, depends on soil moisture content (which depends on soil characteristics such as clay content, effective porosity, etc.), pressure head, hydraulic head, and infiltration rate. Since hydraulic conductivity generally increases with moisture content, flow through the unsaturated zone will be slower than implied by the saturated hydraulic conductivities.

From 1983 through 1985, BNI conducted a water balance study for the raffinate pits. Results from the annual seven-month study periods show a minimal loss of water from the pits which is not attributable to meteorological conditions. The water balance was based on a comparison of rainfall and evaporation measurement with the measured pond level changes. Evapotranspiration was not used in the analysis since it could not be measured with the same precision as the other factors. Each year the loss was measured as a 1 to 2 mm/day (0.04 to 0.08 in/day) decrease in the water level in the pits. The magnitude of the measured losses from the pits corresponds to a soil permeability of approximately 1.0×10^{-8} m/sec (3.28×10^{-8} ft/sec) which is an order of magnitude greater than the median laboratory value for saturated hydraulic conductivities at the site. Laboratory values for saturated overburden hydraulic conductivity range from 1.6×10^{-11} to 2.0×10^{-7} m/sec (5.2×10^{-11} ft/sec to 6.6×10^{-7} ft/sec) (BNI 1986a).

Ten lysimeters are currently in place at three locations around the perimeter of the raffinate pits (Figure 4.5-3). Lysimeters, sometimes called soil-moisture samplers, are commonly used to sample soil-pore liquids in unsaturated media. These lysimeters were installed by UNC Geotech in July 1987 as part of a preliminary assessment of contaminant transport by unsaturated flow in the vicinity of the raffinate pits. The lysimeters were installed in locations where seepage from the raffinate pits was expected to be encountered in the form of unsaturated flow in the vadose zone. Physical data for the lysimeters are provided in Table 4.5-1. During installation of lysimeters 3604, 3605, and 3606, moisture was noted in the bottom few inches of each silt layer just above each clay layer. This indicates that the clay layers impede infiltration as expected. Lysimeters 3601, 3602, and 3603 are located near the base of the raffinate pit 4 berm, where water seeps and collects in a depression near the berm and a road. A mature stand of cattail grows in the depression, and there is standing water throughout the year. Lysimeters 3608, 3609, and 3610 are located in an unsaturated area near a perched water table (UNC Geotech 1988; Cahn 1987).

Previous exploratory drilling investigations at the site indicated areas of anomalously high groundwater elevations or perched groundwater in the vicinity of the raffinate pits (BGA 1984; BNI 1984c; and UNC Geotech 1988). Sixteen observation wells and ten vibrating-wire piezometers have been installed in the overburden as shown in Figure 4.5-4. Completion data for these installations are provided in Table 4.5-2. Three overburden monitoring wells (MW-3012, MW-3014, and W-6) are no longer operational. Of the 26 installations, only two piezometers (B-5 and B-22) and seven wells (MW-3018, -3011, -3013, -4006, -3005, -3004, and OW-3501) have indicated saturated overburden conditions near the raffinate pits. All other installations have been dry. Water levels measured in the overburden monitoring wells are summarized in Table 4.5-3.

North of raffinate pits 3 and 4, MW-3011 originally penetrated saturated soils during BNI's investigation but soon went dry. According to BNI (1984c), water levels in piezometer B-22 appear to drop during the winter and rise during the summer. The overburden in this area consists of fill material placed there after construction of raffinate pit 3. During drilling, BNI encountered pipes, wood posts, cables, and drums and noted decomposing organic materials (BNI 1984c). In addition, vegetation near the dike in this area is darker green than in the other areas, which may be indicative of nitrate migration from the pits (Cahn 1987).

Water has been detected in overburden monitoring wells west of raffinate pit 4. Well MW-3013 penetrates the western dike of raffinate pit 4 (see Figure 4.5-5). Anomalously high water levels—approximately 195 m (640 ft) NVGD—in MW-3013 indicate possible seepage through the earthen dike. Water levels in MW-3018 are consistently higher than the groundwater surface defined by the shallow bedrock wells (see Figures 4.5-5 and 4.5-6). Water levels detected in this well most likely represent localized mounding of the groundwater, possibly due to recharge from the raffinate pits rather than a perched water layer. Based on the maximum water level measured at MW-3018 and the minimum bottom elevation of pit 4 (see Table 4.4-1), it is calculated that approximately 5 m (17 ft) of unsaturated overburden exists below raffinate pit 4. Well MW-4006 was installed in saturated residuum at a relatively remote location from the raffinate pits. A more detailed discussion of groundwater occurrence in the residuum is provided in Section 4.6.

Several installations east of raffinate pit 3 and northwest of raffinate pit 1 indicate saturated overburden conditions. High water levels measured in this area may be indicative of localized mounding, perched water, discharge from nearby drains, or leakage from the raffinate pits. Well OW-3503, installed on the east berm of raffinate pit 3, was dry during BNI's investigation but has contained water continuously during WSSRAP sample collections. The water level elevation in this well is approximately 194 m (635 ft) NVGD which is significantly higher than the groundwater measured in the shallow bedrock wells (see Figure 4.5-6). Relatively high water levels have also been measured at MW-3004 (see Table 4.5-3). The water level at MW-3004 ranges from 194 to 195 m (636 to 640 ft) NVGD while the bottom elevation of raffinate pit 3 ranges from 194 to 197 m (638 to 647 ft) NVGD. This indicates that the unsaturated zone beneath raffinate pit 3 is relatively shallow or nonexistent. Pore pressures measured in piezometer B-5 by BNI also indicate saturated conditions (BNI 1984c). Observations during installation of OW-3501, located immediately to the north of raffinate pit 1, indicate a shallow saturated zone approximately 0.3 m (1 ft) below the surface (MKF and JEG 1988t).

In 1984, BNI conducted a geophysical survey in an effort to determine whether or not velocity data may be indicative of water saturation beneath the pits (BNI 1984c). These data are inconclusive. A comparison of the velocity data (shown in Figure 4.5-4 with the potentiometric data presented in Table 4.5-3, indicate that no clear relationship exists between the investigative techniques.

Water was encountered in boreholes (GT-37 through GT-41 shown on Figure 4.3-2) drilled in June 1988 in the vicinity of the recently erected administration building. After drilling was completed, water began to seep into the boreholes. It is believed the water originated from a leaking or broken water line near the site and was stored near the surface, possibly in pipe backfill (Tom 1988).

Additional plans for physical characterization of the vadose zone specify large-diameter (~12 in.) laboratory permeability testing of overburden materials to determine if fractures present in the Ferrelview Formation and clay till unit influence the present understanding of hydraulic properties as assessed using conventional small-diameter laboratory permeability testing methods.

4.5.2 Overburden/Bedrock Interface

Unsaturated flow will be affected by the abrupt change in hydraulic properties at the overburden/bedrock interface. For example, an abrupt change in hydraulic conductivity or type of flow will influence the direction and rate of flow. Flow in the overburden material is through the pores of the material. In the weathered bedrock, flow is through voids created by joints and fractures. Some of the voids may have been enlarged by solution processes. Many of the voids and fractures are filled with overburden material or weathering products from the bedrock. As water passes through the overburden and into the bedrock, flow may be diverted laterally and converge toward the bedrock voids.

Hydraulic conductivities near the overburden/bedrock interface are generally higher than those of the overlying overburden materials. Mean hydraulic conductivity at the overburden/bedrock interface (base of the residuum unit) was estimated by BNI to be 3.7×10^{-4} m/sec (1.2×10^{-3} ft/sec), with a standard deviation of 4.3×10^{-4} m/sec (1.4×10^{-3} ft/sec). Values ranged from 1.5×10^{-6} m/sec (4.9×10^{-6} ft/sec) to 9.2×10^{-4} m/sec (3.0×10^{-3} ft/sec). Constant head (packer) tests were performed on three boreholes (G-8, G-9, and G-19), and a falling head test was performed on one hole (G-16) (see Figure 4.3-2 for locations). Test intervals ranged from 0.5 to 1.5 m (1.6 to 5 ft) (BNI 1987).

The relatively high hydraulic conductivities measured near the overburden/bedrock interface indicate that this zone may provide a potential pathway for the lateral migration of contaminants. As water enters this zone, some water may be diverted laterally rather than continue downward toward the water table. Water will continue to travel laterally until a conduit or more permeable zone is encountered for the water to continue its downward flow. Saturated conditions (i.e., high water table) which may occur in this zone are discussed in Section 4.6.

4.5.3 Bedrock

Unsaturated flow generally occurs within the upper 6 m (20 ft) of weathered bedrock at the site (MKF and JEG 1988t). Flow in the weathered bedrock is expected to be characterized as macropore flow. Characteristics of the bedrock medium that will influence unsaturated flow are the distribution and lateral and vertical continuity of fractures, the interconnection of fractures, and the presence of solution features along fracture planes.

Data from packer tests in the unsaturated weathered bedrock zone performed by BNI (1987) indicate variations in saturated hydraulic conductivity of up to three orders of magnitude, ranging from 6.8 x 10^{-8} m/sec (2.2 x 10^{-7} ft/sec) to 8.5 x 10^{-5} m/sec (2.8 x 10^{-4} ft/sec). Variations in hydraulic conductivity may be due to the heterogeneous nature of the unsaturated portion of the weathered bedrock with respect to effective porosity. Effective porosity is affected by porespace size, the degree of porespace interconnection, and porespace infilling by detrital material and secondary mineralization. Porespaces may be represented by intergranular voids in porous media, solution enlarged fractures, and bedding planes. The results indicate the bedrock is of variable hydraulic conductivity in the horizontal plane and generally becomes less permeable with depth, as a result of decreased weathering and associated solution activity (BNI 1987).

4.6 Hydrogeology

4.6.1 Aquifer Systems

Three principal aquifer systems have been identified in the Weldon Spring area. These are the alluvial aquifers, the shallow bedrock aquifer system, and the deep bedrock aquifer system (Kleeschulte and Emmett 1987).

The alluvial aquifers include the saturated sands, gravels, and silts in the alluvium of the Missouri and Mississippi Rivers and the alluvium of tributary creeks which can have significant groundwater yields (MKF and JEG 1988t). Yields to wells from these aquifers vary from a few to 10 m^3/min (348 ft^3/min) along the rivers (BNI 1987). As defined, no alluvial aquifers are present at the site.

The shallow bedrock system primarily consists of saturated rock of Mississippian and Devonian Age ranging regionally from 76 to 197 m (250 to 650 ft) in thickness, depending on erosional removal of upper units, and includes formations at the site from the Burlington-Keokuk Limestone down through the lower part of the Sulphur Spring Group. At the Weldon Spring site, the lowermost member in the shallow bedrock system is the Bushberg Sandstone (Figure 4.3-1). Reported yields to wells in this aquifer range from less that 0.02 to 0.06 m^3/min (0.13 ft^3/min to 6.68 ft^3/min) (BNI 1987), but typically are from 0.004 to 0.19 m^3/min (0.67 to 2.0 ft^3/min). The larger-yield wells are those that intercept extensive secondary openings, such as joints and solution openings. Some of the formations comprising the shallow aquifer are more permeable that others, although all seem to be hydraulically connected (Kleeschulte and Emmett 1987).

A leaky confining layer lies below the shallow bedrock aquifer from the top of the Maquoketa Shale down through the Joachim Dolomite. Individual units or zones in this layer may be classified as low yielding aquifers. The confining sequence is generally about 122 m (400 ft) thick (Kleeschulte and Emmett 1986).

The deep bedrock aquifer system primarily consists of Ordovician and Upper Cambrian saturated rocks, which include formations from the St. Peter Sandstone down through the Potosi Dolomite (Kleeschulte and Emmett 1987). The deep bedrock aquifer system is approximately 305 m (1,000 ft) thick. Well yields in this aquifer range from 0.04 to 1.9 m^3/min (1.4 to 67 ft^3/min) (BNI 1987). Lithologic descriptions of the units within the bedrock aquifers are presented on Figure 4.3-1.

Potentiometric surfaces of the shallow and deep bedrock aquifers are depicted on Figures 4.6-1 and 4.6-2. A detailed potentiometric surface of the shallow bedrock aquifer in the vicinity of the site is shown on Figure 4.6-3. Within the shallow bedrock aquifer under the site is a regional groundwater divide which corresponds roughly to the regional surface divide between the Mississippi and Missouri River drainages. To the north of the divide, groundwater moves to the northeast toward Dardenne Creek. South of the divide, groundwater moves to the southeast toward the Missouri River. The groundwater divide in the deep bedrock aquifer is roughly parallel to the shallow bedrock aquifer divide at depth (Figure 4.6-2).

The shallow bedrock aquifer at the site is subdivided into upper and lower zones. The upper zone is the weathered and fractured portion of the Burlington-Keokuk Limestone which is characterized by a higher hydraulic conductivity than the thicker lower zone (MKF and JEG 1988t). Locally, the limestone may be fractured, have numerous clay-filled voids, and contain carbonate solution features. These features may include solution channels that allow conduit-type flow. Where solution channels are present, groundwater may travel hundreds of meters per day through these preferred paths (Kleeschulte and Emmett 1987). The upper zone with in the Burlington-Keokuk Limestone is of main emphasis and concern at the site because it is the zone most likely to permit contaminant migration (MKF and JEG 1988t).

4.6.2 Hydraulic Properties of the Upper Burlington-Keokuk Limestone at the Weldon Spring Site

Groundwater conditions at the site are monitored by the monitoring well network developed by the PMC, as discussed in Section 3.4.1. Table 4.6-1 contains monitoring well construction information relevant to understanding the hydrogeological characterization results.

4.6.2.1 Hydraulic Conductivity. Hydraulic conductivity is a coefficient that expresses the capacity of a porous medium to transport water. It is expressed as the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Hydraulic conductivity in the bedrock at the site has been estimated by packer tests, in-situ tests, and pump tests. Packer tests measure hydraulic conductivity in the vicinity of a discrete length of borehole under pressure. In situ tests determine hydraulic conductivity in the immediate vicinity of a well by noting aquifer response to the addition or withdrawal of a known volume of water. Pumping tests measure hydraulic conductivity in the portion of the aquifer between the pumping well and one or more observation wells. Test results indicate that, while the conceptual model of saturated flow conditions in the Burlington-Keokuk Limestone can be described in terms of Darcian diffuse flow in fine fractures overlain by free-flow zones and conduits, pumping and tracer tests did not intercept free flow zones or conduits capable of supplying sustained pumpage in excess of 1.5 l/min (0.4 gpm). However, slug testing indicates the existence of high porosity zones in the upper saturated portion of the formation. The hydraulic conductivity in the bedrock at the site is highly variable and is lower for the competent portion of the limestone than for the weathered portion of the limestone.

Hydraulic conductivity values have also been determined from the packer tests at wells and boreholes completed in the shallow bedrock aquifer (BNI 1987). Results of the packer tests are summarized on Table 4.6-2. The borehole locations are shown on Figure 4.3-2. Visual logging and RQD results (Section 4.3.1.2) indicate the presence of an upper weathered limestone unit grading down to an unweathered, less fractured competent limestone unit beneath the site. In general, a lower hydraulic conductivity is expected in bedrock that is less weathered and fractured. To examine the possible trend toward lower hydraulic conductivity with depth, the packer test results have been divided into three data groups based on the depth of the tested intervals from the top of bedrock (TOB).

The mean hydraulic conductivity for the group 0 to 5 m (0 to 16.5 ft) below TOB is calculated to be 3.0 x 10^{-3} cm/sec (9.8 x 10^{-5} ft/sec). For the group 2.8 to 7.7 m (9 to 25.1 ft) below TOB, the mean hydraulic conductivity is 6.5 x 10^{-4} cm/sec (2.08 x 10^{-5} ft/sec). For the group 5.5 to 12.2 m (18 to 40 ft) below TOB, mean hydraulic conductivity is 5.9 x 10^{-5} cm/sec (2.31 x 10^{-6} ft/sec). All tests were performed in the weathered limestone stratigraphic unit except for the third group in which several boreholes were tested in the competent limestone unit. Although there is some overlap in the data groups, the mean hydraulic conductivity value decreases by about one order of magnitude for each data group with depth.

A graphical representation of the BNI packer test results illustrates the variability in hydraulic conductivity (Figure 4.6-4). While the statistical mean values of the data showed a trend with depth, the graph shows significant variability in each depth interval. From 0 to 3 m (0 to 10 ft) below top of weathered bedrock, the values are clustered at 10^{-3} and 10^{-7} cm/sec (3.28 x 10^{-5} and 3.28 x 10^{-9} ft/sec). The 3 to 6 m (10 to 20 ft) interval shows the most variation in hydraulic conductivity, while the 6 to 12 m (20 to 40 ft) interval shows a clustering in the 10^{-6} to 10^{-7} cm/sec (3.28 x 10^{-8} and 3.28 x 10^{-9} ft/sec) range.

While the packer test results show general trends, the testing methods limit the interpretation of the results. Test intervals varied from 1.8 to 6.1 m (6 to 20 ft), and no single test covered the entire depth from TOB for any data group. Packer tests are designed to measure hydraulic conductivity only in a portion of a borehole. This can lead to inaccuracies in results, particularly in a fracture flow situation where the actual conductivity in the bedrock is limited to a few discrete zones.

Data from the recent in situ hydraulic conductivity testing (slug testing) program at the site were evaluated using the methods of Hvorslev (1951) and Bouwer and Rice (1976). The data in general represent the average values for both slug (water added to well) and bail (water removed from well) tests. The mean hydraulic conductivity value using the Hvorslev method of analysis was 8.5×10^{-7} m/sec (2.8×10^{-6} ft/sec). Using the Bouwer and Rice method, the mean hydraulic conductivity value was 1.1×10^{-6} m/sec (3.6×10^{-6} ft/sec).

The Bouwer and Rice method is believed to be more reliable for calculating in situ hydraulic conductivities than the Hvorslev method due to the difference in methodologies used to determine the effective radius of influence for a test occurrence (i.e., the radius over which head loss or gain is dissipated). Bouwer and Rice (1976) pointed out that the Hvorslev method, in most cases, assumes that the effective radius of influence is equal to the distance from the bottom of the well to the potentiometric surface. However, in reality, the effective radius of influence is considerably less than the distance from the bottom of the well to the potentiometric surface.

Bouwer and Rice used an electrical resistance network analog to determine the effective radius of influence for different slug test geometries. An empirical equation was then developed to relate the effective radius of the influence to the geometry of the well and the aquifer. This technique is applicable for determining the effective radius of influence for partially penetrating and fully penetrating wells in unconfined aquifers. It can also be used to estimate the hydraulic conductivity of confined aquifers that receive water from the upper confining layer through recharge or compression. With this in mind, the Bouwer and Rice method was used to analyze all data because it is considered to simulate more closely Weldon Spring site conditions. The Hvorslev technique was used because its widespread use in industry allows comparison of site data with other data analyzed by that method.

Tables 4.6-3 and 4.6-4 present the results of in situ tests as analyzed by the Bouwer and Rice method. Well locations are shown on Figure 3.4-2. The shallow well tests were performed at depths from 0 to 12.2 m (0 to 40 ft) below TOB. Intervals tested varied in length from 3.7 to 11.6 m (12 to 38 ft). Most of the shallow well in situ tests were conducted in the weathered limestone stratigraphic unit, or partially in the lower portion of the weathered limestone and partially in the competent limestone stratigraphic unit. The hydraulic conductivity values for the 30 shallow wells ranged from 9.1×10^{-6} cm/sec to 1.0×10^{-3} cm/sec (5.58×10^{-6} ft/sec to 3.28×10^{-3} ft/sec). Tests in deep wells were at depths ranging from 2.1 to 32 m (7 to

105 ft) below TOB with 9 of 10 tests at depths below 18.3 m (60 ft). All deep well tests were conducted within the competent limestone unit. Intervals tested varied in length from approximately 3 to 15 m (10 to 49 ft). The hydraulic conductivity values for the 10 deep wells ranged from 1.7 x 10^{-6} to 2.7 x 10^{-4} cm/sec (5.58 x 10^{-6} to 8.86 x 10^{-4} ft/sec).

Hydraulic conductivity values from in situ tests are compared for paired shallow and deep monitoring wells on Table 4.6-4. Shallow wells were screened in the upper 12.2 m (40 ft) of weathered bedrock as defined by BNI (1987), whereas deep wells were generally screened at a depth of 80 feet below the weathered bedrock surface and within the competent limestone unit. The mean hydraulic conductivity values for the deep and shallow wells were very close, 5.0 x 10^{-5} cm/sec and 5.2 x 10^{-5} cm/sec (1.64 x 10^{-4} ft/sec and 1.71 x 10^{-4} ft/sec), respectively. However, when individual pairs are examined, the deep well showed a lower hydraulic conductivity in six out of nine cases. The results of the in situ tests on shallow and deep paired wells does not support the concept of a trend toward decreased hydraulic conductivity with depth for the intervals tested. However, it may be of significance that most of the shallow well in situ tests were conducted with at least half of the test interval in the competent limestone unit (Table 4.6-3).

A few of the wells on site were tested by both packer and in situ methods. In Table 4.6-5, shallow well data for wells tested by in situ methods are compared to packer test values. In general, hydraulic conductivity values for the in situ tests are slightly higher than the results from the packer tests. A comparison of the two data sets is complicated by the difference in methodology and the lengths of the intervals tested. In general, the in situ tests involved much longer borehole intervals than the packer tests. In a system predominantly controlled by fracture flow in small discrete intervals along the borehole length, a packer test on a short borehole length could show values that are too high for the bedrock system as a whole. On the other hand, if there is a significant zone of deeper weathering and fracturing near the bedrock surface (as visual inspection of borehole cores seems to indicate), a test on too long a borehole interval could yield results that indicate hydraulic conductivities that are too low for the zone at the bedrock surface. This may be the case with many of the in situ tests.

Results of the packer tests performed in the two angled boreholes are presented on Table 4.6-6. The data indicate a higher hydraulic conductivity in the upper 6.1 m (20 ft) of weathered bedrock averaging 6.4 x 10^{-6} m/sec (2.1 x 10^{-5} ft/sec). Mean hydraulic conductivity for the interval from 6.3 to 14.4 m (20.6 to 47.3 ft) below TOB is less than 3.5 x 10^{-8} m/sec (1.2 x 10^{-7} ft/sec). The mean value for the interval from 14.2 to 30.7 m (46.7 to 100.7 ft) is less than 7.1 x 10^{-8} m/sec (2.3 ft/sec). The tests indicated an upper 6 m (20 ft) zone of higher hydraulic conductivity overlying a lower zone from 6.1 to 30.5 m (20 to 100 ft) that displays a lower mean hydraulic conductivity as well as high degree of variability in hydraulic conductivity.

Hydraulic conductivity can also be inferred from pumping test data. Pumping test locations and configurations are shown on Figure 3.4–3. Hydraulic conductivity values obtained from pumping test results are shown on Table 4.6-7. The average hydraulic conductivity for the upper 12.2 m (40 ft) of saturated bedrock at the site is about 3.0 x 10^{-7} m/sec (1.08 x 10^{-5} ft/sec).

The upper saturated portion of the Burlington-Keokuk may be subdivided based on variation in hydraulic conductivity. Field observations during monitor well drilling suggest that the upper, weathered and fractured Burlington-Keokuk Limestone may contain several relatively thin, more highly conductive layers possibly along bedding planes and horizontal fractures incorporated within a less-conductive matrix. Depending on the degree of interconnection of these more highly conductive layers and vertical fracture zones, it may be possible to conceptually model the upper Burlington-Keokuk at the site as a two-zone hydrogeologic system. The thin upper zone, more variable and generally higher in effective hydraulic conductivity, probably about 3 to 6 m (10 to 20 ft) thick, may be underlain by a relatively thick zone of substantially lower hydraulic conductivity. The boundary between the hydrogeologic zones is gradational and somewhat arbitrarily defined, with a significant amount of horizontal variability throughout the site. The boundary between the two zones does not necessarily correspond to the contact between weathered and competent limestone units. The two distinct hydrogeologic units do not necessarily occur in all areas underlying the site.

4.6.2.2 Transmissivity. The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient is called the aquifer transmissivity. Transmissivity values can be calculated from water-level drawdown or recovery data from a pumping well or from nearby observation wells. The most reliable estimates are based on drawdown data from observation wells. Transmissivity values have been determined from water-level drawdown data collected during pumping tests of the three pumping wells using the time-drawdown methods of Cooper and Jacob (1946) and Hantush and Thomas (1966). Pumping test locations are shown on Figure 3.4-3.

Results of the pumping test analyses are shown on Table 4.6-7. These results show average transmissivity values of about 2.8 x 10^{-6} m^2/sec (2.47 x 10^{-5} ft^2/sec) at PW-1, 5.5 x 10^{-6} m^2/sec (0.01 ft^2/sec) at PW-2, and 2.7 x 10^{-6} m^2/sec (2.37 x 10^{-5} ft^2/sec) at PW-3. The somewhat higher value at the PW-2 test location may be due to inhomogeneity in aquifer properties across the site or to the depth of groundwater occurrence below TOB. This may mean the PW-2 well location possesses more fractures, larger fractures apertures, and/or more interconnections between fractures than the locations of wells PW-1 and PW-3. In addition, static groundwater levels prior to testing were 7.6 m (24.8 ft), 2.7 m (9 ft), and 6.9 m (22.7 ft) below TOB for wells PW-1, PW-2, and PW-3, respectively. PW-2 may show higher transmissivity because the interval tested is nearer to the top of weathered bedrock.

4.6.2.3 Storativity. Storativity, also called storage coefficient, is a dimensionless aquifer property derived from the volume of water that can be released from a unit surface area of aquifer under a unit decline in head. For an unconfined aquifer, storativity is equivalent to specific yield. Storativity, like transmissivity, is an effective property of an aquifer which can be determined from pumping test data. Storativity values as determined by the analysis of the two pump tests are shown on Table 4.6-7. The average storativity value is on the order of 5 x 10^{-4}. This calculated storativity is very small for an unconfined aquifer. Generally, storativity values in an unconfined aquifer range from 10^{-1} to 10^{-2}. However, in an aquifer with low porosity and transmissivity like the Burlington-Keokuk, it is not incongruous for the unit to display aquifer properties characteristic of confined aquifers. The low value may also indicate some confinement of groundwater at the depth of the pumping and observation wells. It is likely that the influence of vertical fractures and solution features is not predominant at the depths of the tested aquifer intervals. Visual logging of angled boreholes indicated a 20:1 ratio of horizontal to vertical fractures in the Burlington-Keokuk. Partial confinement may be due to the presence of groundwater along horizontal fractures and bedding planes with limited vertical connection.

4.6.2.4 Porosity. Those portions of a rock or soil not occupied by solid mineral matter can be occupied by groundwater in saturated medium. The porosity of a rock or soil is a measure of the voids it contains, expressed as the ratio of the volume of voids to the total volume of material. The term "effective porosity" refers to the amount of interconnected pore space available for fluid flow and is expressed as a ratio of interconnected voids to total volume (Todd 1980). Porosity values are useful for the calculation of true fluid velocity for groundwater travel time computations. An aquifer may exhibit both primary porosity, resulting from the presence of intergranular voids within the rock matrix, and secondary porosity due to solution-enhanced fractures and joints within the rock.

Secondary porosity is predominant in the upper Burlington-Keokuk at the site because of extensive fractures within the bedrock. Primary porosity, vugs, and isolated, closed fractures of limited extent do not contribute significantly to the effective porosity of the limestone. In a general sense, effective porosity of the bedrock at the site is dependent on the nature, orientation, and frequency of fractures and partings along bedding planes. The nature of the fractures refers to fracture aperture and any mineral or soil filling (which act to reduce effective porosity) it may contain.

Effective porosity of the upper 12.2 m (40 ft) saturated thickness of the Burlington-Keokuk was evaluated by tracer tests at PW-2. Calculated effective porosity averages approximately 0.067 with bounding values at 0.008 and 0.1453 (Hopkins 1991).

4.6.2.5 Anisotropy and Heterogeneity. The shallow bedrock aquifer is believed to be both anisotropic and heterogeneous. Anisotropy refers to variation in one or more aquifer hydraulic properties in different directions. In a bedrock aquifer characterized by significant secondary porosity and permeability, and where preferred orientations of jointing, fracturing, and bedding planes are present (as appears to be the case for the shallow bedrock aquifer at the Weldon Spring site), groundwater can flow more readily parallel to the preferred fracture and bedding orientations than obliquely to those orientation (Fetter 1988). The limited vertical hydraulic connection and predominance of horizontal fractures over vertical fractures encountered in the angled boreholes implies that horizontal hydraulic conductivity is greater than vertical hydraulic conductivity at the site. The difference in groundwater levels between shallow and deep well potentiometric contours (comparing Figures 4.6-5 and 4.6-7 with 4.6-6 and 4.6-8) may be due to anisotropy in the shallow bedrock aquifer. In general, the potentiometric surface at depth is about 1.5 m (5 ft) lower than at the level of the shallow wells, suggesting a limited vertical connection.

Data from pumping tests performed on site were evaluated for lateral anisotropy using the method described by Hantush and Thomas (1966). Results of pumping test data analysis are described in detail in the *Aquifer Characteristics Data Report* (MKF and JEG 1992c). Figure 4.6-8 depicts the results of anisotropic analysis. Anisotropic analysis of transmissivity indicated orientations of maximum transmissivity at N72°W for PW-1, N10°W for PW-2, and N12°E for PW-3. The orientations of maximum transmissivity were compared to vertical fracture trends observed in bedrock exposures near the Weldon Spring site. The orientation of maximum transmissivity at PW-1 coincides with a major fracture set, whereas the orientations of maximum transmissivity at PW-2 and PW-3 are coincident with minor fracture sets. Since the maximum transmissivity observed during pumping was at PW-2 and did not coincide with a principal fracture trend, it can be inferred that groundwater flow is controlled by lateral anisotropy in the form of horizontally oriented fractures and that vertical fractures have little impact on the orientation of lateral anisotropy with respect to diffuse Darcian flow.

Observation well OB-2j was installed to observe potential vertical communication between the pumped horizon, the upper 12.2 m (40 ft) of saturated bedrock, and the screened interval monitored by OB-2j from 23 to 26 m (75 to 85 ft) below the phreatic surface. Observation well OB-2j did not respond to pumping, yet it lies along the principal axis of anisotropy, suggesting that hydraulic influences as stressed by pumping at PW-2 do not extend to the depth of the screened interval of OB-2j.

Lack of response in OB-2j is thought to be due to strong vertical anisotropy due to the layered nature of the unit and the sporadic nature of vertical fracture spacing.

If hydraulic conductivity is dependent on position within a geologic formation, the formation is heterogeneous or nonuniform. In general, carbonate units are heterogeneous if there is a change in bedding thickness or if the degree or nature of fracturing and dissolution varies (Fetter 1988). Inspection of borehole cores at the site indicates a general decrease in voids in the bedrock with depth, which creates a heterogeneous trend in the vertical plane. The reduction in void space probably correlates to the decrease in hydraulic conductivity with depth seen in the mean packer test results (Table 4.6-2). Heterogeneity in the horizontal plane is demonstrated by the range in hydraulic conductivity values for the upper 3.9 m (13 ft) of weathered bedrock. The range in values from packer tests is over 4 orders of magnitude, from

1.6×10^{-6} cm/sec to 4.5×10^{-3} cm/sec (5.25×10^{-9} ft/sec to 1.48×10^{-5} ft/sec) (Table 4.6-2). In the horizontal plane, the aquifer distribution of heterogeneity appears to be primarily a function of the bedrock surface topography in the upper portion of the unit.

4.6.3 Groundwater Flow Dynamics

Groundwater flow in the site vicinity is characterized by Darcian diffuse flow with superimposed conduit flow. The dynamics of groundwater flow through the shallow bedrock aquifer beneath the site can be described in terms of the hydraulic head distribution in the aquifer. That is, groundwater will flow from areas of higher head toward areas of lower head according to Darcian principles. Groundwater flow through a relatively homogeneous porous medium can be described by Darcy's law which states that the volume of flow through a section of porous medium is proportional to the gradient of the hydraulic head across the section. If fractured bedrock has a sufficiently high density of interconnected fractures, Darcy's law may apply at a scale much larger than that of the spacing between individual fractures. Off site, specific conduit flow pathways have been defined (MDNR 1989a).

4.6.3.1 Diffuse Flow and Groundwater Levels. At the Weldon Spring site, the shallow bedrock aquifer is unconfined to semiconfined. The water table may fluctuate in elevation, but generally remains within the upper bedrock. In a limited area on the northern part of the site, groundwater also occurs in the residuum. Groundwater flow dynamics within the upper Burlington-Keokuk can thus be described in terms of the potentiometric surface elevation.

On July 17, 1986, water-level measurements were made using the observation wells in the chemical plant area and wells in the Busch Wildlife Area. These measurement indicated a general northward direction of local groundwater flow in the site vicinity (Figure 4.6-3).

Site-specific investigations of groundwater movement have involved measurement of groundwater levels in the two zones of the uppermost aquifer as defined by the BNI investigation. Contours were developed from groundwater measurements taken in July and December 1988 (Table 4.6-8) to generate the potentiometric surface maps shown in Figures 4.6-5 through 4.6-8. Figures 4.6-5 and 4.6-7 show the potentiometric surface as determined from the shallow bedrock monitoring wells. Shallow wells generally extend less than 15 m (50 ft) into bedrock. Figures 4.6-6 and 4.6-8 show the potentiometric surface at about 18.2 to 24.2 m (60 to 80 ft) into bedrock. The minimal groundwater fluctuation shown between these two dates may not be representative because 1988 was a drought year.

Examination of the potentiometric surface maps indicates that a groundwater divide trends through the southern portion of the site beneath the surface water divide and passes beneath raffinate pits 1 and 2. Groundwater to the north of this divide flows to the north toward Dardenne Creek. Groundwater to the south of the divide flows to the south toward the Missouri River. The groundwater divide of the deep potentiometric surface is slightly north of that for the shallow potentiometric divide and passes beneath raffinate pit 3. However, the location of the deep groundwater divide is not precise because the deep well contour maps are quite subjective, particularly over the southern part of the site where there are only two data points.

Throughout the central and southern portions of the site, shallow groundwater levels appear to have generally increased by as much as 1.2 to 1.5 m (4 or 5 ft) between July and December 1988. Along the northern and western boundary of the site, water levels appear to have remained relatively stable. This may reflect relatively constant recharge from the raffinate pits during the drought or a variable influence of precipitation on the groundwater table below areas covered predominantly with concrete and buildings and those areas with vegetation cover. Water level monitoring data indicate possible mounding of the water table around the pits as well as perched water in overburden materials.

Groundwater gradients appear to be consistently steeper at the northern boundary of the site, regardless of season. Hydraulic gradients can be qualitatively evaluated by examining the spacing between equipotential lines on potentiometric surface maps. Closely spaced equipotential lines indicate a steeper hydraulic gradient, whereas widely spaced lines indicate a shallow hydraulic gradient. Variations in spacing of equipotential lines within an aquifer may indicate a change in aquifer transmissivity, with areas showing a steeper gradient possessing a lower transmissivity. This phenomenon may be responsible for the steeper hydraulic gradients in the area north of Ash Pond. Hydraulic conductivity values from packer tests along boreholes in this area are one to two orders of magnitude below the average for the upper 6 m (20 ft) of aquifer (Table 4.6-2). The shallow groundwater contours also show a north trending trough in the northern portion of the site. This area is underlain by linear bedrock lows (possible paleochannels) and saturated residuum in some cases. This feature is consistent with respect to season and may be a preferred flow path for shallow groundwater.

The groundwater levels on the deep well contour maps are generally about 1.5 m (5 ft) lower than for shallow wells in the north and central parts of the site, and 4.6 to 6 m (15 to 20 ft) in the southeast part of the site. This may simply be a function of reduced hydraulic conductivity with depth due to aquifer heterogeneity and vertical anisotropy due to the layered nature of the formation. Well MW-2024 shows the lowest water level on both maps. This well is also the deepest monitoring well (Table 4.6-1). An alternative possibility is that there is a discharge point which might locally drain the deeper groundwater system resulting in the observed lower water levels. One possible location of discharge is to springs and seeps along the steep slopes to the south and southeast of the site. The surface topography drops off steeply, which may allow discharge from deeper levels of the aquifer to the slopes (Figure 3.4-4). The slope change may also account for the increased head differential between shallow and deep wells to the southeast and for the displacement of the groundwater divide on the deep well maps away from the southeastern slopes (Figures 4.6-6 and 4.6-8). A third possibility is the existence of semiconfining conditions. Thin, shaley layers were observed between beds in the Burlington-Keokuk during drilling operations (BNI 1987). These layers may act as semiconfining layers.

The low storativity values obtained from the pumping tests also indicate confinement of groundwater.

Figure 4.6-9 is a location map for the hydrogeologic cross sections depicted on Figures 4.6-10 through 4.6-12. These cross sections also illustrate the generally higher water levels in the shallower bedrock wells, relative to those in the deeper wells, based on December 1988 data. Depth to groundwater from the top of the weathered bedrock surface varies greatly. For example, on Figure 4.6-10 the water table occurs from 0.6 m (2 ft) above the top of the weathered bedrock surface at well MW-2001, to 12.2 m (40 ft) below top of bedrock at well MW-4003. Hydraulic conductivity values from the PMC in situ tests are shown on the cross sections.

Groundwater level fluctuation through time can be illustrated by well hydrographs. Figures 4.6-13 through 4.6-16 are hydrographs for wells MW-2001, MW-2004, MW-2010, and MW-2012, respectively. The four hydrographs include data from mid-1986 through mid-1991. Water level monitoring took place at irregular intervals during this time period. The length of time between measurements varied from less than one week to about three months. Some preliminary observations can be made:

- In general, yearly fluctuations in each well show the highest water levels in the fall and the lowest levels in late winter and spring.

- Monitoring wells MW-2001 and MW-2004 are located on the western side of the site about 305 m (1,000 ft) apart. Water levels in both wells fluctuated less than 0.6 m (2 ft) during the 5-year monitoring period.

- Monitoring wells MW-2010 and MW-2012 are located on the eastern end of the site about 152 m (500 ft) apart. Well MW-2010 fluctuated 0.6 m (2 ft) in 5 years, while well MW-2012 fluctuated 2.7 m (9 ft) during the same time period. The two wells may be subjected to different amounts or rates of recharge or the different fluctuation rates may be related to differing degrees of connection to conductive fractures. For example, water levels in both MW-2010 and MW-2012 appear to have been influenced by record high precipitation in late 1986, although MW-2012 exhibited a higher fluctuation during this period. Additionally, while both wells show similar trends in water level history, fluctuations in MW-2012 during subsequent drought conditions and normal periods of precipitation are more than twice that observed in MW-2010.

To more closely examine water level fluctuations around the site, Figure 4.6-17 presents a summary of water table fluctuations in wells that were monitored from 1986 to 1988. In general, wells located along the eastern and southern portions of the site fluctuated in excess of 1.5 m (5 ft) during the monitoring period, while wells in the western and northern portions of the site fluctuated less than 1 m (3 ft) during the same period. Several factors may explain this apparent location-dependence of water level fluctuation:

- It is possible that the greater water level fluctuation in wells in the eastern portion of the site is related to the way recharge is received from the surface. The eastern half of the site is covered by pavement and buildings and, to a large extent, infiltration from the surface is confined to storm ditches and possibly leaking underground storm sewers. Wells in the vicinity of a leaking sewer pipe may receive recharge in more discrete slugs, while wells in the western half of the site receive recharge in the form of infiltration from precipitation.

- The results of packer testing generally indicate a decrease in hydraulic conductivity at the transition from unsaturated to saturated bedrock. Higher hydraulic conductivity in unsaturated bedrock corresponds to a more porous portion of the bedrock as a result of weathering. Consequently, water levels which do not fluctuate to a high degree may be influenced by a dramatically higher storage potential in the unsaturated bedrock just above the average phreatic surface. The *Aquifer Characteristics Data Report* (MKF and JEG 1992c) includes a more thorough discussion of water level fluctuation.

- Ash Pond and the raffinate pits may act as continuous sources of recharge. This would tend to attenuate the impact of discrete recharge events on water level fluctuation.

- Differences in properties of the vadose zone at the site (e.g., thicker in the north) may influence water table fluctuation.

The upper 3 m (10 ft) of weathered bedrock may be a significant region of horizontal groundwater flow and contaminant migration due to its higher hydraulic conductivity. Figure 4.6-18 shows the occurrence of groundwater in the residuum and upper 3 m (10 ft) of weathered bedrock. Groundwater is shown to occur in the upper bedrock in the vicinity of Ash Pond and at the raffinate pits.

These areas generally correspond to linear fractures in the bedrock surface which are interpreted to be paleochannels and which may serve as preferred pathways for groundwater flow and contaminant transport.

4.6.3.2 Conduit Flow Paths. Dye trace tests and seepage runs have been conducted by the MDNR and USGS to characterize conduit flow in the site vicinity. Dyes injected into boreholes on site were not detected at sampling points in quantities above background. Dye tests and seepage runs defined several significant subsurface pathways off site. Subsurface water flow was detected in the immediate vicinity of Burgermeister Spring using a spontaneous potential geophysical survey.

Dye trace tests in boreholes on site were conducted during drilling operations in 1983 and 1988 by the MDNR. It was recognized prior to testing that tracer tests by dye injection into wells had a low to moderate chance for successfully locating conduits. The principal injection zones and results of the tests are summarized on Table 4.6-9. The injection (or water loss) zone was either an area where circulation was lost during drilling, or a fracture zone or solution feature observed on video logs or rock cores. In three tests (wells MW-2020, MW-3007, MW-4016), the water loss zone occurred from 1.2 to 4.0 m (4 to 13 ft) above the static groundwater level. Dye injected above the groundwater table may have been less likely to reach groundwater conduits. In two other tests (MW-4014, MW-4023), the dyes used are considered experimental. In all the tests, no dye was recovered at any monitoring station that could be attributed to well injection (MDNR 1989a).

Results of dye trace tests and seepage runs conducted by the MDNR and the USGS indicate significant groundwater pathways off site. These tests are summarized in Section 4.4.4. Figure 1.3-1 depicts the known groundwater flow paths as determined by off-site tests.

No conduits were found to extend under the site. However, the injection point for trace 3 on Figure 4.4-10 was located 244 m (800 ft) from the Ash Pond outfall. The dye trace indicated that subsurface conduit flow extended from the point of injection to Burgermeister Spring. Before Ash Pond was constructed, the drainage trace in which this dye injection was performed extended over the area now covered by the pond. It is possible, based on the configuration of the erosional surface of the bedrock (i.e., paleochannels), that the conduit toward Burgermeister Spring may extend at depth under the site. The north trending "trough" feature present in the shallow potentiometric surface extends over linear bedrock lows (i.e., paleochannels) present in the Ash Pond area. This is further hydrologic evidence that a preferred flow pathway or conduit may exist beneath the northern portion of the site.

The spontaneous potential survey at Burgermeister Spring detected subsurface flow in an area within 213 m (700 ft) south of the spring. Results of the survey indicate groundwater flow along discrete paths near the spring (MDNR 1989a).

4.6.3.3 Groundwater Velocity Calculation. The average linear velocity of groundwater can be approximated by a modified form of Darcy's law (Freeze and Cherry 1979):

$$V = \frac{Ki}{n}$$

where

V = groundwater velocity (length/time)
K = hydraulic conductivity (length/time)
i = hydraulic gradient (dimensionless)
n = effective porosity (dimensionless)

Horizontal hydraulic gradients were determined for six potential flow paths, four in the shallower portion and two in the deeper portion of Burlington-Keokuk Limestone based on December 1988 potentiometric data.

Hydraulic conductivity values used to determine linear groundwater velocities and hydraulic gradients obtained along selected flow paths are presented in Table 4.6-10. An effective porosity range of 0.008 to 0.1453 for the weathered portion of the Burlington-Keokuk Limestone, as determined from tracer tests, was used for all velocity calculations.

Using hydraulic conductivities determined from the Bouwer and Rice method, average linear velocities ranged from a minimum of 0.022 m/day (0.07 ft/day) between OB-2f and MW-4021 to a maximum of 0.12 m/day (0.39 ft/day) between MW-2018 and MW-4022. Using hydraulic conductivities determined using the Hvorslev method, average linear velocities ranged from a minimum of 0.033 m/day (0.12 ft/day) between OB-2f and MW-4021 to a maximum of 0.44 m/day (1.4 ft/day) between MW-2018 and MW-4022.

A preliminary estimate of vertical groundwater flow can be calculated on a clustered pair of wells using a variation of the previous equation. In this case hydraulic gradient (i) is determined by the head differential between the two wells:

$$i = \frac{dh}{dl}$$

where dh = head differential between paired wells
dl = vertical length between screened intervals in wells

Using data from the paired wells MW-2015 and MW-2028, the hydraulic conductivity for the vertical length is 1.5×10^{-2} m/day (4.9×10^{-2} ft/day), dh is 2.5 m (8.2 ft) (for December

1988), and dl is 18.3 m (60 ft). The resulting downward interstitial velocity is 0.3 m/day (0.98 ft/day). However, the large value of dh suggests a lack of vertical connection. It is very likely that the vertical hydraulic conductivity is lower than horizontal hydraulic conductivity, making this velocity estimate too high. At the present time no determination of vertical hydraulic conductivity has been made at the site.

Both conduit flow through large aperture fractures and solution channels and Darcian diffuse flow through fine interconnected fractures are assumed to be present in the shallow bedrock in the vicinity of the site. Outcrop observations suggest that diffuse Darcian flow with superimposed localized conduit flow predominates in the upper weathered portion of the Burlington-Keokuk Limestone while fracture flow is dominant in the deeper competent portions of the unit.

Off-site conduit flow velocities have been characterized by trace tests. Dye trace studies showed that surface flow from the Ash Pond and raffinate pit drainages went underground to the west of the site and reemerged at Burgermeister Spring an estimated 48 to 72 hours later, depending of precipitation conditions (Dean 1984a). This indicated a conduit flow velocity of 0.4 to 0.7 m/min (1.5 to 2.2 ft/min). The direction of this flow is shown on Figure 4.4-4.

4.6.3.4 Aquifer Boundaries and Recharge/Discharge. The upper bedrock aquifer may exhibit hydraulic boundaries in areas where the unit crops out, is truncated by a major fault trace, or is hydraulically connected to a major surface water body. The boundary could be a barrier boundary across which no flow takes place or a constant-head recharge or discharge boundary. Examination of pumping test data indicated that observation wells at all three pumping locations exhibited evidence of significant temporary recharge in the late portions of the tests. The most plausible explanation for most of the recharge effects exhibited during pumping is drainage of local fracture zones of limited storage capacity. Additionally, local barrier boundary effects were observed which suggest poor lateral communication between wells such as would be expected with fracture porosity (MKF and JEG 1992c).

Boundaries tending to inhibit vertical transfer of water include the lower portion of the Burlington-Keokuk Limestone, and the 107-m- (350-ft-) thick leaky confining layer between the shallow and deep bedrock aquifer systems (Figure 4.3-1). Specific units that may minimize vertical movement of groundwater in the leaky confining layer are not defined (MKF and JEG 1988t).

Recharge to the shallow bedrock aquifer is diffuse throughout virtually the entire surface area of St. Charles County. Infiltration of precipitation in the area where the shallow bedrock formations are near the surface is the principal source of recharge to the aquifer. Water moves through permeable soil and rock in the vadose zone and enters the bedrock along fractures, bedding planes, and solution openings. Recharge also occurs from water entering the aquifer through losing streams. This type of recharge is restricted in area to losing stream segments

(Figure 4.4-9). An example of such recharge is the unnamed tributary of Schote Creek that drains the raffinate pit area and Ash Pond. Water flows into the headwaters of this tributary during and after precipitation events. Flow is lost by infiltration to solution-enlarged fractures within the groundwater system before it reaches the main stem of Schote Creek (Kleeschulte and Emmett 1987).

Discharge from the shallow bedrock aquifer system occurs primarily as springs, seeps, and discharge to alluvium. Groundwater discharges from the aquifer can be observed locally in or near gullies as seeps and springs (Dean 1984a; 1984b; 1985). Intermittent and perennial springs and seeps in the site vicinity are depicted on Figure 4.4-4. Dardenne Creek and the associated alluvium may be a constant discharge boundary for most of the near surface flow in the shallow bedrock aquifer to the north of the groundwater divide. Southward flow in the upper zone of the shallow bedrock aquifer is discharged along the alluvium of the Missouri River floodplain creating a constant discharge boundary. Discharge to the alluvium of the Dardenne Creek drainage and the alluvium of the Missouri River floodplain through springs and seeps and underground discharge are likely the major controls on the location of the regional groundwater divide in the shallow bedrock aquifer in the site vicinity.

As discussed in Section 4.4.4, dye trace tests and seepage run results have demonstrated that surface water and groundwater form a complex recharge/discharge system in the site vicinity. Major surface water features displaying hydraulic connection to groundwater flow include Burgermeister Spring and other perennial springs in the site vicinity; Busch Wildlife Area Lakes 34, 35, and 36; and the southeast drainage area.

Local wells completed within the shallow bedrock aquifer may be points of discharge. Smaller-yield residential, stock-watering, and irrigation wells are completed in water-bearing zones encountered in the shallow bedrock. Figure 3.4-5 shows the locations of private water wells as determined by SCCAHW and the USGS. Many of these wells are completed in the shallow bedrock aquifer and represent potential points of discharge from the aquifer. Very few of these wells are believed to be currently in use, however, and it is not known if any of them are completed in the upper zone of the shallow bedrock.

Discharge as leakage from the upper zone of the Burlington-Keokuk to lower zones within the shallow bedrock aquifer with potentially exploitable groundwater resources is believed to be insignificant. A regional three-dimensional groundwater flow model was developed by the USGS (Kleeschulte and Imes 1991) to qualitatively assess the groundwater recharge in the shallow aquifer that infiltrates and recharges the deep aquifer. The results of the steady-state model simulation indicate that 10% of the recharge originating in the shallow aquifer in the vicinity of the chemical plant site would reach the deep aquifer. The travel time for water originating at the chemical plant to reach the public water supply wells in the O'Fallon and Wentzville area was determined to be about 2,800 years, using model parameters and assuming strictly porous media flow (Kleeschulte and Imes 1991).

The data from groundwater studies have been incorporated in a conceptual groundwater flow model that is described in Appendix C.

4.7 Human Population and Current Land Use

4.7.1 Historical/Current Population

The Weldon Spring site is located in the western part of the St. Louis metropolitan area in St. Charles County, Missouri. The county population in 1990 was 211,168 persons, about 20% of whom lived in the city of St. Charles. Numerous other municipalities are located within a 48-km (30-mi) radius of the site and range in size from small towns to the city of St. Louis. The nearest communities, Weldon Spring and Weldon Spring Heights, are located about 3.2 km (2 mi) northeast of the site and have populations of 755 and 97, respectively (Figure 1.2) (Missouri State Census Data Center).

The population trends for the city of St. Louis and the counties that comprise the St. Louis standard metropolitan statistical area (SMSA) are presented in Table 4.7-1. The city of St. Louis has been losing population since 1960, whereas several of the surrounding counties have been gaining population. St. Charles County, with six decades of continuous population growth, has experienced the greatest percentage of increased population size in comparison to the other counties within the SMSA.

Population trends for communities in the region around the site are indicated in Table 4.7-2. The city of St. Charles has the largest population. St. Peters experienced the most growth from 1970 to 1990, with an increase in population from 486 to 40,259. O'Fallon and Lake St. Louis had the next largest populations in 1990 (Missouri State Census Data Center 1990).

4.7.2 Projected Population

The population in St. Charles County increased by about 46.5% from 1980 to 1990. According to the St. Charles County Planning Department, the projected population for the county by 2010 is 293,633. This translates to an expected population increase of 39.1% over the next 20 years.

4.7.3 Site-Specific Land Use

The raffinate pit and chemical plant areas comprise a managed environment where the vegetation is mowed and the roads are maintained. Man-made structures are present in both areas. Architecturally, the chemical plant reflects the World War II and postwar periods.

Public access is prohibited at the raffinate pits and chemical plant. However, these areas are visible through the perimeter fences. The raffinate pit area is situated away from major highways and is screened from highway travelers. Consequently, the number of individuals observing the area is small. The chemical plant area is readily visible from State Route 94.

4.7.4 Adjacent/Surrounding Land Use

Francis Howell High School is located about 0.8 km (0.5 mi) northeast of the site on State Route 94. The school employs approximately 160 faculty and staff, and about 1,600 students attend school (Hartwig 1992). The St. Charles County Extension Center was adjacent to the high school. The extension center closed in 1988; the building is currently used as the school administration annex.

Other institutional facilities in the area include a state highway maintenance facility, which employ nine full time staff and one mechanic (Sizemore 1991), located on State Route 94 just west of the school and immediately northeast of the chemical plant, and the Army Reserve and National Guard training area adjacent to the site on the southwest. Approximately 3,300 local Army reservists and 3,400 other military reserve troops may use the training area each year. An average of 150 to 400 Army reservists are present in the area on weekends during 35 to 48 weeks of the year for 2-day drill training (Daubel 1992). An active water treatment plant is located about 4.8 km (3 mi) southwest of the site, adjacent to State Route 94.

The Busch Wildlife Area is located north of the raffinate pit and chemical plant areas, and the Weldon Spring Wildlife Area is situated south of State Route 94. Both of these areas are park-like tracts administered by the MDOC and are dedicated to various kinds of recreational uses. Most of the visitors to the wildlife centers are from the St. Louis metropolitan area. Annual visitation to these two areas is estimated to be 1,200,000 people (Crigler 1992). The average duration of each visit to the Busch Wildlife Area is four hours. Use is heaviest in the spring and summer, ranging from 102,000 to 130,000 visitors per month.

The St. Charles County well field, located about 8 km (5 mi) south of the site, is a source of water for county residents. Public Water District #2, Missouri Cities Water Company, Francis Howell High School, the Army, and many of the outlying county residents rely on this well field for all or part of their water supply. These wells provide water to many of the communities, institutions, and facilities surrounding the Weldon Spring site. The larger communities of St. Charles, O'Fallon, and St. Peters rely on their own water sources.

4.7.5 Projected Land Use

Urban areas occupy 6% and nonurban areas 90% of the county land. The remaining area is dedicated to transportation and water uses. The St. Charles County Planning Department estimates that approximately 4% of the county's nonurban land will be converted to urban uses between 1980 and 2000. Development in the county has been dynamic in the past, and strong residential, commercial, and industrial demands are expected to continue. St. Charles, St. Peters, O'Fallon, Lake St. Louis, and Wentzville are located along Interstate 70 where major development has occurred. The area south of Interstate 70 from St. Charles to Wentzville and bounded by U.S. Highway 40/61 to the west and the Missouri-Kansas-Texas (MKT) Railroad to the south is locally referred to as the "Golden Triangle." This area is considered likely to experience the most growth in the coming decades. The Golden Triangle includes St. Charles, St. Peters, O'Fallon, Lake St. Louis, Wentzville, Weldon Spring, Cottleville, Harvester, Weldon Spring Heights, Dardenne, and All Saints Village.

In addition to development within the Golden Triangle, there is substantial development potential in other areas of the county. A development of 400 to 500 parcels of land has recently been approved along U.S. Highway 40/61. The University of Missouri is developing a 283-ha (700-ac) tract of land for a high-technology park. The land will remain under the ownership of the University of Missouri and will be developed as a research park to stimulate the development of high-technology industries in the St. Louis area (DOE 1987).

County-assessed values for private property are strongly controlled by current and projected land use. Land-use patterns are determined in part by ongoing socioeconomic trends. The area north of the Weldon Spring site and along U.S. Highway 40/61 appears to be experiencing a slowdown in property development and sales. However, over the last two years a number of commercial projects have been built, including a bank, service stations, supermarkets, and shopping centers. New homes and condominiums valued at $75,000 to over $100,000 are being constructed. South of the site, the area has remained farmland with very little change in land use. It is anticipated that land values will continue to increase.

5 NATURE AND EXTENT OF RADIOLOGICAL AND CHEMICAL CONTAMINATION

5.1 Contaminant Sources

Past operations and waste handling practices at the Weldon Spring site have resulted in several potential sources for contamination of surface water, groundwater, and soil. The major identified contaminant sources include the Weldon Spring chemical plant buildings and related facilities, the raffinate pits, Ash Pond, Frog Pond, the north dump area, and the southeast drainage area. These areas are delineated on Figure 3.1-1.

The buildings and facilities are a potential source for radioactive contaminants including uranium, radium, and thorium. The buildings and facilities also may contribute asbestos, polychlorinated biphenyls (PCBs), and various process chemicals to the surrounding environmental media. The raffinate pit waters and sludges contain uranium, thorium, radium, nitrate, and heavy metals. Surface water and sediment in Ash Pond and Frog Pond may be sources of uranium, thorium, radium, and nitrate. The north dump has soils contaminated by uranium. The southeast drainage area is a potential source of uranium, thorium, radium and nitrate. Previous operation of the Weldon Spring ordnance works resulted in soil contamination by nitroaromatic compounds. Soil around Ash Pond has been found to contain these compounds.

5.1.1 Weldon Spring Chemical Plant Buildings

The chemical plant presently consists of 13 major buildings, approximately 30 support structures, and other miscellaneous facilities and equipment, including sewage treatment facilities, a water tower, and railroad rail and ties (Table 4.1-1 and Figure 4.1-3). The buildings contain varying degrees of chemical and radiological contamination, depending largely on their function. The process buildings exhibit greater contamination than the non-process buildings.

5.1.1.1 Chemical Contamination. Nonradioactive chemicals, such as nitroaromatics, heavy metals, strong acid salts, and some other organic compounds, are present at the site as a result of trinitrotoluene (TNT) production and uranium processing activities. In addition, contaminants such as PCBs and asbestos are present because of previous uses of equipment and buildings at the site (ORNL 1988).

During TNT production at the ordnance works, wastewater was discharged to several lagoons on the production site and occasionally directly to surface drainages (MKF and JEG 1988t). Explosives production also resulted in chemical contamination of ordnance works structures, concrete foundations, soil, underground wastewater lines, and catch basins. Only a small portion of the ordnance works underlies the present chemical plant and raffinate pit area. Plate 1 shows this relationship. Most of the processing equipment, buildings, appurtenances, and contaminated soil were removed prior to Atomic Energy Commission (AEC) construction of the uranium processing facility at the site (RETA 1978). The Project Management Contractor (PMC) (MKF and JEG 1987o) has described several potential sources of nitroaromatics and other chemical contaminants, as shown on Figures 5.1-1 and 5.1-2. Additional sources of chemical contamination associated with uranium processing activities are briefly described in Table 5.1-1 and located on Figure 5.1-3. Descriptions of the manufacturing processes at both the ordnance works and uranium feed materials plant are found in Appendix D.

Numerous tanks were present on site, either within the process buildings or on concrete storage pads. A preliminary listing of these tanks is summarized on Table 5.1-2. The information presented in this table is based on survey work conducted in 1988. More definitive inventory and characterization work has since been carried out and is presented in the *WSSRAP Buildings Characterization-Chemical Characterization Report* (MKF and JEG 1991a). Some tanks were removed during the dismantlement of buildings 435, 436, 437, and 438. Remaining tanks will be removed as part of site remediation.

From March to May 1986, Bechtel National, Inc. (BNI) was contracted by the U.S. Department of Energy (DOE) to chemically and radiologically characterize the buildings within the chemical plant. The contract was terminated before BNI could complete the characterization. Brief chemical characterization surveys were conducted of buildings 201, 301, 403, and 404. The surveys were limited to pH and combustible gas measurements at very few locations.

Samples for measurements of pH were taken from the locations listed below. All samples were tested with litmus paper, and all showed a neutral pH.

- Water from sumps in rooms 103 and 107 of building 201
- A paste of white powder in room 107 of building 201
- A wipe of yellow powder in room 111 of building 201
- The inside flange on the top of an anhydrous hydrogen fluoride tank in building 201
- A pool of standing water in room 105 of building 201
- Water in a canal in the floor of building 301
- Water in six floor sumps in building 403.

Water samples from the sumps contained only low contaminant levels. However, the sludges in the bottoms of the sumps contained elevated concentrations of metals. A more comprehensive characterization of these sumps was conducted in 1991 as part of a building characterization study (MKF and JEG 1991a).

Combustible gases were measured using an Enmet CG-100 combustible-gas indicator. No combustible gases were detected in the buildings surveyed.

Polychlorinated Biphenyls

In March, 1987, samples were collected from existing oil-filled electrical transformers and other electrical components in the chemical plant area to determine if the units contained PCBs. The results confirmed that 20 of the 34 oil-filled transformers sampled, and several smaller capacitors and switches, contained PCB oil or PCB-contaminated oil. The locations of the PCB-containing electrical equipment are indicated in Figure 5.1-4. All releaseable transformers were removed from the site in 1988 (IRA 2, see Table 1.2-2) and 1991.

The PMC has conducted chemical characterization of the nonprocess buildings. The principal contaminants investigated include asbestos and PCBs. The results of PMC sampling to date for PCBs are summarized on Table 5.1-3. Sampling was conducted in 1987, 1988, and early 1989. Swipe samples of surfaces and bulk samples of residues and sediments were collected as described in Section 3.1.1.4. Twenty-eight buildings were sampled, with 252 swipe samples and 97 bulk samples collected. Of the 252 surface swipe samples, 93 had less than 1 μg PCB per 100 cm^2 (15.5 in^2) of surface area, while 37 exceeded the most restrictive potential cleanup criterion of 10 μg/100 cm^2. On the other hand, of the 97 bulk samples, only 14 were below the minimum detection levels of 2 or 5 μg/g, while 56 exceeded the most restrictive potential cleanup criterion of 10 μg/g. Three bulk samples, one each in buildings 408 (maintenance and storage), 432 (outfall sewer sampling station) and 439 (fire training building) exceeded 1,000 μg/g PCBs.

In addition to the swipe and bulk sampling, the PMC has initiated a PCBs volumetric sampling program of porous materials such as concrete and wood in some buildings. Results will be used during buildings dismantlement.

Asbestos Containing Material

Sampling for preliminary identification of interior asbestos-containing materials (ACM) was conducted in August 1986 and May 1987. The objective of the interior bulk sampling was to identify typical building materials which contain asbestos (such as equipment insulation) rather than to conduct a comprehensive survey of the site for ACM (MKF and JEG 1986). Bulk samples were collected from buildings 101 (feed sampling and preparation), 401 (steam plant), 407 (laboratory), 409 (cafeteria), and 410 (administration). Materials sampled were pipe insulation (101), steam valve insulation (401), corrugated siding (101, 401), floor tile (407, 410), duct insulation (409, 410) and acoustical ceiling tile (407, 409, 410). A single sample was taken of each material. The investigation found that ACM is present as pipe insulation, steam valve insulation, heating duct insulation, and corrugated siding. Asbestos concentrations in these materials ranged from 15% to 30% in pipe insulation to 50% to 75% in duct insulation.

A subsequent study of asbestos content of pipe insulation on outdoor overhead utilities (MKF and JEG, 1987s) determined that friable asbestos materials are present in all pipe insulation at the site, except for straight sections of ethylene glycol piping. Samples were collected from 10 locations within the chemical plant complex (see Figure 5.1-5). The sampling locations were selected so that insulation on all types of pipe (steam, raffinate, ethylene glycol, and process) and all sizes of each type of pipe could be sampled. In total, 42 samples were collected. Each sample was a complete cross-section of the pipe insulation, including sheathing. Results of sample analysis are shown in Table 5.1-4. Asbestos concentrations greater than 1% were found in all insulation samples from steam and raffinate pipes. Asbestos was also found on all elbows and all repair sections of all insulated pipes including ethylene glycol pipes. The level of asbestos in the samples ranged from trace amounts (0.1% or less) in two of the samples to 50% to 60%. Of 31 samples analyzed, two contained trace amounts, three contained 1% to 5%, and the other 26 contained more than 10%.

The results of sampling for ACM show that asbestos is present in varying levels and in many forms throughout the chemical plant. Extrapolating from the pipe insulation sampled, it can be concluded that all interior steam, raffinate, process and ethylene-glycol pipe insulation contains asbestos, and additional sampling of these lines is unnecessary; all insulation on these lines is considered ACM.

Additional asbestos sampling was conducted in non-process buildings in 1987, 1988 and 1989 as described in Section 3.1.1.4. Based on the working assumption that all pipe insulation at the plant contains ACM, there was no additional sampling of pipe insulation. The asbestos measurements conducted to date (with the exception of the pipe insulation data in Table 5.1-4) are summarized in Table 5.1-5. A total of 199 samples has been collected from 19 buildings and 151 samples had asbestos contents of less than 1%. In seven of the buildings sampled, all samples had non-detectable levels of asbestos (MKF and JEG 1989d).

In November 1987, asbestos samples were collected to determine the natural background concentrations of uranium-238 and daughter products in asbestos. In addition to determining the natural background concentrations, asbestos samples were collected from the overhead piping where the protective covering was deteriorated or where asbestos had fallen to the ground below the overhead piping. The purpose of this sampling was to determine whether asbestos had become contaminated with above background concentrations of radioactivity. Table 5.1-6 is a listing of all samples where radiologic contamination was suspected, and Table 5.1-7 is a listing of all samples where no radiologic contamination was suspected. Fifteen of the 29 samples suspected of being radiologically contaminated showed a positive identification of radiologic contamination. Only two of the 17 unsuspected samples showed positive identification, with both of the samples having positive identification approximating the lower limit of detection of 2 pCi/g for uranium-238. Both samples were taken from the same unopened bag of asbestos cement on the second floor of building 401. It is, therefore, indicated that these samples contain uranium-238 concentrations at background levels.

From this information some conclusions can be drawn. First, natural background concentrations of uranium-238 in asbestos are less than 2 pCi/g. Second, asbestos material which has an intact outer covering may not be radiologically contaminated. Third, some asbestos at this site which has deteriorated outer covering or no outer covering contains above background concentrations of radioactivity (MKF and JEG 1987m). The PMC will implement additional sampling to further characterize possible radiological contamination of asbestos material as part of the buildings dismantlement work.

5.1.1.2 Radiological Contamination. As discussed in Section 3.1.1, all chemical plant buildings have, to varying degrees, been surveyed for radioactive contamination by three previous groups and by the PMC. Reports provided by the Department of the Army (DA) and Ryckman, Edgerly, Tomlinson & Associates (RETA) contain limited useful radiological characterization data. BNI characterization reports provide useful data for the buildings where uranium and thorium were processed, while the PMC data mainly focus on the non-process buildings.

This subsection summarizes general trends discovered during radiological characterization of the buildings. Much greater detail concerning physical and functional descriptions of buildings, building-specific measurement results, and data analysis can be found in the Weldon Spring chemical plant buildings radiological characterization report (MKF and JEG 1990a).

The structural material comprising the five main process buildings (buildings 101, 103, 105, 201, and 301) and the pilot plant buildings (buildings 403, 404, and 405A & B), along with the equipment remaining in these buildings, are generally contaminated to levels near or above the DOE surface contamination guidelines for unrestricted use (DOE Order 5400.5). The primary radioactive contaminant in these buildings is uranium; however, natural thorium (thorium-232 and associated decay products) is also present to varying degrees. Uranium contamination is a result of uranium metal and oxide production from uranium ore concentrates, while natural thorium contamination is a result of thorium processing.

All non-process buildings contain radioactively contaminated equipment and/or structural materials to varying degrees. Buildings 108, 407, 408, 433, 435, 436, and 438 contain relatively large amounts of equipment contaminated to levels near or above the DOE surface contamination guidelines. Some of the structural material (structural steel, concrete floors, walls, ceilings, and/or roofs) comprising buildings 407, 408, 410, and 417 is contaminated to levels near or above the DOE surface contamination guidelines. In most other non-process buildings, structural material and/or remaining equipment is generally below the DOE surface contamination guidelines.

As is the case in the process buildings, the primary radioactive contaminant in the non-process buildings is uranium. However, some non-process buildings also contain much lower concentrations of natural thorium along with the uranium contamination. The general trend of uranium and/or natural thorium as the primary radioactive contaminants is not without exception. For example, the primary radioactive contaminant in building 406 is thorium-230, a radionuclide of the uranium-238 series.

5.1.2 Raffinate Pit Water and Sludge

Three reports have been prepared regarding various contaminants in the raffinate pit sludges and sediments. Surface water characterization was also performed as part of the Phase 1 water quality assessment and a confirmatory PMC study in 1989.

5.1.2.1 Bechtel National, Incorporated - 1983 (with Eberline Instrument Corporation). Analytical results of sludge samples indicate high concentrations of silicon, zirconium, sodium, nitrate, and fluoride, as well as elevated levels of arsenic, calcium, magnesium, molybdenum, and radioactive materials in all four pits. The level of radiation at approximately 0.3 m (1.0 ft) above the sludge ranges from 0.2 to 1.5 mR/h (BNI 1984a).

5.1.2.2 Bechtel National, Incorporated - 1986 (with Thermoanalytic/Eberline Laboratory). Sludge samples were analyzed for uranium-234 and -238, thorium-230 and -232, radium-226 and -228, lead-210, and polonium-210. Results are shown in Table 5.1-8. Eighteen samples were analyzed for EP toxicity, metals, reactivity, ignitability, PCBs, and pH. All chemical results reported were below regulatory limits.

5.1.2.3 WSSRAP Project Management Contractor Study - 1987. Results from the Phase I water quality assessment were as follows.

<u>Nitroaromatics</u>

Surface water samples from each pit were analyzed for nitroaromatics. No nitroaromatics were detected in any of the pit waters.

<u>Inorganic Anions and Water Quality</u>

Raffinate pit water samples were tested for inorganic anions (nitrate, sulfate, chloride, and fluoride) and water quality indicator parameters (total organic carbon, total dissolved solids, and hardness). The results of these analyses are shown in Table 5.1-9. A comparison of recent data to historical data for the four inorganic anions is presented in Table 5.1-10.

The feed materials plant uranium purification process resulted in high levels of nitrates and sulfates in the raffinate slurry and interstitial water. Sludge stratification and lack of mixing would allow significant quantities of the inorganic anions to be bound in the sludge and interstitial water. Much higher nitrate and sulfate levels existed in previous raffinate pit water samples and in the raffinate sludge (Table 5.1-10). The nitrate originated from the nitric acid used as a process material by the feed materials plant. Sulfate contamination probably originated as wastes from the yellowcake impurities removed by the solvent extraction process. The contamination may also be due to past site usage of sulfuric acid in the production of both sellite (sodium sulfite) and TNT.

Fluoride levels range from 1.57 to 4.69 mg/l in raffinate pit waters. Fluoride is a result of the use of magnesium fluoride and hydrofluoric acid in the operation of the uranium feed materials plant.

Total dissolved solids and hardness varied from pit to pit. The highest and lowest values were observed in raffinate pit 3 and pit 4, respectively.

Total organic carbon concentrations ranged from 6 to 12 mg/l. Since no organic contaminants were detected in the raffinate pit water, these levels are probably a result of natural organic sources such as algae (which are present in all four pits) or decaying organic matter. However, another source of organic carbon includes the solvent tributyl phosphate (TBP) used in the solvent extraction process at the Weldon Spring uranium feed materials plant. Chloride levels were low for all four pits (1.50 to 5.69 mg/l).

Metals

Water samples from the raffinate pits contained varying amounts of metals. The results for each pit are shown in Table 5.1-11. The metals present in the ponded waters are also present at higher concentrations in the raffinate sludge. The pH of the raffinate pit water is 8.4 to 9.4. Since metals exhibit limited solubility in high pH aqueous solutions, it may be expected that metals would exist as solids within the sludge. Most of the metals originated as impurities removed from yellowcake feed material during processing. Lime (calcium carbonate) was used to neutralize the acidic process waste before the wastes were slurried to the raffinate pits. This lime use at the feed materials plant contributed to the elevated levels of calcium in the four pits.

The magnesium fluoride slag from the final process stage was redissolved with yellowcake feed material to recover unreacted uranium. This action likely contributed substantial quantities of magnesium fluoride for disposal in the pits and explains the elevated magnesium concentrations in the raffinate pits. The remaining metals (Table 5.1-11) probably originated as impurities in the original ore. Metals in the raffinate pit waters and sludges and the groundwater (see Section 5.4) implicate the raffinate pits as a groundwater contamination source.

The data summarized in Table 5.1-11 suggest substantial increases in the concentrations of several metals (aluminum, chromium, copper, iron, lead, nickel, and silver) in all four raffinate pits between 1986 and 1987. The reason for this apparent increase has not been established. The 1986 and older data are reportedly dissolved concentrations detected in filtered samples. The 1987 PMC data are total metal concentrations detected in unfiltered samples. The increase may result from the presence of suspended particulates in the 1987 samples. However, preliminary mass balance calculations suggest that the 1987 samples would have required extremely high concentrations of suspended solids to yield the observed metal concentrations, which is inconsistent with both the visible clarity of the raffinate pit water samples and the reported concentrations of other inorganic ions.

Organic Contaminants

Surface water samples from all four raffinate pits were analyzed for volatile and semivolatile organics, pesticides, and PCBs to determine the potential for groundwater contamination and to determine parameters for design of a wastewater treatment plant. None of these compounds were detected.

Radiochemistry

The raffinate pits contain the impurities removed from the concentrated uranium oxide processed at the Weldon Spring site. Thorium-232 processing wastes are also included in the pits. Uranium decay and trace amounts of radium in the yellowcake added radium to the raffinate pit inventory. Some plant feed materials consisted of high-grade uranium ore which contributed both thorium-230 and radium-226 to the raffinate pit sludges. The sludges in the pits are stratified and heterogeneous, and mostly contained in raffinate pit 3.

The water radiochemistry is directly related to the sludge composition in the raffinate pits. The methods used in uranium processing resulted in the presence of thorium-230 with the uranium. Uranium milling leaves a significant portion of thorium in the uranium oxide. The uranium feed materials plant process extracted the thorium-230 and sent it to the raffinate pits. Although the concentrations of radionuclides, inorganic anions, and metals in the pit water vary with water levels, pH, and temperature (MKF and JEG 1987o), the relative solubilities of uranium, thorium, and radium determine the radiological composition of the raffinate pit water. Thorium is the most insoluble of the three radiologic parameters in aqueous solutions. Radium is slightly soluble in water, and several uranium compounds are stable in solution. Consequently, uranium activities should be greater than radium activities and both uranium and radium activities should be greater than thorium activities. The uranium, radium, and thorium activities for raffinate pit waters are shown in Table 5.1-12. The higher uranium levels in raffinate pit 4 are probably a result of the uranium-laden debris dumped in this pit.

The amount of surface water covering the wastes varies during the year. In summer, all surface water may evaporate from raffinate pits 1 and 2, although this has not happened since 1980. In 1988 the water level in pits 1 and 2 was only 15 cm (6 in). Surface water is always present in raffinate pits 3 and 4. Raffinate pit 3 is designed to overflow into pit 4 through a pipe in the dike wall common to both pits (National Lead Company of Ohio 1977; BNI 1984a). Raffinate pit characteristics are summarized in Table 5.1-13.

5.1.2.4 WSSRAP Project Management Contractor Study - 1988-1989. Results of the 1988-1989 raffinate sludge sampling were as follows.

Nitroaromatics

Sludge samples from all four pits were analyzed for nitroaromatic compounds; none were detected.

Inorganic Ions

Sludge samples were analyzed for nitrite, nitrate, sulfate, chloride, and fluoride. Table 5.1-14 lists the lowest and highest values, average values and standard deviation for each pit and each anion. Elevated levels of nitrate and sulfate were detected in all the pits with pit 4 having substantially lower concentrations. Nitrite levels were elevated in all pits, with the exception of pit 4. Chloride levels were slightly elevated in pits 1, 2, and 3. Fluoride levels were only slightly elevated with the higher levels in pit 4.

Elevated nitrite and nitrate levels are associated with neutralized nitric acid which entered the pits during operation of the uranium feed materials plant. The elevated levels were expected due to previous studies and knowledge of plant processes (see Appendix D).

Elevated sulfate levels probably originated as wastes from yellowcake impurities removed by the solvent extraction process. This was also expected due to previous studies and knowledge of the process of the feed materials plant. The manufacture of sellite and TNT also required use of sulfuric acid.

The presence of elevated fluoride levels in the pits is due to the reintroduction of magnesium fluoride into the digestion phase of the process to recover entrapped uranium. Higher levels of fluoride were documented in previous studies. Since the most recent investigation was the most thorough and complete when compared to previous studies, it was considered a more reliable source. Due to the high solubility of fluoride, it is believed that most of the fluoride left the site in effluent streams. A simple mass balance using the amount of uranium produced each year of operation can be used to estimate the amount of fluoride generated each year. The reaction was as follows:

$$UF_4 + 2Mg \rightarrow U + 2Mg\,F_2$$

The uranium feed materials plant processed about 14,512 metric tons (16,000 tons) of uranium materials each year. This production rate would have generated approximately 46,259 metric tons (51,000 tons) of fluoride over the 10-year period of operation. This number represents the total quantity of fluoride which would have been deposited in the pits. Were all the fluoride to remain in the pits today, that number would represent 25% of the total quantity of material which is presently in the pits. This number is about four orders of magnitude above the levels detected in fluoride analysis as seen in averages listed in Table 5.1-14. This would indicate that almost all the fluoride left the raffinate pits in soluble form through effluent streams (decant overflow).

Volatiles and Semivolatiles

No organic chemical contamination from volatile and semivolatile fractions was expected in the sludge; however, a scan was performed to confirm their presence or absence. Low levels of six compounds were detected by lab analysis of sludge samples. However, some of the results of the laboratory analysis were suspect, as noted below. A discussion of the procedural requirements for validation of analytical results is presented in the *Data Validation Report* (MKF and JEG 1992b).

Acetone and methylene chloride were found in quality control blank samples as well as sludge samples suggesting that they are probably a result of contamination in the laboratory.

Sample analysis indicated the presence of 1-2 dichloropropane at a level of 8 μg/kg (detection limit of 5 μg/kg) at one location in pit 2. 1-2 dichloropropane is used in insecticide sprays and also as a solvent. It is not definitely known where this contaminant originated, but it is probable that insecticide spraying around the pits was the source.

Low levels of toluene were found in sample analyses from one sample location in pit 2 (6.0 μg/kg) and two sample locations in pit 3 (38.0 and 290 μg/kg). Low levels of 2-butanone were found in sample analyses from one sample location in pit 1 and one sample location in pit 3. It is not known where this solvent contamination originated, but laboratory contamination is suspected as a potential source. Another potential source is paints and adhesives that may have been used at the site.

Analyses of samples from pits 1, 2, and 3 indicated benzene concentrations ranging from the detection limit to 88 μg/kg. Since there are no defined sources of benzene contamination on site, laboratory contamination is suspected here also. Another possible explanation of benzene contamination is fuels and oils that may have been stored on site.

Low levels of bis(2-ethylhexyl) phthalate were detected in laboratory sample analyses from one location in pit 1 and three locations in pit 4. Low levels of di-n-butylphthalate were detected in laboratory sample analyses from four locations in pit 1 and one location in pit 3. Sample analysis detected no semivolatile contamination above detection limits from pit 2. The two phthalates detected in the pits were also detected in blank samples suggesting that they are a result of laboratory contamination.

Metals

Raffinate pit sludge samples were analyzed for Contract Laboratory Program (CLP) metals plus lithium, molybdenum, and zirconium. Lithium was added because it had been detected in monitoring wells near the pits. Molybdenum could have been an impurity in the yellowcake processed at the feed materials plant. Zirconium was added to clarify the results of the BNI 1983 study, which found zirconium at high levels in the sludges. Table 5.1-15 is a metals content summary table presenting the lowest and highest values, average values, and standard deviations for each pit. Raffinate pit sample analyses showed varying amounts of metals. Pit 1 analyses showed values above detection limits for all metals analyzed except lithium. Pit 2 analyses showed values above detection limits for all metals analyzed except potassium and selenium. Pit 3 analyses contained levels above detection limits for all metals analyzed. Pit 4 analyses contained values above detection limits for all metals analyzed except silver. Pit 4 in general contained lower concentrations of metals than the other pits. High levels of calcium were found in sample analyses for all four pits.

Levels of magnesium were detected in sample analyses for all four pits. In the final process stage, magnesium fluoride slag was redissolved with yellowcake feed material to recover unreacted uranium. This is the most likely source of magnesium in the pits. As with the fluoride analysis, magnesium levels were lower than expected, and most of the magnesium is believed to have been discharged from the pits in the decant water stream. A simple mass balance can be used to estimate the amount of magnesium sent to the pits each year. The reaction is as follows:

$$UF_4 + 2Mg \rightarrow U + MgF_2$$

As mentioned previously, the uranium feed materials plant processed about 14,512 metric tons (16,000 tons) of uranium materials each year. This would have generated approximately 29,931 metric tons (33,000 tons) of magnesium over the 10-year period of operation. This number represents the total quantity of magnesium which would have been deposited in the pits. Were all the magnesium to remain in the pits today, that number would represent about 16% of the total quantity of material which is presently in the pits. This number is about two orders of magnitude above the levels detected in magnesium analysis as seen in averages listed in Table 5.1-15. Magnesium appears to have been discharged in the effluent stream (decant overflow) with the fluoride, although to a lesser extent, due to the lower solubility of magnesium.

Lithium was detected in lab analyses from pits 2, 3, and 4. It is probable that lithium levels detected in monitoring wells near the pits are a result of contamination from the pits. The lithium is believed to be a result of lithium chloride used as an electrolytic salt at the feed materials plant.

Levels of barium were found in sludge analyses for all four pits. Barium fluoride which was used as a radium coprecipitate or electrolytic salt at the plant is believed to be the source of this contamination.

High levels of sodium were detected in sludge analyses for all four pits. The sodium is believed to have come from sodium carbonate which was used in the solvent treatment process at the plant.

Potash was used in the pilot-scale buildings and various other facets of the operation, which probably explains the elevated potassium levels. The other metals are probably a result of impurities in the original ore processed at the feed materials plant.

Polychlorinated Biphenyls and Pesticides

Sludge samples were analyzed for PCBs and pesticides. Thirteen samples from pit 1 and eleven samples from pit 2 were analyzed. Two samples from pit 1 and one sample from pit 2 had low levels of the pesticide 4,4 DDE detected in analyses. One sample from pit 1 had a level of 26 μg/kg beta-BHC, another pesticide, detected in sample analyses. There were two levels of the PCB Aroclor 1254 detected in sample analyses from pit 2. Three samples from pit 1 had levels slightly above detection limits of the PCB Aroclor 1248, and three samples had similar levels of the PCB Aroclor 1254 detected in sample analyses.

Twenty-one samples from pit 3 and seventeen samples from pit 4 were analyzed. No samples from pits 3 and 4 had detectable levels of pesticides found in analyses. Aroclor 1248 was detected in one sample, and Aroclor 1254 was detected in analyses from four samples of pit 3. Levels of Aroclor 1248 ranging from 424 to 1,637 μg/kg were found in two samples from pit 4, and Aroclor 1254 was detected in five samples from pit 4 ranging from 354 to 11,000 μg/kg. These were the highest levels of PCBs detected in the pits.

The source of the detected pesticides is unknown, but insecticides used in the area are suspected. The source of PCBs is believed to be PCB-contaminated oil from transformers and equipment used on site.

Miscellaneous

Raffinate pit sludge samples were analyzed for oil and grease, total organic halogens, and total organic carbon. No levels above detection limits resulted from total organic halogen analyses.

Samples analyzed had detectable levels of oil and grease, ranging from 0.8% to 0.94%. These levels were expected and are believed to be a result of tributyl phosphate (TBP) contamination from the solvent extraction process used at the uranium feed materials plant. During sampling, the sludge was observed as having an oily texture with color ranging from white to dark red to dark yellow. This observation supports the TBP origin, since TBP is a yellow viscous fluid used as a solvent.

Total organic carbon (TOC) concentrations ranged from 605 to 2,646 μg/g. The TBP contamination is also believed to be the main contributor to the TOC levels detected in the pits. The algae and decaying organic matter in the pits may also contribute to the TOC levels. The TOC values are in general one order of magnitude less than the oil and grease values. This is probably due to either sodium carbonate, which was used in the solvent extraction process at the plant, or calcium carbonate used to neutralize the acidic process waste before it entered the raffinate pits.

Radiochemistry

The purpose of the radiological characterization of the raffinate pit sludges was twofold. First, it was necessary to estimate the radium-226 source term in order to design an effective radon-222 barrier as part of an engineered cover for a disposal cell. Second, a knowledge of the radionuclides and their relative quantities will help assess the feasibility of recovering any constituents from the sludges.

Results of the 1988 sludge sampling and analysis are shown in Table 5.1-16. Several conclusions can be drawn from the results of this study.

The first conclusion is that the sludge has been characterized to the level indicated in the sampling plan (MKF and JEG 1988i). Regarding the source term (in units of total activity and concentration) for radium-226 and thorium-230, the total sludge volume (all four pits) has been characterized to within the accuracy goal specified in the sampling plan. Tables 5.1-17 and 5.1-18 show the radium-226 total activity levels and concentrations respectively per pit at the time of sampling and at 200 and 1,000 years after sampling.

The fact that the relative error of the mean radium-226 concentration in pit 2 does not meet the sampling plan objective of less than 30% does not appreciably impact the radiological characterization of the total sludge volume. The impact is minimal since the sludge volume of pit 2 is small compared to the total volume of sludge. Also, and more importantly, the thorium-230 concentration controls the radium-226 concentration over extended time periods. As a result, the lack of accuracy in the radium-226 mean concentration is insignificant and therefore acceptable.

The relative error of the mean thorium-230 concentration of pit 4 also did not meet the sampling plan objective; the mean thorium-230 concentration for pit 4 has a relative error of 34% at the 90% confidence limits. However, the sludge volume and mean thorium-230 concentration of pit 4 are small enough such that the lack of accuracy in the mean thorium-230 concentration of pit 4 has negligible impact on the mean thorium-230 concentration of the total sludge volume.

Thorium-232 values are not reported here for the following reasons. The high concentrations of thorium-230 in pits 1, 2, and 3 caused excessive analytical interference with the thorium-232 results. The thorium-230 alpha spectroscopy peak significantly overlapped the thorium-232 peak. This interference was not applicable for pit 4 due to the lower thorium-230 concentrations. However, it is believed that thorium-232 concentrations for pits 1, 2 and 3 can be estimated based on its daughters, radium-228 and thorium-228. This assumption is based on the following:

1) The radium-228 and thorium-228 are in equilibrium, in pits 1, 3, and 4.

2) Most (>90%) of the radium was removed at the mill site; therefore, the unsupported radium-228 (i.e., radium-228 removed from parent source material) has transformed to 6% of original levels, given an average of 27 years since pits 1, 2, and 3 were filled. Supported radium-228 has transformed to 94% secular equilibrium with thorium–232.

3) Unsupported thorium-232 daughters below radium-228, due to their short half-life relative to the long storage time of the sludges in the pits, would not be present.

In pit 4 several biased locations were sampled. Two locations were near regions of debris and rubble. The samples from these locations exhibited no radiological characteristics that would indicate the sludge at these locations is any different from the other sludge in pit 4. Four locations generally defined the sludge boundaries. No sludge existed at two of these locations, and was very thin (less than 15 cm or 6 in) at the other two.

The sample results are consistent with the implied and documented history of the pits. The sample data indicated a greater degree of concentration homogeneity in pits 1, 2, and 3 than in pit 4. The rate of fill of pits 1, 2, and 3 and the lack of significant changes in process operations and in material balance records for the time period prior to construction of pit 4 support the assumption of sludge homogeneity within pits 1, 2, and 3.

As part of the sludge sampling effort, six sludge samples were analyzed for isotopic uranium. Uranium-238 and -234 are found in nature in a state of secular equilibrium. Uranium ore mining and processing, up to and including that which occurred at the feed materials plant, were not designed to separate the uranium isotopes. Therefore secular equilibrium should be assumed between uranium-238 and uranium-234 activity concentrations found in the sludge samples. Three of the six samples analyzed for isotopic uranium had equal mean activity concentrations of uranium-238 and –234. The remaining three samples exhibited activity concentrations of uranium-238 and -234 within plus or minus one standard deviation of the mean.

The other uranium isotope (uranium-235) comprising natural uranium is present at low activity concentrations relative to uranium-238 and uranium-234 both in nature and in the sludge. The uranium-235 activity concentration might be construed to indicate the presence of depleted uranium. However, this condition has been interpreted to be the result of laboratory error. The reason for this interpretation is that uranium depleted in uranium-235 would also be depleted in uranium-234. This is because the enrichment/depletion mechanism is a direct function of the isotope masses. In fact, if the uranium in the sludges were depleted, the uranium–238 activity concentration would be approximately 85% of the total uranium activity concentration. This is not the case as stated above; i.e., the uranium-238 and uranium-234 activity concentrations are equal. It should be noted that both slightly enriched (<1%) and depleted uranium were sometimes processed at the plant (DOE 1986). Total discards of slightly enriched or depleted uranium to the raffinate pits amounted to less than 2% of the total uranium discards.

5.1.2.5 WSSRAP Project Management Contractor Study - Pit Surface Water Sampling-1989. As part of the raffinate pits characterization, it was determined necessary to identify and quantify the concentrations of radionuclides and metals in the waters ponded in the pits.

Sampling of surface water was performed from a 14-foot john boat with the use of a peristaltic pump. Water was collected from four locations in each pit to make one composite sample for each pit. A similar composite sample was also collected near the bottom of pit 4. Sampling occurred during March of 1989. Table 5.1-19 contains the results of the radiological analyses. All samples collected for radionuclide analyses were unfiltered.

The radionuclides analyzed were chosen on the basis of knowledge of the sludge constituents. Gross alpha and gross beta parameters are not included in this report. These parameters are highly dependent on the solids content of the water sample. Solids suspended in the water cause unquantifiable variation in analysis due to alpha and beta absorption within the prepared sample. The sampling results shown in Table 5.1-19 indicate uranium to be the primary radionuclide present in the water. Uranium is the more water soluble of the radionuclides analyzed with radium the next most soluble. From a qualitative sense the data in Table 5.1-19 are as expected. The greater uranium concentration for the water in pit 4 is explained by the equipment dumped along the edges and into the water of pit 4. This equipment likely contributed loose material to the water in pit 4. The sample from the bottom of pit 4 indicates that no stratification, relative to radionuclide concentration, occurs in the waters ponded in the raffinate pits. Table 5.1-19 presents data considered to be consistent with that shown in Table 5.1-12.

Table 5.1-20 contains the results of pit water analyses. A comparison of the total water samples to the filtered water samples suggests that the pit water contains some small amounts of suspended metals. Sixteen of the 25 metals analyzed were detected in at least one of the pits. Most of the metals are expected to exist as solids in the sludge. A detailed description of where these metals originated may be found in Section 5.1.2.4. The pit water samples had levels of molybdenum detected at near or above the sludge sample analyses. The molybdenum is believed to have originated as an impurity in the original ore processed at the uranium feed materials plant. The analysis of the filtered sample for pit 1 revealed levels below detection limits for calcium, lithium, magnesium, and potassium. These levels are believed to be false negatives and attributed to laboratory error.

5.1.3 Ash Pond

The U.S. Geological Survey (USGS) reported dissolved uranium concentrations of 820 μg/l in Ash Pond (MKF and JEG 1987o). Radium-226 and thorium-230 concentrations were at background levels. A possible source of the uranium may be contaminated soil that has washed into the pond. Another source may be uranium retained in coal ash as a natural constituent of coal. This ash was disposed of in the pond.

Surface water from Ash Pond had an average nitrate concentration of 18.8 mg/l (as nitrogen). The Ash Pond nitrate levels are probably attributable to surface water flowing over nitrate-contaminated soil. Soil contamination is discussed in Section 5.2.1. Samples from Ash Pond did not have increased concentrations of trace metals (MKF and JEG 1987o). The drainage system affected by contamination from Ash Pond is discussed in Section 5.3.1 of this report.

The area between raffinate pits 3 and 4 and the actual body of water comprising Ash Pond is the site of the south dump. Radiological soil characterization in this area indicates that the greatest source of uranium contamination for Ash Pond extends from a drainage in the south dump area where leaking barrels of yellowcake were located. This material was removed in 1991 and is being held in controlled storage until final disposition. The soil in this area is contaminated to an average depth of 0.8 m (2.5 ft), with an average uranium-238 concentration of 572 pCi/g (MKF and JEG 1988q). Chemical and radiological contamination of the soils is discussed in Section 5.2 of this report.

5.1.4 North Dump Area

The north dump area was located along the northern perimeter of the site. The area was used for storage of barrels. A radiological soil survey by RETA for the Department of the Army (DA) in 1977 found the north dump area contained the most highly contaminated soil on the site. One surface sample had a uranium-238 content of nearly 14% by weight. Contamination in this area extended at least 0.9 m (3 ft) deep in some locations (MKF and JEG 1988q).

The PMC completed a comprehensive radiological soil characterization study for the chemical plant and raffinate pit area. In the north dump area, radiological soil contamination was found to an average depth of 0.9 m (3 ft) with an average uranium-238 concentration of 220 pCi/g. Selected soil samples were analyzed for radium-226, thorium-230, and thorium-232. These radionuclides were not present in significant quantities (MKF and JEG 1988q). Soil characterization results are described in Section 5.2 of this report.

5.1.5 Frog Pond

Samples of the surface water in Frog Pond have been analyzed. The samples contained a sulfate concentration of 72 mg/l. This was above the background level of 55 mg/l (background evaluation in Appendix B), but below the U.S. Environmental Protection Agency (EPA) secondary drinking water standard of 250 mg/l and Missouri's standard of 125 mg/l. The average nitrate concentration was below background. The average chloride concentration was 367 mg/l, a level which is above the EPA secondary drinking water standard of 250 mg/l. The sodium level was 792 mg/l. The chloride and sodium concentrations are attributable to runoff from the Missouri Highway Department maintenance facility's salt pile located upstream of Frog Pond.

The average uranium concentration for the Frog Pond sample was 216 pCi/l. Radium-226, radium-228, thorium-230, and thorium-232 activities were all below detection limits (MKF and JEG 1987o). The drainage system affected by contamination from Frog Pond is discussed in Section 5.3.2 of this report.

5.1.6 Southeast Site Area

The southeast site area includes 9.1 ha (22.5 acres) of the chemical plant site that drains to the southeast drainage (Figure 5.1-6). It extends from building 302 south to the property line. The process sewer extends from building 427 approximately 200 m (650 ft) to the NPDES discharge point into the southeast drainage (NP-0001). Most of the water which entered the chemical plant process and sanitary sewer systems discharged from the process sewer, but presently, only precipitation and water that infiltrates into the sewer lines is discharged. The rain water enters various building sumps and drains due to disrepair of some building roofs.

The southeast drainage area is preliminarily defined as the area of the drainage downgradient from the chemical plant boundary. Contamination may continue to enter the southeast drainage until cleanup activities at the chemical plant site are complete. The southeast drainage area will therefore be further characterized and, after the chemical plant site cleanup is complete, will be the subject of a separate decision-making process regarding any future actions.

The southeast site area was previously surveyed for radiological soil contamination by Oak Ridge Associated Universities (ORAU) as part of the Weldon Spring Wildlife Area Property (ORAU 1986b). Radionuclide concentrations detected in samples collected from the borehole at the origin of the drainage area did not differ significantly from concentrations detected in baseline samples. The findings of the ORAU survey are included in the discussion of the southeast drainage area (Section 5.2.3.3).

5.2 Soil Contamination

5.2.1 Chemical Soil Contamination

Several general assessments of the chemical soil at the Weldon Spring site have been completed since the shutdown of operations in 1966. These studies include those completed by the U.S. Army Chemical Demilitarization and Installation Restoration (DACDIR) team in 1975 and the Phase I and Phase II chemical soil contamination studies completed by the PMC in 1988 and 1989, respectively (see Section 3.2). A separate interim response action (IRA) study completed by the PMC in 1988 (MKF and JEG 1988u) also included additional analysis of chemical soil contamination at the site.

The DACDIR study, designed to investigate the effects of ordnance works operations on the site, established the presence of nitrated toluene compounds in site soils at low concentrations. Cross trenching operations completed during the study failed to expose any remaining underground wastewater lines. A comparison of photographs taken during construction of the uranium feed materials plant to the locations of ordnance works wastewater lines suggests that feed materials plant construction would have encountered any remaining unexcavated wastewater lines. While the analytical results from the DACDIR study do not meet current data validation standards, the study suggests that there are no longer significant deposits of nitroaromatics in the soils at the site. However, the sampling effort did not incorporate cut and fill relationships between the ordnance works and uranium feed materials plant topographies. A more extensive effort was required to ensure total decontamination and removal of hazardous explosives material.

Phase I soil samples were collected to assess the effects of both the ordnance works and the feed materials plant operations on site soils. The Phase I samples were analyzed for nitroaromatics, metals, nitrate, sulfate, fluoride, chloride, and percent moisture. Analytical results indicated elevated levels of lead, zinc, barium, nitrate, and sulfate in site soils. Although nitroaromatics were not detected in on-site soils during this investigation, they were detected just off the northeast corner of the site in samples from ordnance works waste lagoon 1.

The Phase II chemical soil investigation identified contamination source areas, determined the extent and magnitude of contamination, and documented uncontaminated areas. The overall soil investigation consisted of two biased sampling programs, one unbiased program, and a program to define background concentrations of metals and inorganic anions. One biased sampling program detected contamination originating from ordnance works sources while the other detected contamination originating from feed materials plant sources. The unbiased program detected contamination originating from any source and identified uncontaminated areas. The background sampling program established background contaminant concentrations and verified background concentrations used in the Phase I and IRA studies.

The 1988 PMC IRA study was performed to support the design of interim response actions. One hundred and fifty samples from 30 locations were analyzed for inorganic anions, metals, and nitroaromatics. Select locations were analyzed for Hazardous Substance List (HSL) volatiles, semivolatiles, pesticides, and PCBs. Although some sample locations were disturbed during the implementation of the IRAs, most of the data are still valid and were used in the analysis presented in this report.

Background contaminant concentrations were evaluated in the IRA study and in the Phase I and Phase II studies. On-site anion background concentrations were statistically evaluated during the IRA study while on-site metal background concentrations were statistically determined during the Phase I soil investigation. Off-site background concentrations for both anions and metals were determined at an uncontaminated area less than 8 km (5 mi) from the site during the Phase II study. To compare background concentrations, the studies focused on the same soil units at on- and off-site locations. The off-site inorganic anion and metal background concentrations determined through the Phase II study generally agree with on-site background concentrations determined with the IRA and Phase I studies.

Upper background limits used to evaluate data in this report were established using data from the background sampling portion of the Phase II study. Mean background concentrations were calculated for each parameter. Standard deviations were also calculated, and upper background limits for each parameter were established by adding two times the standard deviation to the corresponding mean background concentration. This approach was selected for establishing upper background concentration limits because there is a 95% probability that concentrations above these limits represent contamination rather than background concentrations.

Table 5.2-1 provides a statistical summary of the background soil analysis. For a given parameter, this table includes values for the number of samples considered, the detection limit for the compound, the minimum and maximum contaminant concentrations observed, the mean background concentration (M), the standard deviation (S), and the upper background limit (M+2S). Background limits for some parameters were established at their detection limits. Since nitroaromatics, PCBs, and some semivolatile and volatile organic compounds do not occur naturally, any concentration above the detection limit is contamination. For other compounds that do occur naturally, background limits were established as described above.

Also shown in Table 5.2-1 are values termed outliers and values used to calculate the mean and standard deviation which were greater than the upper background limit. Outliers are values judged to be anomalous and not representative of background concentrations. Values could be anomalous due to analytical errors or other errors which have unknown sources. A more complete discussion of anomalous or outlier values is presented in the *Data Validation Report* (MKF and JEG 1992b).

Discussions of the nature and extent of chemical contamination at the site is presented in this report in terms of groups of analytical parameters. These parameters include:

- Nitroaromatics
- Inorganic anions
- Metals
- PCBs
- Pesticides
- Semivolatile organic compounds
- Volatile organic compounds

The discussion of inorganic anion contamination is further subdivided to address each anion of concern while the discussion of metal contamination is similarly divided to address each metal of concern. The discussion of semivolatile organic compounds is sub-divided to address subgroups of related compounds.

The general areas containing chemical soil contaminants are represented on Figures 5.2-1 through Figures 5.2-31. For each chemical contaminant, these figures show sample locations contaminated above the upper background limit. Table 5.2-1 presents the elevated inorganic anion and metals data displayed in Figures 5.2-2 through 5.2-30.

A discussion of nitroaromatic, inorganic anion, metal, pesticide, PCB, and semivolatile organic compounds follow. Since no volatile organic compounds were detected, only a brief discussion of these compounds is included.

5.2.1.1 Nitroaromatics. Nitroaromatic compounds are potential soil contaminants from ordnance works processes (see Appendix D). Soil samples from the biased sampling program boreholes in the ordnance works area were analyzed for nitroaromatic compounds. The uppermost samples from the unbiased sampling program were also analyzed for nitroaromatics to detect contamination in areas not suspected of being affected by ordnance works processes. Phase I and IRA samples were also analyzed for nitroaromatic compounds.

Areas sampled for nitroaromatic compounds include ordnance works process areas, drainageways, the burning area, and rubble areas. Nitroaromatic compounds were detected at the 19 locations shown in Figure 5.2-1. The depth intervals and contaminant concentrations are presented in Table 5.2-2. The results of the ordnance works biased sampling program generally confirm previous results from the Phase I and IRA studies which indicated that the Ash Pond area contains the most extensive nitroaromatic contamination. The contaminated areas are near the former primary TNT production and wastewater management facilities.

Contamination was detected in the wash house area of TNT production lines 1, 2, and 3. Gross contamination has been identified in similar settings on the adjoining Army Reserve training area. The contamination probably originated as wastewater spilled on the soil from the wash house building. Most gross contamination in these areas was apparently removed during decontamination efforts prior to construction of the feed materials plant facilities in about 1954. The depth to contamination is consistent with cut and fill mapping. Construction and subsequent removal of building foundations would have disturbed soil, allowing contaminant migration to the depths which sampling has indicated are contaminated.

Samples collected from near wastewater settling tanks on TNT production lines 1, 2, and 3 also exhibited contamination. These settling tanks collected particulate material (primarily TNT) from the wastewater generated in washing TNT crystals. These tanks reportedly frequently overflowed as wastewater lines clogged (Fishel and Williams 1944). The contamination probably originated from the spilled wastewater or from settling tank cleaning operations. The extent of contamination in these areas was controlled by ordnance works topography. These settling tanks were located near natural drainageways. The contamination has been detected in the soil below the fill placed over ordnance works topography, as expected.

The highest concentrations of nitroaromatic contamination were from samples collected at site coordinates 51280 East and 100890 North. A TNT concentration of 647 μg/g and a 1,3,5-trinitrobenzene concentration of 1.21 μg/g in the 0.6- to 1.2-m- (2- to 4-ft) depth interval were detected at this location. This depth interval is consistent with cut and fill mapping which indicates 0.6 m (2.0 ft) of fill in this area. This borehole is located in the final production area of TNT production line 2. The probable source of this contamination is the grainer house and associated wastewater. The extent of this area of contamination is very limited because no contamination was detected in numerous samples collected nearby.

Additional nitroaromatic contamination was detected in samples collected near the location of the trinitrating house of TNT production lines 1 and 4. The nitroaromatic contamination was detected in subsurface samples corresponding with the amount of fill at those locations.

The remaining locations with nitroaromatic contamination are associated with ordnance works rubble or wastewater lines. Contamination originating either as leakage from the wooden wastewater line or as spillage when the wastewater line was removed may have resulted in low-level contamination along all old ordnance works wastewater ditches shown on Figure 5.2-1. Gross contamination and wastewater lines were removed during the decontamination effort prior to transfer to AEC control in 1954, and nitroaromatic contamination was not associated with the presence of elevated levels of other contaminants.

The results of all nitroaromatic analyses indicate the absence of extensive nitroaromatic contamination in site soils. Low-level contamination is present in areas associated with ordnance works processes. No major on-site nitroaromatic sources were detected.

5.2.1.2 Inorganic Anions. Elevated inorganic anion concentrations have been detected in samples from the chemical plant and raffinate pit areas, and numerous potential sources exist for this contamination. Both the ordnance works and the feed materials plant used nitric and sulfuric acids in their processes. Spills and routine discharges provided mechanisms for nitrate, nitrite, and sulfate soil contamination. The feed materials plant also used hydrofluoric acid which provided a potential source for fluoride contamination.

Nitrate

Nitrate contamination is present at the site from both ordnance works and feed materials plant sources. Soil sampling locations which had elevated nitrate concentrations are shown in Figure 5.2-2 and Table 5.2-2. The highest nitrate concentrations were detected in samples from locations adjacent to the raffinate pits. The raffinate material typically contains very high nitrate concentrations (MKF and JEG 1988j). Water from the raffinate pits containing highly mobile nitrates seeping through the unsaturated soil zone is the probable source of this contamination. The presence of elevated nitrate concentrations in the soil at some of the sampling locations adjacent to the pits indicates that the soil underlying and immediately adjacent to the pits contains significant quantities of nitrates. It may also indicate preferred migration pathways from the pits.

Elevated nitrate concentrations were also observed in the final production area of TNT production lines 1 and 2 and in the ordnance works rubble areas and drainageways. Spills, leaks, and other possible discharges of acidic wastewater provided a source and release mechanism for these contaminants.

Samples from locations in the chemical plant area exhibited elevated nitrate concentrations, apparently related to feed materials plant sources. The source of these areas of contamination is probably spilled acidic materials. The extent of contamination in these locations appears limited to a small area given the results from adjacent boreholes.

The identification of nitrate soil contamination leads to several conclusions. The soils underlying, and adjacent to, the raffinate pits contain the highest nitrate concentrations on site and could represent a source for continuing groundwater contamination following pit water and raffinate removal. Other areas of nitrate contamination do not appear to be significant sources for groundwater contamination. Biological usage of nitrate has reduced the extent and magnitude of nitrate contamination, especially in surface and near-surface soils.

Nitrite

As shown in Figure 5.2-3 and Table 5.2-2, nitrite contamination is limited to isolated locations on the site. However, like nitrate it appears to be associated with the feed materials plant raffinate pits and process areas and the ordnance works wastewater and rubble areas.

Sulfate

Sulfate soil contamination is widespread across the site. Locations with concentrations exceeding the upper background limit shown in Table 5.2-2 and Figure 5.2-4. Sulfate contamination in Ash Pond and other ordnance works process areas are believed to have originated from ordnance production areas where wastewater was produced. Mixed nitric and sulfuric acid was used in the ordnance works to nitrate toluene. Wastewater generated during the purification process typically contained sulfate and sulfonated compounds. Contamination at these locations is generally restricted to the intervals directly underlying fill. Some locations are associated with ordnance works rubble and drainageways.

Elevated sulfate levels are also a likely result of wastes from yellowcake impurities removed by the solvent extraction process and the use of sulfuric acid in the uranium processing operation.

In general, sulfate contamination is in low concentrations, with moderate areal extent. However, several isolated areas of higher concentrations are present. The low concentrations do not appear to represent a significant source of groundwater contamination. Because most sulfate contamination is in subsurface soils and surface contamination affects a small area, surface runoff is probably not affected by sulfate contamination.

Elevated sulfate concentrations were detected in soil samples at a number of locations in the raffinate pit area. The raffinate pit wastes also contain sulfates. However, the lack of sulfates in deeper soil samples at these locations indicates that raffinate pits 3 and 4 may not the sources of this contamination. A possible source may be contaminated soil moved from ordnance works process areas to the raffinate pit area prior to construction of the pits.

Elevated sulfate concentrations were detected in samples from five locations at the coal pile north of building 401. There are two potential sources for this sulfate contamination. Sulfur, originating as pyrite in the coal stored in the coal pile, may be the source. Alternatively sulfate-contaminated fill may have been used to construct the coal pile base. Sulfate contamination patterns in the boreholes at the coal pile indicate that contamination is present from both sources. Surface and near-surface samples typically contained sulfate at concentrations from 200 μg/g to 400 μg/g. This contamination exists throughout the coal pile area and is directly attributable to the residual coal material remaining at the surface.

The remaining locations with elevated sulfate concentrations are related to either uranium feed materials plant processes or ordnance works contaminated soil used as fill over the majority of the area. Since no documentation of spills or other discharges exist, the exact source of this contamination is unknown. Sulfate concentrations in samples are generally less than 300 μg/g. The contamination is apparently limited in horizontal and vertical extent.

Several locations are clustered in the southernmost portion of the chemical plant around several feed materials plant support facilities. Sulfate concentrations were generally less than 200 μg/g. These elevated levels are present in subsurface samples, indicating contamination from ordnance works fill sources.

Fluoride

Locations with elevated fluoride concentrations are shown in Figure 5.2-5 and Table 5.2-2. Elevated fluoride concentrations were detected in the uppermost sample from locations adjacent to the hydrogen fluoride tanks. Spilled hydrogen fluoride in this area is the most likely source of this contamination. The extent of fluoride contamination in this area is limited both horizontally and vertically, based on analytical results for samples from adjacent boreholes.

Fluoride contamination was also detected at other locations within the chemical plant and raffinate pit areas. The use of magnesium fluoride and hydrofluoric acid in the uranium processing operation provided a source of fluoride contamination. However, the extent of contamination appears to be limited based on sampled intervals and adjacent borings.

Chloride

Locations with chloride concentrations greater than two times the upper background limit for chloride are shown in Figure 5.2-6. These locations are summarized in Table 5.2-2. Although the source of chloride is unknown, the chloride levels may be associated with snow removal operations (salting the roadways).

5.2.1.3 Metals. Samples collected as part of the biased programs were analyzed for different combinations of metals. Samples from the ordnance works biased sampling program were analyzed for selected metals while samples from the feed materials plant were analyzed for the complete EPA CLP list of metals. Samples from the unbiased sampling program (near-surface samples only) were also analyzed for the complete CLP list of metals. As a result of the use of acids in the processes at the ordnance works and the feed materials plant, soil contamination with metals is likely. Although contamination by different metals represents varying degrees of hazard, each metal is addressed here in alphabetical order (by chemical symbol) for ease of reference by the reader.

Silver (Ag)

Silver at elevated levels was found at locations distributed across the site as shown in Figure 5.2-7. Table 5.2-2 summarizes the locations where elevated silver levels were found. Although these locations are widely distributed across the site, contamination appears to be limited in extent around these locations. The source of elevated silver concentrations is not known.

Aluminum (Al)

Aluminum was detected at the locations shown in Figure 5.2-8 and is characterized in Table 5.2-2. The aluminum concentrations found at these locations fall within the range found in normal soils as published by Lindsay (1979). The exact sources of these areas of contamination are not known but are probably related to the widespread use of nitric, sulfuric, and hydrofluoric acids on the site.

Arsenic (As)

Locations showing elevated levels of arsenic are widely distributed across the site as shown in Figure 5.2-9. However, results from adjacent locations indicate that elevated arsenic levels are relatively localized. Locations with arsenic levels at concentrations greater than the upper background limit for arsenic are shown in Table 5.2-2. Arsenic contamination appears to be attributable to processes used in the ordnance works and uranium feed materials plant, although the specific sources are not known. This interpretation is based on the relationships among contamination, process areas, and drainageways.

Barium (Ba)

Elevated barium concentrations were found at a number of locations on the site as shown in Figure 5.2-10. These locations are summarized in Table 5.2-2. As shown in Figure 5.2-10, elevated barium levels are relatively localized. A potential source of the elevated barium levels observed is the use of barium fluoride as a coprecipitate of radium during plant operations. No conclusive evidence exists to identify other sources of barium in soils at the site.

Beryllium (Be)

Locations with beryllium concentrations greater than two times the upper background limit for this element are shown in Figure 5.2-11. These locations are summarized in Table 5.2-2. Four of these locations are associated with the coal pile. The source of elevated beryllium levels is unknown.

Calcium (Ca)

Locations with elevated calcium levels are shown in Figure 5.2-12 and summarized in Table 5.2-2. As shown in Figure 5.2-12, locations with elevated calcium levels are widely distributed across the site. Although elevated calcium levels are widespread, they are not unexpected given the widespread use of acid on the site, the use of some stone aggregate on site, and the limestone geology of the area. The elevated calcium levels were probably caused by acid contact with limestone, with the dissolved material retained by the natural soil.

Cadmium (Cd)

Locations with elevated cadmium levels are shown in Figure 5.2-13. Locations with cadmium levels greater than two times the upper background limit for this element are summarized in Table 5.2-2. Locations with elevated cadmium levels are distributed across the site. In normal soils, Cadmium concentrations range from 0.01 to 0.7 μg/g (Lindsay 1979). As shown by the values in Table 5.2-2, cadmium concentrations found at the site are frequently above this range. The source of elevated cadmium concentrations is unknown.

Cobalt (Co)

Cobalt levels greater than the upper background limit were found at 60 locations on the site. These locations are shown in Figure 5.2-14 and summarized in Table 5.2-2. Cobalt concentrations detected at these locations are above the range published by Lindsay for normal soils (Lindsay 1979). The sources of cobalt contamination are unknown.

Chromium (Cr)

The locations with chromium concentrations greater than the upper background limit for chromium are shown in Figure 5.2-15. These locations are summarized in Table 5.2-2. The source of this localized contamination is unknown but may be related to the use of acid with stainless steel equipment.

Copper (Cu)

Locations with elevated copper concentrations are shown in Figure 5.2-16. Locations with copper levels greater than two times the upper background limit are summarized in Table 5.2-2. Copper concentrations at these locations fall outside the range of copper concentrations for normal soils (Lindsay 1979). The source of copper contamination is unknown.

Iron (Fe)

Locations with elevated iron concentrations are shown in Figure 5.2-17. Table 5.2-2 summarizes the locations with iron concentrations at levels greater than the upper background limit. The source of these elevated iron levels is not known, but it appears to be related to the widespread use of acids at the ordnance works.

Mercury (Hg)

Locations with elevated mercury levels are shown in Figure 5.2-18 while locations with mercury levels greater than the upper background limit are summarized in Table 5.2-2. The source of elevated mercury levels may be the result of damaged instrumentation used on the site when it was in operation or may be attributable to impurities in the uranium ore.

Potassium (K)

Locations with elevated potassium concentrations are shown in Figure 5.2-19. Locations with potassium levels greater than the upper background limit are summarized in Table 5.2-2. Locations with elevated potassium levels are widely distributed across the site. Potash was used in the pilot-scale buildings and various other facets of the operation which probably explains the elevated potassium levels.

Lithium (Li)

Only one location exhibited a lithium concentration greater than two times the upper background limit. This location is shown in Figure 5.2-20 and summarized in Table 5.2-2. Lithium contamination may be a result of lithium chloride which was used as an electrolytic salt at the feed materials plant.

Magnesium (Mg)

As shown by Figure 5.2-21, elevated magnesium levels are found in locations widely distributed across the site. The presence of elevated magnesium levels is likely due to the use of magnesium fluoride in the digestion phase of uranium processing. The widespread use of acids and the dissolution of process equipment may also account for the distribution of this element in elevated concentrations. Table 5.2-2 summarizes the locations with magnesium levels greater than the upper background limit.

Manganese (Mn)

Manganese was found in elevated concentrations at a number of locations on the site as shown by Figure 5.2-22. Locations that have manganese concentrations greater than two times the upper background limit are summarized in Table 5.2-2. The source of elevated manganese concentrations is unknown but may be partially attributable to pyrolucite in the soil.

Molybdenum (Mo)

Only one location showed molybdenum concentrations greater than, or equal to, two times the upper background limit. This location is shown on Figure 5.2-23 and summarized in Table 5.2-2. The source of this elevated molybdenum concentration may be related to the dissolution of steel alloys by acids or a result of impurities in yellowcake processed at the uranium feed materials plant.

Sodium (Na)

Elevated sodium levels occur at the locations as shown in Figure 5.2-24. The data for these locations are summarized in Table 5.2-2. The source of these elevated concentrations is believed to have come from sodium carbonate which was used in the solvent extraction process.

Nickel (Ni)

Elevated nickel concentrations occur at the locations shown on Figure 5.2-25. Locations with nickel concentrations greater than the upper background limit are summarized in Table 5.2-2. Nickel contamination is relatively localized and is probably related to the dissolution of ordnance works and uranium feed materials plant process equipment by acids.

Lead (Pb)

Elevated lead levels are found at the locations shown in Figure 5.2-26. Many of these locations can be related to drainage areas for ordnance works acidic wastewater. Process buildings in the ordnance works were lead sheathed to help prevent sparking. Acid dissolution of this material may account for some of the locations with elevated lead levels. Locations with lead levels greater than the upper background limit are summarized in Table 5.2-2.

Selenium (Se)

Locations with elevated selenium levels are shown in Figure 5.2-27. Locations with selenium levels greater than the upper background limit are summarized in Table 5.2-2. Selenium concentrations greater than the upper background limit are distributed in the ordnance works and/or the uranium feed materials plant process areas. Since selenium is used in alloys to make chemical tanks, it is likely that the selenium found at these locations resulted from the dissolution of chemical storage tank material.

Thallium (Tl)

Elevated thallium concentrations were detected at the locations shown in Figure 5.2-28. Locations of thallium levels greater than the upper background limit are summarized on Table 5.2-2. The source of this contamination is not known.

Vanadium (V)

Vanadium was only found at concentrations greater than the upper background limit at the locations shown in Figure 5.2-29. The data is summarized in Table 5.2-2. The source of these elevated levels of vanadium is unknown.

Zinc (Zn)

Locations with elevated zinc levels are shown on Figure 5.2-30, and locations with zinc concentrations greater than the upper background limit are summarized in Table 5.2-2. The source of the elevated zinc levels at these locations is unknown.

5.2.1.4 Pesticides. Pesticides were not manufactured at the site but may have been used to control insects. Therefore, samples from the feed materials plant biased and random sampling programs were analyzed for pesticides.

Pesticides were detected in 10 samples collected from seven locations. These samples contained Aldrin, Beta-BHC, and Endosulfan I at maximum concentrations of 1,660 μg/kg, 267 μg/kg, and 31 μg/kg, respectively. The source of this pesticide contamination is not known, but the extent is extremely limited as indicated by analytical results from adjacent borehole samples.

The pesticide Aldrin was detected in four samples from a borehole located at site coordinates 51137 East, 101068 North at concentrations ranging from 20 μg/kg to 1,660 μg/kg. The source of this contamination is not known, but the extent is limited as indicated by analytical results of samples from adjacent boreholes.

The pesticide results confirm that pesticides were not widely used or disposed of at the site. Isolated areas of low concentrations of pesticides are present but do not represent a source for surface water or groundwater contamination.

5.2.1.5 Polychlorinated Biphenyls. PCBs were used at the uranium feed materials plant as fluid in oil-cooled transformers. Spillage, resulting from normal transformer servicing, and leakage from transformers comprise the primary release mechanisms for PCB soil contamination. PCB oils were also apparently used as lubricating fluids in numerous buildings on site.

PCBs were detected in 25 samples collected from 23 different locations. Five of the 23 locations were near transformers which contained PCBs. PCBs were also detected in samples from 20 locations in the chemical plant area including tank farm areas 102A and 102B and several underground tank areas. Detected levels ranged from 180 μg/kg to 665,000 μg/kg and were primarily in surface soils (MKF and JEG 1988c).

5.2.1.6 Semivolatile Organic Compounds. Semivolatile organic compounds (SOCs) have been detected in previous investigations at the Weldon Spring site (MKF and JEG 1988z). Samples from the Phase II chemical plant biased sampling program and the Phase II unbiased sampling program were analyzed for the CLP semivolatile compound list. The SOCs detected in these investigations agree closely with respect to both compounds and concentrations.

Compounds associated with coal, petroleum products, and incomplete combustion of organic material were detected in several samples. These compounds include naphthalenes, chrysene, pyrenes, phenanthrene, fluoranthenes, anthracenes, and dibenzofuran. These compounds were detected in samples collected in the primary drainage from the coal storage area and elevated concentrations were also observed in samples collected from the coal storage pile. The coal pile and residual coal represent a source for these compounds, and the extent is probably limited to the immediate vicinity of the coal pile and drainageway. Elevated concentrations of these compounds were also detected in a surface soil sample collected near a small concrete pad of unknown usage. The source of this contamination is not known.

The other group of SOCs which were detected is phthalates, which were detected in samples from numerous locations during IRA characterization studies (MKF and JEG 1988u). Concentrations of phthalates were detected primarily in near surface soils. Phthalates were not used in any ordnance works or feed materials plant processes, so the source is not known. There are two possible sources: insecticide propellant and laboratory contaminants. Phthalates were commonly used as propellants for insecticides. Therefore, treatment for pest control could have provided a source for the contamination identified in this investigation. However, the presence of phthalates in numerous laboratory blanks indicates that the more likely source is laboratory contaminants. Phthalates are probably not present in site soils. Figure 5.2-31 shows the locations where semivolatile compounds were detected. Table 5.2-2 summarizes the characteristics of the locations.

5.2.1.7 Volatile Organic Compounds. Ordnance works and feed materials plant processes used volatile organic compounds including toluene, hexane, and ethyl ether. The feed materials plant biased sampling locations were selected so that these potential sources of volatile organic compounds could be evaluated. The uppermost samples from the random boreholes were also analyzed for volatile organic compounds to detect unexpected contamination.

Minor amounts of volatile organic compounds indicating soil contamination were detected in site soils adjacent to WSUFMP buildings. Low concentrations of acetone, methylene chloride and toluene were detected in some samples. Acetone and methylene chloride are common laboratory contaminants and were also observed in blank samples. Acetone and toluene were used to decontaminate sampling equipment and low concentrations in samples could represent contamination from these decontamination practices.

The absence of widespread volatile organic compounds suggests that uncontrolled waste disposal of chemicals stored in chemical plant buildings did not occur. This also suggests that any quantities spilled were not large and have evaporated or degraded. These results were expected because of the controlled nature of the site.

5.2.2 Radiological Soil Contamination

This section discusses the present understanding of the nature and extent of radiological contamination in soils at the site. In order to accomplish this purpose, radiological characterization measurements taken at the site by three different contractors, BNI, UNC Geotech (UNC), and the PMC, were combined and interpreted in order to identify areas and volumes of soils containing radiological contamination, and areas on and off site where further radiological characterization efforts are required. Soil characterization could not be carried out beneath the site buildings, raffinate pits, and Ash Pond. During site characterization, elevated contamination levels at the maximum depth sampled were identified for several soil sampling locations. In order to more accurately define maximum depths of contamination at these locations, additional soil characterization work will be performed in conjunction with remediation engineering.

Reference Levels

The site was divided into 11 regions for ease of presentation. The interpretation of all soils radiological characterization data resulted in the creation of zones containing above reference-level radionuclide concentrations. All regions and zones and many physical features of the site are shown on Plate 2, and a summary of the estimated areas, depths, and volumes of the zones is presented in Table 5.2-4. A detailed discussion of all zones is presented in

Subsections 5.2.2.1 through 5.2.2.11. These zones were identified by reference levels rather than guidelines because site-specific guidelines had not yet been developed for the site.

Reference-level concentrations were created for discussion purposes in order to provide benchmarks from which soils characterization data could be interpreted. The same reference-level concentrations were chosen for radium-226, radium-228, and thorium-230, namely 5 pCi/g in soils from ground level to 15 cm (0.5 ft) in depth and 15 pCi/g in soils lying beyond 15 cm (0.5 ft) in depth. These concentrations correspond to those stated in 40 CFR 192, which applies to the DOE Uranium Mill Tailings Remedial Action Project and to DOE guidelines for surplus facilities (Gilbert et al. 1989). The reference-level uranium-238 concentration used in this report is 15 pCi/g regardless of depth. It must be emphasized that these reference-level concentrations are not site-specific guidelines developed for unrestricted use. These concentrations were developed for presentation purposes only. The estimated zone areas, depths, and volumes found in Subsections 5.2.2.1 through 5.2.2.11 and summarized in Table 5.2-4 were based upon these reference-level concentrations and will most likely change if final site-specific guideline concentrations differ from these reference-levels.

Although the reference level concentrations used for radium and thorium are the same concentrations specified in 40 CFR 192 and used on other Formerly Utilized Sites Remedial Action Program (FUSRAP) and Environmental Restoration and Waste Management Program sites, the 15 pCi/g reference level for uranium-238 is not based on any current potential applicable or relevant and appropriate requirements (ARARs). Until an actual uranium-238 cleanup guideline is established through the Remedial Investigation/Feasibility Study (RI/FS) process for the site, it is useful to evaluate the way the areal extent and volume of above reference level contamination would be reduced if a uranium-238 cleanup guideline greater than 15 pCi/g were determined for use at the site. For example, if a reference level of 60 pCi/g uranium-238 is used, the overall volume of above reference-level contamination would be 34,723 m^3 (45,390 yd^3) (MKF and JEG 1988q), which is about 45% less than the 63,711 m^3 (83,283 yd^3) using a 15 pCi/g reference level. The large reduction in volume is not surprising since, as detailed in later sections of this report, uranium is the primary contaminant in site soils.

The reference-level concentrations were used to determine a mixture-rule concentration in the following manner. The individual radionuclide concentrations detected in each soil sample were divided by the corresponding reference level and summed. If the sum of these fractions was greater than or equal to one (unity), the sample was considered to contain an above mixture-rule concentration. This determination is consistent with DOE guidance (DOE Order 5400.5).

The reference-level radionuclide and calculated mixture-rule concentrations were used to determine the depth of above reference-level concentrations existing at boreholes or near-surface sample locations shown on Plate 2 as follows. Radionuclide concentration results from each sample depth interval were evaluated to determine if above reference-level radionuclide or above mixture-rule concentrations were present.

A depth of above reference-level or above mixture-rule concentrations was assigned to each location when the succeeding sample depth interval contained no above reference-level or above mixture-rule concentrations. In cases where a sample of soil was collected in a 30 cm (1 ft) long increment and the succeeding sample depth interval contained radionuclide concentrations greater than one-half of, but less than, the reference-level or mixture-rule concentrations, above reference-level or mixture-rule concentrations were conservatively assumed to be confined to the upper half of the sample. When this occurred, the depth of contamination was extended by 15 cm (0.5 ft).

Depths of contamination were not assigned to locations where above reference-level or mixture-rule concentrations extended to the maximum drill depth, since confirmatory evidence of the extent of these concentrations was not available. Such locations are designated by a "+" symbol next to the maximum drill depth shown in Plate 2. Some borehole and near-surface sample locations are not shown in Plate 2. Inclusion of all sample locations in this plate would have resulted in overprints, making some location numbers and depths unreadable. All sample locations that are not printed in Plate 2 are listed in Table 5.2-3 along with the respective regions and zones, depths of above reference-level radionuclide concentrations, and distances from the closest printed sample locations. In cases where an unprinted sample location coincides with a printed location, the printed location number is listed in the "Common Location" column of the table.

Sample Analyses

Soil sample analysis, which is the most quantitative method for determining radionuclide concentrations in soils, was used to determine zone depths and in many cases areal extents. These soil sample analysis results were considered important enough in the development of these zones to warrant inclusion in this report and can be found in Appendix F. Areal extents of zones were also determined through the use of in situ radiological measurements which are more qualitative but also easier and quicker measurements to perform than are soil sample analyses. Soil samples were analyzed for uranium-238, radium-226, radium-228, and thorium-230. A summary of important findings for each of these radionuclides follows.

Uranium is the primary radiological contaminant in soils at the site as evidenced by the uranium-238 soil sample analyses presented in Appendix F. Almost all zones identified at the site contain above reference-level uranium-238 concentrations, and in most cases uranium-238 concentrations were the highest of the nuclides analyzed. Above reference-level uranium-238 concentrations typically extended beyond the depths of above reference-level radium-226, radium-228, and thorium-230 concentrations in those boreholes where these nuclides were analyzed. A decreasing uranium-238 concentration gradient with depth was observed in most boreholes. This gradient is probably due to leaching from surface deposition. Notable exceptions to the decreasing concentration gradient were found in Region 4, where burial activity occurred, and a few other localized areas. Above reference-level radionuclide concentrations were found to a depth not exceeding 30 cm (1 ft) in 32 of the 51 zones identified at the site.

The radium-226 and -228 analyses found in Appendix F indicate that both of these radium isotopes are present in relatively small concentrations over relatively small areas in site soils. Only 29 of all samples analyzed for radium-226 contained concentrations greater than 5 pCi/g, and only 7 of these samples contained concentrations greater than 15 pCi/g. Seventeen samples analyzed for radium-228 contained concentrations greater than 5 pCi/g, and only six of these contained concentrations greater than 15 pCi/g. Most above background radium concentrations were confined to soils surrounding process buildings and areas where radiologically contaminated material was either stored on the surface or buried.

Thorium-230 concentrations above 5 pCi/g were found in only 26 of all samples analyzed for this nuclide, and 19 of these contained concentrations below 15 pCi/g. This indicates, in general, the existence of relatively low thorium-230 concentrations in relatively small areas of the site, particularly in areas surrounding the raffinate pits and the south dump area south of Ash Pond.

Data Needs

As evidenced in Appendix F and shown on Plate 2, a vast quantity of radiological data pertaining to soils has been gathered at the site. Large areas of the site are contained within the zones and even larger areas are believed to be free of above reference-level radionuclide concentrations based on interpretation of characterization measurements. However, it is believed that more data are necessary in relatively small and specific areas both on and off site before all areas can be considered to be adequately characterized. These data needs are minor in nature and should not be construed to impact any decision regarding regulatory disposition of the site remedial action effort. Data needs concerning the process sewer system and soils underlying buildings and paved areas are discussed below, while localized areas requiring further radiological characterization are discussed in Subsections 5.2.2.1, 5.2.2.3, 5.2.2.4, 5.2.2.5, 5.2.2.9, and 5.2.2.11.

The process sewer system at the Weldon Spring site handled non-raffinate wastes associated with uranium and thorium processing at the feed materials plant. This waste contained chemicals and radioactive material which eventually were discharged into the southeast drainage which flows to the Missouri River. Recent characterization surveys performed at the site have investigated the process sewer system to determine the extent of contamination. When available, survey results will be compiled into a report to support site remediation. Previous limited data obtained by the PMC in 1988 indicated above reference-level concentrations of uranium-238, radium-226, and thorium-230 in a proof sampling station, which is an above ground structure associated with the process sewers. Natural uranium was found to be the predominant radiological contaminant. The RETA survey also obtained samples from the process sewer system which also indicated uranium as the predominant radionuclide.

During the period of plant operation from 1955 to 1966, fractures in the pipe and/or leaking pipe junctions could have developed in the sewer system. These openings in the process sewer pipes could have allowed wastes to seep into the ground, and this may have produced above reference-level concentrations in the surrounding soils. The extent of above reference-level concentrations, if present, cannot be estimated at the present time. After the sewer system has been removed, the surrounding soils will be characterized in order to determine the nature and extent of above reference-level radionuclide concentrations, if any.

None of the soils lying beneath buildings have been characterized. A few boreholes have been taken through the floors of some of the site buildings as can be seen on Plate 2. Soil samples from some of these boreholes contained above reference-level radionuclide concentrations, while some did not. The presence or absence of above reference-level concentrations in these boreholes is not considered to characterize underlying soils since building floors were known to have cracked and to have been re-leveled during feed materials plant operation (Meyer 1989). These actions could have allowed heterogeneous contamination of underlying soils. Such heterogeneous contaminant deposition would not be adequately characterized with the limited data presently available. Further characterization efforts are required to adequately characterize soils beneath the buildings, and the optimum time to begin this characterization is when the buildings have been removed so that measurements can be taken without interference from physical structures or detection interference from radiologically contaminated material inside the buildings.

Soils lying beneath paved and/or graveled areas also have not been characterized. The potential for above reference-level radionuclide concentrations existing below these areas is much less than that below most buildings since radioactive material was not processed or stored on most paved or graveled areas as it was inside some buildings. In addition, most paved or graveled areas will be used for transportation or storage purposes during remedial action and thus will be subject to possible spills of radioactive material which could change the underlying soils characterization if performed before all other remedial action has ended. Therefore, soils underlying paved or graveled areas should be characterized after all other remedial action is complete. This will minimize the need for repeating characterization efforts if radiological conditions change.

The data needs discussed in Subsections 5.2.2.1, 5.2.2.3, 5.2.2.4, 5.2.2.5, 5.2.2.9, and 5.2.2.11 are minor and should not be construed to impact any decision regarding regulatory disposition of the site remedial action effort. These data needs will be addressed in most cases through collection of additional soil samples by PMC personnel and/or through analysis of archived soil samples via on-site radiological laboratory capabilities.

Soil samples collected by both UNC and the PMC were archived and are available for future reference at the site. The PMC performed small-scale sampling and analytical efforts in fiscal year 1990 to fill the identified characterization limitations in the areas where archived samples were not available. Additionally, during remedial action activities, the PMC will collect and analyze excavation control samples which will accurately determine contamination depths and boundaries in localized areas of the zones. The excavation control monitoring process is described later in this section.

Radionuclides Not Analyzed

Soil sample analysis typically did not include uranium-234, uranium-235, thorium-232, and lead-210. The absence of soils data relating to these radionuclides is not believed to be of major concern as discussed in the following paragraphs.

The radiological soil characterization did not include analysis for uranium-234 or uranium-235. There is no reason to suspect that uranium ore concentrates processed at the feed materials plant contained uranium-238, uranium-235, or uranium-234 in any activity ratio other than 1:0.047:1, respectively. This is the activity ratio of these uranium isotopes that occurs in nature. The uranium ore concentrates which were processed were all obtained from natural ore deposits and were not enriched in any isotope prior to delivery to the feed materials plant.

The feed materials plant did process scrap material containing uranium both slightly enriched (less than 1% by weight) and depleted in the uranium-235 isotope. However, total receipts of slightly enriched and depleted uranium amounted to less than 1% by mass of the total uranium concentrates received (DOE 1986). This information indicates that if enriched or depleted uranium is present in soils at the site, the proportion of soils affected would be indistinguishable from those containing uranium in the natural activity ratio.

None of the soil samples were analyzed for thorium-232. However, the soil samples were analyzed for radium-228, the first daughter of thorium-232. The thorium-232 concentration can be estimated from the radium-228 concentration based on the assumption of secular equilibrium between thorium-232 and its daughter radium-228.

Lead-210 is a daughter radionuclide of radium-226. The hazards of lead-210 as well as all other daughters of radium-226 are typically taken into account in the development of site-specific radium-226 guidelines by assuming secular equilibrium between radium-226 and all daughters. The existence of secular equilibrium between radium-226 and lead-210 has not been documented at the site; however, very few samples have been analyzed for lead-210.

The absence of lead-210 analysis is not of major concern because the available soil sample data (presented in Appendix F) shows most samples containing above background radium-226 concentrations have less than 15 pCi/g radium-226. Five samples contain concentrations between 20 and 100 pCi/g, and only two samples contain radium-226 concentrations greater than 100 pCi/g. These above guidelines radium-226 concentrations exist in a very small fraction of the site, mostly in soils surrounding the process buildings. If lead-210 is not in secular equilibrium with radium-226 at the site, the soils surrounding the process buildings would be the major area affected. Since these soils account for only a small fraction of the total area contained within zones at the site, lead-210 concentrations, whether in secular equilibrium with radium-226 or not, should not be of major concern.

In Situ Measurements

Three types of in situ measurements—exposure rate, spectrometer, and field instrument for the detection of low-energy radiation (FIDLER) measurements—were used along with physical features in the determination of zone boundaries. These in situ measurements were used to varying degrees as discussed below. Tables of exposure rates and spectrometer and FIDLER data taken at the site have been published in a separate document (UNC 1988).

Exposure rate measurements were the most extensive in situ measurement technique used to help determine zone boundary placement by considering where exposure rates approached natural background levels. Exposure rate measurements detect gamma emitting radionuclides in soils and are especially useful for detecting radionuclides such as the daughters of radium-226 and radium-228 which emit relatively high gamma ray energies. Because of the abundance of relatively high energy gamma rays, exposure rate measurements are able to detect radium-226 and radium-228 concentrations as low as the reference levels. Exposure rate measurements are also able to detect uranium-238, but only at above reference-level concentrations since uranium-238 and daughters emit a lower abundance of gamma rays with generally lower energies than those emitted by radium-226 and radium-228 daughters.

Spectrometer measurements are useful in detecting radium-226 and radium-228 concentrations in soils but cannot determine the maximum depth of above reference-level radium-226 and radium-228 concentrations. Because of this, above reference-level radium-226 and radium-228 concentrations detected by spectrometer measurements were included in zones but were not used to determine the average depth of above reference-level radionuclide concentrations within zones.

FIDLER measurements are designed to detect uranium-238 within surface soils arising from surface deposition. In the years between uranium deposition and radiological characterization, much of the uranium originally deposited on the ground surface has migrated into the soil, as evidenced in the uranium-238 concentrations found in many of the borehole locations. Much of this migration has occurred beyond surface soils to depths beyond FIDLER measurement capabilities. For this reason FIDLER measurements were found to be of limited use during data interpretation.

A process known as excavation control is used to identify localized areas within zones where contamination extends beyond the average zone depth or the zone boundaries. The excavation control process begins when the zone has been excavated to the estimated depth of contamination. At that point, in situ gamma measurements are taken on the floor of the excavation and excavation continues until these measurements indicate below guideline concentrations of gamma-emitting radionuclides. When in situ gamma measurements indicate below guideline concentrations, excavation control soil samples are collected and a quick turnaround analysis is performed. These samples are collected to determine if below guideline radionuclide concentrations exist. If below guideline radionuclide concentrations are found in all excavation control soil samples, excavation activities cease. At this time post-remedial soil samples are collected and an independent verification survey can be performed.

5.2.2.1 Region 1 - North Dump Area. Region 1 is located in the extreme northwest corner of the site as shown in Plate 2 and contains the area known as the north dump. The north dump was used as a surface storage area for radiologically contaminated equipment during and after the operational period of the feed materials plant, and as a disposal area for rubble produced from the demolition of the ordnance works. There is no known record of radiologically contaminated material being buried in this area. Region 1 was characterized by five boreholes containing a total of 31 borehole soil samples, six near-surface soil sample sites containing a total of seven soil samples, 20 surface and 1-meter exposure rate measurements, 16 spectrometer measurements, and 17 FIDLER measurements. Analysis of these measurements indicated two zones of above reference-level radionuclide concentrations in Region 1. Radionuclide concentration ranges found in Region 1 were uranium-238 from 0.3 to 1,380.3 pCi/g, radium-226 from 0.9 to 6.9 pCi/g, radium-228 from 1.0 to 1.8 pCi/g, and thorium-230 from 1.7 to 9.5 pCi/g.

Zone 1, Region 1

Zone 1 of Region 1 occupies 6,091 m^2 (65,491 ft^2) and contains the north dump. Radionuclide concentration ranges found in Zone 1 are uranium-238 from 1.64 to 1,380 pCi/g, radium-226 from 0.9 to 3.6 pCi/g, radium-228 from 1.0 to 1.8 pCi/g, and thorium-230 from 1.7 to 9.5 pCi/g.

Three boreholes, numbers 242, 243, and 501, were drilled to depths of 1.5, 1.8, and 3.0 m (5, 6, and 10 ft), respectively. All soil samples from borehole 501 were analyzed for uranium-238, radium-226, and radium-228, while soil samples from the other two boreholes were analyzed for uranium-238 alone. In addition, the 0-to-30-cm (0-to-1-ft) sample from borehole 501 was also analyzed for thorium-230. Soil sample analyses indicate above reference-level uranium-238 concentrations to depths of at least 1.5 m (5 ft), 1.1 m (3.5 ft), and 91 cm (3 ft) in boreholes 242, 243, and 501, respectively. Borehole 501 also contained near-background concentrations of radium-226, radium-228, and thorium-230. Borehole 242 soil samples exhibit an erratic uranium-238 concentration gradient with depth which would be expected in a radioactive material burial area, not a surface storage area as site history indicates the north dump to be. However, samples from boreholes 243 and 501 exhibit decreasing uranium-238 concentration gradients with depth, as would be expected in a surface storage area. Spills of radioactive material occurring at surface level would produce high concentrations in the surface soil and lower concentrations with depth, since a portion of the surface uranium-238 is transported by water percolating through the soil. The highest uranium-238 concentrations found in all three boreholes exist in the surface (0-to-30-cm or 0-to-1-ft) samples, as would be expected in a surface storage area.

Four near-surface sample sites, numbers 731, 732, 734, and 735 are located within Zone 1. Soil samples collected from three of these sites (731, 734, and 735) were analyzed for uranium-238, radium-226, and radium-228, while the sample collected from site 732 was analyzed for radium-228 and thorium-230. The results of these analyses helped to define more accurately the areal extent of above reference-level radionuclide concentrations and to determine whether radionuclides other than uranium-238 are of concern in this area. Analyses of soil samples collected from sites 731, 734, and 735 indicated above reference-level concentrations of uranium-238 to maximum sampling depths of 15 cm (0.5 ft), and 30 cm (1.0 ft) respectively, with all other radionuclides either near or slightly above background concentrations. A sample collected from 732 revealed an above reference-level concentration of thorium-230 to 15 cm (0.5 ft).

Analyses of soil samples from Zone 1 indicate the main radiological contaminant to be uranium. The estimated average depth of above reference-level radionuclide concentrations in Zone 1 is 91 cm (3 ft) based on averaging the above reference-level concentration depths found in boreholes 243 and 501. Analytical results for samples collected from borehole 242 are not considered to be representative of the profile of above reference-level radionuclide concentrations present in Zone 1, based on the historical information and conflicting concentration gradients previously discussed. Boundaries of Zone 1 include the area surrounding boreholes 242, 243, and 501 and exclude nearby borehole 431 which contained no above reference-level uranium-238 concentrations. The absence of elevated in situ measurements outside of Zone 1 provides further confidence in the choice of boundary placement. Zone 1 is estimated to contain 5,567 m^3 (7,277 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 1 lies near a drainage leading off-site. Cursory surveys performed by the PMC have revealed above background gamma radiation levels in this off-site drainage. Precipitation events most likely have transported and continue to transport soil containing uranium-238 and possibly other radionuclides into this drainage. Further characterization efforts are required to better determine the nature and extent of radionuclide concentrations in this drainage.

Zone 2, Region 1

Zone 2 occupies 1,582 m^2 (17,015 ft^2) east of the north dump and includes one near-surface and no borehole soil sample sites. Two near-surface soil samples, collected from site 745, were taken to a depth of 15 cm (0.5 ft) and were analyzed for uranium-238, radium-226, and radium-228; results indicated an above reference-level concentration of radium-226 only. Based on the disposal history of this area as explained in the Zone 1 presentation, decreasing concentrations with depth are expected here, and since the subsurface radium-226 reference-level is less than the observed radium-226 concentration of 6.9 pCi/g, the estimated depth of above reference-level radium-226 concentration in Zone 2 is 15 cm (0.5 ft).

The five surface exposure rate measurements and five spectrometer measurements taken in and around Zone 2 do not indicate the presence of above reference-level concentrations of radium-226, radium-228, or thorium-232 other than the radium-226 found in samples from site 745. Also, analyses of near-surface soil samples collected from site 740 and from borehole 245 do not indicate the presence of above reference-level concentrations of radium-226, radium-228, or uranium-238. These data indicate that Zone 2 is a small area slightly above the radium-226 surface reference level which could have been due to a spill from a truck, based on the proximity of sample 745 to the road.

Zone 2 boundaries were drawn to include sample site 745 and exclude near-surface sample site 740 and borehole 245. On the basis of the considerations above, Zone 2 contains an estimated 241 m^3 (315 yd^3) of soils with above reference-level radionuclide concentrations.

5.2.2.2 Region 2 - North Central Area. Region 2 is located directly east of Region 1 on the north boundary of the site, as shown in Plate 2. There is no known history of disposal or storage of radiologically contaminated material in this area. Region 2 was characterized by eight boreholes containing a total of 42 borehole soil samples, five near-surface sample sites containing a total of six soil samples, 64 surface and 1-meter exposure rate measurements, six spectrometer measurements, and 55 FIDLER measurements. Radionuclide concentration ranges found in Region 2 were uranium-238 from 0.3 to 6.3 pCi/g, radium-226 from 1.1 to 1.7 pCi/g, and radium-228 from 0.9 to 1.8 pCi/g. Six of the eight boreholes located in Region 2 were drilled to 1.5 m (5 ft), while the remaining two were drilled to 1.8 m (6 ft). All borehole soil samples were analyzed for uranium-238; no sample showed concentrations above the reference-level. The samples collected from the five near-surface soil sample sites were analyzed for radium-226 and -228. All radium-226 and -228 concentrations were near background levels. Results of the exposure rate, spectrometer, and FIDLER measurements indicated no above reference-level concentrations of the radionuclides that these respective methods can detect.

None of the borehole samples or near-surface soil samples collected in Region 2 were analyzed for thorium-230. Exposure rate, spectrometer, and FIDLER measurements will not detect concentrations of thorium-230 at or near the reference level. The absence of data regarding thorium-230 concentrations in Region 2 is not a gap in the data because there is no recorded history of disposal in this area and because above reference-level concentrations of other radionuclides were not found in samples from Region 2. Results of all measurements indicate that there are no above reference-level radionuclide concentrations within Region 2. Accordingly, there are no zones of above reference-level radionuclide concentrations located within Region 2.

The area comprising Region 2 drains off-site by way of three drainages. Since no above reference-level radionuclide concentrations were found in Region 2, these drainages are not expected to contain above reference-level concentrations; however, there are no characterization data available here, and a minor characterization effort is required to determine the nature and extent of radionuclide concentrations in these drainages.

5.2.2.3 Region 3 - Frog Pond Area. Region 3 is located in the extreme northeast corner of the site and includes Frog Pond as shown in Plate 2. Frog Pond is a man-made pond excavated out of an existing drainage at some time during the operation of the feed materials plant. Frog Pond receives precipitation runoff from the northeast corner of the chemical plant and from the plant storm sewer system. There is no known record of radiologically contaminated material being stored or buried in Region 3. It is known, however, that a spill of uranyl nitrate hexahydrate occurred in building 403 at some time during the operation of the feed materials plant, a portion or all of which could have entered the Frog Pond drainage system (Meyer 1989).

Region 3 was characterized by eight boreholes containing a total of 42 borehole soil samples, 14 near-surface sample sites containing a total of 19 soil samples, 59 surface and 1-meter exposure rate measurements, one spectrometer measurement, and 56 FIDLER measurements. Radionuclide concentration ranges found in Region 3 were uranium-238 from 0.3 to 280.4 pCi/g, radium-226 from 0.6 to 1.9 pCi/g, and radium-228 from 0.6 to 1.9 pCi/g. Analysis of these measurements indicates four zones of above reference-level radionuclide concentrations.

<u>Zone 1, Region 3</u>

Zone 1 occupies 2,395 m^2 (25,757 ft^2) and encompasses a drainage which receives effluent from Frog Pond. Radionuclide concentration ranges found in Zone 1 are uranium-238 from 3.3 to 24.2 pCi/g, radium-226 from 0.6 to 1.5 pCi/g, and radium-228 from 0.6 to 1.2 pCi/g. Borehole 239 and three near-surface sample sites, 739, 747, and 748, were taken within this zone. Borehole 239 was drilled to 46 cm (1.5 ft) and two soil samples, both of which were analyzed for uranium-238, were taken from it. An above reference-level concentration is estimated to 15 cm (0.5 ft) by assuming all uranium-238 activity occurs in the upper 15 cm (0.5 ft of the 0-to-30-cm (0-to-1-ft) sample. Sample sites 739, 747, and 748 were drilled to 15, 30, and 46 cm (0.5, 1, and 1.5 ft), respectively. Soil samples from sites 739 and 747 were analyzed for uranium-238, radium-226, and radium-228, while soil samples from site 748 were analyzed for uranium-238 only. An above reference-level uranium-238 concentration was found to the 30-cm (1-ft) maximum sampling depth in site 747 along with near background radium-226 and -228 concentrations. Sites 739 and 748 contained below-reference-level uranium-238 concentrations; site 739 also contained near background radium-226 and -228 concentrations.

On the basis of borehole 239 and sample site 747 results, above reference-level uranium-238 concentrations are estimated to an average depth of 30 cm (1 ft) in this zone. The source of above reference-level uranium-238 concentrations found here may be effluent from Frog Pond and/or effluent from Zone 1 of Region 5, which flows through a drainage emptying into this zone. Boundaries of Zone 1 were drawn based on topography to encompass the drainage from the Frog Pond berm to the DOE property fence line. The absence of elevated in situ measurements outside this zone provides further confidence in the choice of boundary placement. Zone 1 is estimated to contain 730 m^3 (954 yd^3) of soils with above reference-level radionuclide concentrations.

The Frog Pond drainage continues off site and eventually ends at the inlet to Lake 36 on the Busch Wildlife Area. ORAU collected 27 soil samples in the drainage and found above background uranium-238 concentrations ranging from 13.1 to 65.2 pCi/g in 26 of these samples. Near-background radium-226 and thorium-232 concentrations were reported in all 27 samples (ORAU 1986b). This drainage is subject to further influence from Frog Pond effluent and so will be fully characterized by the PMC after major remedial actions are completed.

Zone 2, Region 3

Zone 2 is a 869-m^2 (9,348-ft^2) area which was identified by above background gamma radiation levels measured during a cursory walkover scan performed by the PMC in this area. A walkover scan involves the use of a sodium iodide (NaI) scintillometer, which is highly sensitive to environmental levels of gamma radiation, to search for areas containing above background levels of gamma-emitting radionuclides. A walkover scan can easily identify areas containing above background levels of gamma-emitting radionuclides, but cannot easily quantify the types or concentrations of gamma-emitting radionuclides present.

The preferred method of quantifying radionuclide concentrations—soil sample analysis—was not performed in Zone 2. However, since there is no record of radioactive material storage or burial in Region 3, and since Zone 2 receives effluent from Zones 1 and 2 in Region 5, the assumed method of contaminant deposition in Zone 2 is transport via surface water flow from Zones 1 and 2 in Region 5. Based on the assumed method of contaminant deposition, the estimated depth of above reference-level radionuclide concentrations in Zone 2 is 30 cm (1 ft), which is the same depth estimated for Zone 1 in Region 5. On the basis of this information, Zone 2 is estimated to contain 265 m^3 (346 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 2 lies within a drainage connecting Zone 1 of Region 5 with Zone 1 of Region 3. The above background gamma radiation levels found here during the PMC walkover scan indicate the presence of above background concentrations of gamma-emitting radionuclides, the nature and extent of which is unknown since soil samples were not taken. Further characterization efforts are required in this drainage in order to determine the nature and extent of radionuclide concentrations.

Zone 3, Region 3

Zone 3 occupies an 869-m^2 (9,348-ft^2) area east of Frog Pond. Surface water from Zone 2 in Region 5 flows across this zone toward the Frog Pond drainage. Near-surface sample site 721 was located within Zone 3 to a depth of 15 cm (0.5 ft), and the sample collected from the site was analyzed for uranium-238, radium-226, and radium-228. An above reference-level uranium-238 concentration of 24.2 pCi/g was found, along with near background radium-226 and -228 concentrations.

Based on this information, the estimated depth of above reference-level radionuclide concentrations in Zone 3 is 15 cm (0.5 ft). A possible method of contaminant transport to this zone is surface water flow from Zone 2 in Region 5. The boundaries of Zone 3 include sample site 721 and exclude nearby sample sites 727 and 728, which contain below-reference-level concentrations of uranium-238, radium-226, and radium-228. The absence of elevated in situ measurements outside this zone further supports the choice of boundary placement. Zone 3 is estimated to contain 132 m^3 (173 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 4, Region 3

Zone 4 occupies 3,430 m^2 (36,885 ft^2) and encompasses Frog Pond and its drainage inlet to the southeast. The drainage inlet channels surface water runoff and storm sewer effluent from the northeast section of the chemical plant to Frog Pond. Three boreholes, 230, 234, and 238, and one near-surface soil sample site, 717, were located in Zone 4. Boreholes 230 and 234 were drilled in the drainage inlet to depths of 1.7 m (5.5 ft) and 1.5 m (5 ft), respectively; soil samples from these boreholes were analyzed for uranium-238 only. Soil sample analyses indicate above reference-level uranium-238 concentrations extending to a depth of 1.2 m (4 ft) in each borehole. Borehole 238 was drilled along the northeast edge of Frog Pond to a depth of 1.5 m (5 ft). Borehole 238 soil sample results, analyzed for uranium-238 only, show above reference-level uranium-238 concentrations to a depth of 30 cm (1 ft). At site 717, one near-surface soil sample was taken to 15 cm (0.5 ft) in the drainage inlet and analyzed for uranium-238, radium-226, and radium-228; analysis results indicate above reference-level concentrations of uranium-238 and near-background radium-226 and radium-228 concentrations.

The sediment under Frog Pond itself was not sampled because, even in the driest conditions encountered, the sampling vehicles could not safely travel over the pond sediment. Since the borehole results indicate an above reference-level uranium-238 concentration depth of 1.2 m (4 ft) in the drainage inlet, it is estimated that the above reference-level concentrations under Frog Pond also extend to 1.2 m (4-ft).

Based on boreholes 230 and 234 results, the estimated depth of above reference-level radionuclide concentrations in Zone 4 is 1.2 m (4 ft). Zone 4 boundaries were drawn to include all of Frog Pond and its southeast inlet. The absence of elevated in situ measurements outside this zone provides further confidence in the choice of boundary placement.

Although there is no known history of disposal operations occurring in Zone 4, a possible explanation for the origin of uranium-238 concentrations there comes from topographical considerations and information provided by a former maintenance worker employed at the site during the operating period of the feed materials plant (Meyer 1989). The former maintenance worker recalled that a pipeline carrying uranyl nitrate hexahydrate ruptured in building 403 sometime during the operating period of the plant. The uranyl nitrate hexahydrate spill could have followed the natural drainage, possibly contaminating Zone 1 of Region 6 before reaching the Frog Pond inlet. The spill may have percolated through the gravel north of the building and entered an underground water collection system connected to the storm sewer system emptying into the Frog Pond inlet. The PMC performed a preliminary NaI scintillometer survey of an exposed catch basin connected to this sewer system at a point northeast of building 404. Gamma radiation far exceeding the background count rate was discovered in this catch basin, corresponding to an exposure rate of approximately 0.1 mR/h. The source of this high exposure rate may be residue from this spill.

Another possible route for this spill could have been from a process sewer line lift station serving building 403 to an open culvert which drains into the Frog Pond inlet. The lift station lies directly south of building 405A and uphill from the open culvert leading to the storm sewer. Above background levels of gamma radiation coming from the soil near the edge of the lift station and in the open culvert were detected by PMC personnel during the NaI scintillometer survey of the area. This suggests the possibility of the uranyl nitrate hexahydrate spill entering the process sewer and overflowing from the lift station into the open culvert.

The spill, following one or more of the transport routes to the Frog Pond inlet discussed, along with storm runoff from the northern section of the plant, could be the sources of the above reference-level uranium-238 concentrations found in Zone 4. Zone 4 contains an estimated 4,180 m^3 (5,464 yd^3) of soils containing above reference-level radionuclide concentrations.

5.2.2.4 Region 4 - Ash Pond and South Dump Area. Region 4 lies in the northwest section of the site and includes Ash Pond and the south dump. Ash Pond was used as a disposal area for ashes generated from the burning of coal in building 401, the steam plant. A slurry line transported the ash from building 401 to the pond where it was spread with earth moving equipment. Most of the ash is believed to be contained in Zone 2 of this region.

South of Ash Pond lies the area known as the south dump. This area was used during the operational period of the feed materials plant as a burn area for combustible material, a burial area for non-combustible material, and a surface storage area for drums, hoppers, rubble, and other debris (Meyer 1989). Radioactive material was also handled in the south dump by the Department of the Army (DA) during its operations at the chemical plant. Surveys performed by the PMC have identified above background levels of beta-gamma emitting radionuclides on much of the surface-stored materials, as well as above background beta-gamma count rates in areas where no surface-stored materials are present. These latter count rates are probably associated with the burial of radioactively contaminated material. On the basis of historical information, locations of surface-stored material, results of soil sample analyses, and in situ measurements, the south dump is believed to be contained within Zone 4 of Region 4.

Region 4 was characterized by 108 boreholes containing a total of 611 soil samples, 19 near-surface sample sites containing a total of 24 soil samples, 188 exposure rate measurements, 38 spectrometer measurements, and 64 FIDLER measurements. Five zones containing above reference-level radionuclide concentrations were identified in Region 4 based on these soil sample analyses and in situ measurements. The zones of Region 4 are shown on Plate 2.

Zone 1, Region 4

Zone 1 occupies 700 m^2 (7,525 ft^2) in a natural drainage which lies west of the northwest dike of Ash Pond and drains off site to the DA property. Water from Ash Pond enters the drainage through an underground pipe connected to an overflow outlet chamber within the pond. A weir was constructed in 1989 to provide a flow monitoring station.

Zone 1 contains two boreholes, numbers 414 and 426, which were drilled to 2.5 m (8.25 ft) and 46 cm (1.5 ft), respectively. Soil samples from borehole 414 were analyzed for uranium-238 and thorium-230, while borehole 426 soil samples were analyzed for uranium-238 only. Sample analyses from borehole 414 indicate no above reference-level concentrations of thorium-230, but above reference-level concentrations of uranium-238 were found to a depth of 1.5 m (5 ft). Borehole 426 results indicated above reference-level uranium-238 concentrations extending beyond the maximum sampling depth of 46 cm (1.5 ft). Concentrations of uranium-238 found in Zone 1 range from 0.3 to 109.9 pCi/g, and thorium-230 concentrations range from 0.4 to 1.0 pCi/g.

There is no history of storage or disposal of radiologically contaminated materials in this drainage. The most likely method of contaminant transport to the drainage is through water flow from Ash Pond. Precipitation flows through the south dump area and draws uranium from soils known to contain uranium-238 concentrations above the reference level. This water collects in

Ash Pond and eventually evaporates or leaves through an outfall connected to the drainage. Water samples taken at the weir outlet confirm the presence of above background uranium concentrations (MKF and JEG 1987o). As water exits Ash Pond through the overflow outlet and enters the Zone 1 drainage, a fraction of the uranium is deposited in the soils of the drainage. This method of contaminant transport has occurred for many years. Based on borehole 414 results, the estimated depth of above reference-level radionuclides in Zone 1 is 1.5 m (5 ft).

Since water flow is the most likely method of contaminant transport, the boundaries of Zone 1 were demarcated based on the topography of the drainage. Exposure rate measurements in and around the drainage gave no indication of above reference-level radionuclide concentrations lying outside of the boundaries. There is an estimated 1,066 m^3 (1,394 yd^3) of soils containing above reference-level radionuclide concentrations in Zone 1.

Zone 2, Region 4

Zone 2 occupies 28,439 m^2 (305,791 ft^2); radium-226 and uranium-238 are the main radiological contaminants. This zone includes most of Ash Pond.

On the basis of analysis of borehole and near-surface soil samples taken within Zone 2, uranium-238 concentrations ranged from 0.3 to 13.9 pCi/g, radium-226 concentrations ranged from 3.8 to 6.5 pCi/g, radium-228 concentrations ranged from 1.6 to 2.4 pCi/g, and thorium-230 concentrations ranged from 0.5 to 4.6 pCi/g. In general, the radium-226 concentrations found in Zone 2 are near the surface reference level of 5 pCi/g, while uranium-238 concentrations are about one-half of the 15 pCi/g reference level. Most radionuclide concentrations found in the soil samples collected from Zone 2 are also within the range of those found naturally in coal (Eisenbud 1987). These concentrations may be due to the ash present in this zone, since coal is known to contain naturally occurring radionuclides, with uranium-238 concentrations ranging from 0.1 to 29 pCi/g and thorium-232 concentrations ranging from 0.1 to 9 pCi/g in various types (Eisenbud 1987). Various daughter radionuclides of uranium-238 and thorium-232 have been found to be in secular equilibrium in coal. It is also known that these radionuclides become concentrated in the ash produced as coal burns (Eisenbud 1987). Most radionuclide concentrations found in the soil samples of Zone 2 are within the range of those found naturally in coal.

Zone 2 contains 17 boreholes: numbers 110, 114, 115, 116, 120, 121, 122, 123, 127, 128, 129, 130, 134, 138, 359, 415, and 416. Soil samples from all boreholes were analyzed for uranium-238 except those from borehole 116, which were analyzed for thorium-230. Samples from borehole 359 were analyzed for thorium-230 in addition to uranium-238.

Borehole 359 was drilled to 2.7 m (8.9 ft) and an above mixture-rule concentration of uranium-238 and thorium-230 was found to 15 cm (0.5 ft). Borehole 134 was drilled to 1.8 m

(6 ft) and no above reference-level uranium-238 concentrations were found. Borehole 114 was drilled to 2.1 m (7 ft) and an above reference-level uranium-238 concentration was found to 15 cm (0.5 ft. All other boreholes in Zone 2 were drilled to 1.5 m (5 ft). Boreholes 110, 115, 123, 138, and 416 were found to contain above reference-level uranium-238 concentrations to 15 cm (0.5 ft). The other boreholes contained no above reference-level uranium-238 concentrations.

Six near-surface sample sites are within Zone 2: numbers 688, 692, 693, 698, 699, and 701. Sample sites 692, 693, 699, and 701 were drilled to 30 cm (1 ft) and each contained two 15-cm (0.5-ft) samples. Sample sites 688 and 698 each contained one 0-to-15-cm (0-to-0.5-ft) sample. All near-surface samples were analyzed for uranium-238, radium-226, and radium-228. Sample sites 692 and 699 contained radium-226 concentrations above the surface reference level to a depth of 15 cm (0.5 ft). An above mixture-rule concentration of radium-226 and uranium-238 was evidenced in sample sites 688 and 701 to a depth of 15 cm (0.5 ft), and in sample site 698 to at least 15 cm (0.5 ft). Radionuclide concentrations beyond 15 cm (0.5 ft) are not available for sample site 698 since no sample deeper than 15 cm (0.5 ft) was taken there. Sample site 693 contained an above reference-level radium-226 concentration in the 0-to-15-cm (0-to-0.5-ft) sample, and an above mixture-rule concentration of radium-226 and uranium-238 in the 15-to-30-cm (0.5-to-1.0-ft) sample.

Of the 13 boreholes and near-surface sample sites showing above reference-level or mixture-rule concentrations, only one sample—collected from site 693—positively identified elevated concentrations at a depth greater than 15 cm (0.5 ft). Since the majority of samples in this zone indicate a depth of 15 cm (0.5 ft) for above reference-level or above mixture-rule concentrations, 15 cm (0.5 ft) is the estimated average depth within Zone 2.

Ten of the boreholes within Zone 2 indicated no above reference-level uranium-238 concentrations. Typically, boreholes containing no above reference-level concentrations were not included in zones, and were often used to help determine the areal extent of above reference-level radionuclide concentrations. However, surface exposure rate measurements taken above these boreholes were found to be elevated just above the reference level. These boreholes are located in areas where ash is potentially present. As discussed previously, ash can contain near-surface reference-level radium-226 concentrations or near mixture-rule concentrations of uranium-238 and radium-226. Five of the six near surface sample sites in Zone 2 that contained above reference-level radium-226 or above mixture-rule concentrations also had elevated exposure rate measurements. Therefore, the exposure rates identified at the 10 boreholes in this zone were assumed to originate from above reference-level radium-226 or above mixture-rule concentrations and were included in Zone 2.

The western section of Zone 2 located near the northwest dike is the deepest part of Ash Pond. Although, no soil samples or in situ measurements were taken in this area to determine if above reference-level radionuclides are present, it is assumed to contain above reference-level radium-226 concentrations from ash which could have been deposited by slurry flowing to this area. The dike is a physical barrier preventing contaminant transport beyond this area, so it was used as the northwest boundary of this zone. The other boundaries of Zone 2 were determined by exposure rate measurements on the north and east, and by the south dump area to the south.

Based on the above information, Zone 2 is estimated to contain 4,332 m^3 (5,663 yd^3) of soils containing above reference-level and above mixture-rule radionuclide concentrations.

Zone 3, Region 4

Zone 3 is an area of 5,153 m^2 (55,408 ft^2) in the southwest corner of the region containing uranium-238 concentrations near the reference-level in the first 15 cm (0.5 ft) of soil. Uranium-238 concentrations range from 0.3 to 10.6 pCi/g, and thorium-230 concentrations range from 0.3 to 6.3 pCi/g.

Seven boreholes, numbers 344, 345, 351, 353, 354, 355, and 365, and no near-surface sample sites are located in Zone 5. Soil samples from boreholes 345, 351, 353, 355, and 365 were analyzed for uranium-238 and thorium-230. Samples from boreholes 344 and 354 were analyzed for thorium-230. One sample from borehole 354 was also analyzed for uranium-238, radium-226, and radium-228.

Boreholes 345, 351, and 365, drilled to 20, 5, and 1.5 m (60, 15, and 5 ft), respectively, exhibited no above reference-level concentrations of uranium-238 or thorium-230 beyond the 0-to-30-cm (0-to-1-ft) depth interval. The 0-to-30-cm (0-to-1-ft) samples contain uranium-238 and/or thorium-230 concentrations that, if assumed to reside in only the upper 15 cm (0.5 ft) of the sample, exhibit above reference-level concentrations to 15 cm (0.5 ft).

Boreholes 344, 353, and 355 were all drilled to 1.5 m (5 ft). Soil samples from boreholes 344 and 355 contained no above reference-level concentrations of the radionuclides analyzed for. Borehole 353 contained a thorium-230 concentration of 6.3 pCi/g and a uranium-238 concentration of 9.3 pCi/g in the 0-to-30-cm (0-to-1-ft) sample. This indicates above reference-level concentrations extending to 15 cm (0.5 ft) when all activity is assumed to reside in the upper 15 cm (0.5 ft) of the sample.

Borehole 354 was drilled to 4.6 m (15 ft). The 0-to-30-cm (0-to-1-ft) sample contained an above mixture-rule concentration of uranium-238, radium-226, and thorium-230. Although there are no uranium-238, radium-226, or radium-228 analyses beyond 30 cm (1 ft) in this borehole, the uranium-238 concentration is similar to the 0-to-30-cm (0-to-1-ft) sample concentration in nearby borehole 353, and by assuming similar concentration gradients in these boreholes, and that all radionuclide activity resides in the upper 15 cm (0.5 ft) of the sample, the estimated depth of above mixture-rule concentrations in borehole 354 is 15 cm (0.5 ft).

The estimated depth of above reference-level radionuclide concentrations in Zone 3 is 15 cm (0.5 ft). This estimation is based on the same 15-cm (0.5-ft) estimated depth for all five boreholes containing above-reference-level radionuclide concentrations. The boundaries of Zone 3 were drawn to incorporate the above background exposure rate measurements found above every Zone 3 borehole and to exclude background exposure rates north and west of the zone. The south boundary follows the roadway while the east boundary is shared with Zone 4.

Zone 3 is estimated to contain 785 m^3 (1,026 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 4, Region 4

Zone 4 occupies 16,953 m^2 (182,290 ft^2) in the southern section of Region 4 which by a combination of historical information, physical locations of scrap and debris, soil sample analyses, and in situ measurements, is indicated to be the south dump. Scrap and debris are widely scattered about at ground level, and borehole soil sample analyses indicate burial of radiologically contaminated material at varied depths.

Decreasing radionuclide concentration gradients with depth, and depth of above reference radionuclide concentration trends appear to be evident in the northwest and extreme southern portions of the zone, but these trends are interrupted by much higher radionuclide concentrations and greater depths of above reference-level radionuclide concentrations in adjacent areas of the zone. The exposure rate measurements taken in this zone range from 14 to 75 μR/h, and are generally higher than the other zones of Region 4.

Seventeen boreholes were drilled within Zone 4, numbers 108, 109, 339, 340, 341, 342, 346, 347, 348, 349, 350, 356, 417, 418, 419, 420, and 500, to depths ranging from 0.91 to 3.1 m (3 to 10 ft). Soil samples from all boreholes, except numbers 340, 342, 346, 348, 350, and 356, were analyzed for uranium-238. Samples from all boreholes, except numbers 108, 109, 417, 418, 419, 420 and 500, were analyzed for thorium-230. In addition, selected samples from boreholes 340, 342, 350 and 356 were analyzed for uranium-238, radium-226, and radium-228. All samples from borehole 500 were analyzed for uranium-238, radium-226, and radium-228. Uranium-238 concentrations ranged from 0.3 to 2,105 pCi/g, radium-226 concentrations ranged from 1.0 to 7.1 pCi/g, radium-228 concentrations ranged from 0.5 to 5.1 pCi/g, and thorium-230 concentrations ranged from 0.8 to 123.0 pCi/g.

Two near-surface sample sites, numbers 686 and 687, are located in Zone 4. All near-surface soil samples were analyzed for uranium-238, radium-226 and radium-228. The two samples from site number 687 were also analyzed for thorium-230.

In the northwest section of Zone 4, a general trend of surface uranium-238 concentrations on the order of 100 pCi/g, along with a decreasing uranium-238 concentration gradient with depth to about 61 cm (2 ft) is evidenced in boreholes 417, 418, 500, and near-surface sample site 687. Of these three boreholes, only borehole 500 (drilled to 3.1 m or 10 ft) was deep enough to establish a maximum depth of above reference-level uranium-238 concentration, namely 1.7 m (5.5 ft). Borehole 419 shows a uranium-238 concentration gradient to a depth of 61 cm (2 ft) which is similar to boreholes 417, 418, and 500, but contains a 149 pCi/g uranium-238 concentration in the 61-to-91-cm (2-to-3-ft) sample. This higher concentration is not seen in the other boreholes and is indicative of radioactive material burial at this location. Borehole 420 contains a lower surface uranium-238 concentration than do these other boreholes, and the above reference-level concentrations extend to 1.1 m (3.5 ft) here. The difference in depths and magnitudes of above reference-level uranium-238 concentrations in boreholes 419, 420, and the other three boreholes provides evidence of the heterogeneous nature of surface and subsurface contaminant deposition within relatively small areas of the south dump.

Boreholes 339, 341, and 349 in the southern section of Zone 4 show uranium-238 concentrations on the order of twice the reference-level to a depth of about 61 cm (2 ft). Boreholes 339 and 349 show thorium-230 concentrations near the surface reference-level and greatly exceeding the reference-level, respectively, in the 0-to-30-cm (0-to-1-ft) samples, but above reference-level thorium-230 concentrations are confined to 30 cm (1 ft) in both boreholes. Above reference-level uranium-238 concentrations extend deeper than above reference-level thorium-230 concentrations in these two boreholes and in four of the five other Zone 4 boreholes and one near-surface sample site where both above reference-level uranium-238 and thorium-230 concentrations were found. This evidence suggests that remediating soils to uranium-238 reference levels will typically ensure removal of above reference-level thorium-230 concentrations.

The relatively low uranium-238 concentrations seen near the surface in boreholes 339 and 341 are not confirmed in borehole 340, which lies between these boreholes. Only the 0-to-30-cm (0-to-1-ft) and 30-to-61-cm (1-to-2-ft) samples from borehole 340 were analyzed for uranium-238, and results were 167.8 and 101.1 pCi/g, respectively. This is another example of the heterogeneous nature of radionuclide concentrations within the south dump. Other examples of heterogeneous contaminants are found in boreholes 347 and 350.

Borehole 350 contains a 1 pCi/g thorium-230 concentration in the 0-to-30-cm (0-to-1-ft) sample, followed by a 123 pCi/g concentration in the 30-to-61-cm (1-to-2-ft) sample. These concentrations may be due to contaminated material burial or runoff from the raffinate pits, since this borehole was placed in the drainage between the raffinate pit area and Ash Pond.

Results of soil sample analyses indicate that while a few trends are present in areas of Zone 4, heterogeneous radionuclide concentrations and various above reference-level concentration depths are found throughout the zone. This heterogeneous nature is expected in a known radioactive material burial area, and complicates the task of assigning an average depth of above reference-level radionuclide concentration in Zone 4.

Nine boreholes, numbers 108, 109, 339, 341, 342, 347, 349, 420, and 500, were used to determine the average depth of above reference-level uranium-238 concentrations in Zone 4. This average is 76 cm (2.5 ft). Soil samples from these nine boreholes were analyzed for uranium-238. Boreholes containing samples not analyzed for uranium-238, such as numbers 346 and 348, were not included in this average because uranium-238 concentrations typically determine the maximum depth of above reference-level radionuclide concentrations based on uranium migration in soil.

It is understood that removing the first 76 cm (2.5 ft) of soil will not remove all known above reference-level radionuclide concentrations in all areas of Zone 4, but it will remove all known above reference-level thorium-230 concentrations except near borehole 347, which contains above reference-level thorium-230 concentrations to 91 cm (3 ft). All other known above reference-level concentrations beyond 76 cm (2.5 ft) are due to uranium-238, which is relatively quick and easy to detect in the field during remedial action, therefore allowing the field technicians to direct remedial action work beyond the initial 76-cm (2.5-ft) excavation through the use of excavation control samples and, to a lesser extent, in situ measurements. Thorium-230 analysis is not as easily detected; therefore, all known above reference-level thorium-230 concentrations should be removed before excavation control samples are taken. Samples from borehole 347 contain above reference-level uranium-238 concentrations to 1.2 m (4 ft) which will be removed through the excavation control process along with the accompanying thorium-230 between 76 cm (2.5 ft) and 91 cm (3 ft).

Zone 4 is estimated to contain a minimum of 12,912 m^3 (16,879 yd^3) of soils with above reference-level radionuclide concentrations. This volume is based on a 76-cm (2.5-ft) average depth in this zone.

Zone 5, Region 4

Zone 5 occupies 709 m^2 (7,621 ft^2) southeast of Ash Pond and the south dump and was identified by a high (107 μR/h) surface exposure rate measurement. An exposure rate of this magnitude is indicative of some combination of high uranium-238 concentrations and/or radium-226 or radium-228 concentrations.

PMC personnel obtained three surface (0-to-15 cm or 0-to-0.5 ft) soil samples from sample sites 764, 765, and 766 at locations exhibiting elevated exposure rates within the zone. The samples were analyzed by the PMC for uranium-238, radium-226, and radium-228, and the results indicate above reference-level concentrations of uranium-238 and radium-228, with below-surface reference-level concentrations of radium-226.

Since no samples beyond 15 cm (0.5 ft) in depth were collected in this zone, the terminating depth of above reference-level radionuclide concentrations is unknown. The mode of contaminant transport to this zone is also not known. If the transport mechanism was a liquid spill or leakage from surface storage of radiologically contaminated materials, the depth of this zone should not extend beyond approximately 61 cm (2 ft). If radioactive material burial is the mechanism, however, the depth may extend beyond 61 cm (2 ft). The actual depth of this zone can easily be determined during remedial action by the elevated exposure rate associated with radium-228 and daughters, and through the collection of excavation control soil samples, which determine when all soils containing above reference-level radionuclide concentrations have been removed from a zone. The depth of Zone 5 is estimated at 15 cm (0.5 ft) to correspond to the currently available information discussed above.

Boundaries of Zone 5 were created by splitting the linear distance between the high exposure rate initially identifying the zone and neighboring exposure rate measurements, all near background levels. Zone 5 is estimated to contain at least 108 m^3 (141 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 6, Region 4

Zone 6 occupies 4,447 m^2 (47,820 ft^2) and lies along the toe of the north berm of raffinate pits 3 and 4. The depths and magnitudes of above reference-level radionuclide concentrations identify this area as an extension of Zone 1 in Region 9. The same methods of contaminant transport, liquid overflow from the raffinate pits and/or airborne deposition resulting from resuspension of raffinate particulates during dry periods, could have occurred in both zones. Above reference-level concentrations of uranium-238 and thorium-230 are estimated to 15 cm (0.5 ft) in both zones. The uranium-238 and thorium-230 concentration ranges found in Zone 6 are 0.3 to 8.3 pCi/g and 0.4 and 3.9 pCi/g, respectively.

Six boreholes, numbers 313, 314, 315, 316, 317, and 328, were drilled in Zone 6. All samples were analyzed for thorium-230, and all samples except those from borehole 328 were analyzed for uranium-238. No radium-226 or -228 analyses were performed on samples from this zone. In all cases, the 0-to-30-cm (0-to-1-ft) samples had uranium-238 and thorium-230 concentrations below the reference levels. However, assuming that all radionuclides reside in the upper 15 cm (0.5 ft) of the sample, an activity concentration twice that of the 0-to-30-cm (0-to-1-ft) sample concentration was presumed to exist in the 0-to-15-cm (0-to-0.5-ft) layer. This estimated concentration was found to be above either the surface reference-level or mixture-rule concentration in every Zone 6 borehole. On the basis of an estimated 15 cm (0.5 ft) depth of above reference-level concentrations, Zone 6 is estimated to contain 678 m^3 (886 yd^3) of soils with above reference-level concentrations.

The six boreholes in Zone 6 were among the deepest drilled during the radiological characterization of the site. These boreholes, drilled up to 7.3 m (24 ft) deep, were intended to identify possible leakage from raffinate pit 3. Boreholes of similar depths were also drilled around pit 4 and north of pit 1 for the same purpose. Ninety of the 124 soil samples taken from the Zone 11 boreholes were archived without analysis. All samples from borehole 328 were analyzed, providing a thorium-230 concentration profile to a depth of 4.3 m (14 ft) at this location. Analyses of all samples beyond the 0-to-30-cm (0-to-1-ft) interval exhibited near-background thorium-230 concentrations. Since the average thorium-230 concentration of raffinate in pit 3 is 17,000 pCi/g (MKF and JEG 1989e), the thorium-230 concentrations found in borehole 328 provide evidence of no radionuclide migration from raffinate pit 3 at this location.

Samples from the remaining boreholes located in Zone 6 were not analyzed for every depth interval, as was done for samples from borehole 328. The 0-to-30-cm (0-to-1-ft) and 30-to-61-cm (1-to-2-ft) samples from boreholes 313, 314, 316, and 317 were analyzed, as well as the 0-to-30-cm (0-to-1-ft) sample from borehole 315. Samples beyond 61 cm (2 ft) receiving analysis were the 4.6-m (15-ft) through 5.5-m (18-ft) samples of borehole 313, the 5.8-m (19-ft) through 6.4-m (21-ft) samples from borehole 314, the 6.4-m (21-ft) through 7-m (23-ft) samples from borehole 315, the 3.7-m (12-ft) through 4.3-m (14-ft) samples from borehole 316, and the 4.9- to 5.2-m (16- to 17-ft) and 6.1- to 6.4-m (20- to 21-ft) samples from borehole 317. These samples, except for the 0-to-30-cm (0-to-1-ft) intervals, all indicated near-background concentrations of uranium-238 and thorium-230, similar to borehole 328 results.

Boreholes 313 through 317 are located approximately 15.3 m (50 ft) closer to the toe of the berm than borehole 328 and therefore would intercept pit leakage much sooner than would borehole 328, if leakage were present. A lack of radiological soil sample analysis, especially at depths of 61 cm (2 ft) through 3.1 m (10 ft), from boreholes 313 through 317 does not allow conclusions to be drawn as to whether radionuclides are migrating from the area of pit 3. However, analyses for chemical contaminants, notably nitrate, indicate that leakage in this area is occurring. Radiological analysis of archived samples from boreholes 313 through 317 would provide a better indication of the presence or absence of radionuclide migration from the north berm of raffinate pit 3.

Since both Zone 6 in Region 4 and Zone 1 in Region 9 contain above reference-level radionuclide concentrations, and both zones drain into Ash Pond through a drainage located north of Zone 7, this drainage is suspected of containing above reference-level radionuclide concentrations. This drainage, shown on Plate 2, had seven boreholes drilled along its edges. Results of soil sample analyses from these boreholes indicated no above reference-level radionuclide concentrations. However, no samples or in situ measurements were taken within the drainage where above reference-level radionuclide concentrations may be present. Minor characterization work in this small drainage is required to determine radionuclide concentrations.

5.2.2.5 Region 5 - Northwest Buildings Area. Region 5 lies in the northwest section of the chemical plant and includes soils surrounding buildings 101, 103, 105, 108, 401, 406, and 413. Buildings 101, 103, and 105 were major process buildings which handled large quantities of chemical compounds containing uranium-238, radium-226, radium-228, thorium-230, thorium-232, and radioactive daughter products of these nuclides. Soils surrounding these buildings contain above reference-level radionuclide concentrations probably resulting from airborne deposition and/or from spills of radionuclide-containing compounds.

Buildings 108 and 406 handled compounds containing radionuclides at lower concentrations than those in the major process buildings, but may have contributed to above reference-level concentrations found in surrounding soils. Buildings 401 and 413 did not process materials containing high radionuclide concentrations.

Region 5 was characterized by 35 boreholes from which 162 soil samples were taken, 20 near-surface sample sites from which 29 soil samples were taken, 120 surface and 1-meter exposure rate measurements, 74 spectrometer measurements, and 97 FIDLER measurements. On the basis of these measurements, 11 zones of above reference-level radionuclide concentrations were identified in Region 5, as shown in Plate 2.

Zone 1, Region 5

Zone 1 occupies 1,503 m^2 (16,156 ft^2) in the northwest section of Region 5. Surface water originating from precipitation events flows from the northern section of Region 5 across Zone 1 and collects in the drainage northwest of Frog Pond. Borehole 502 and near-surface sample site 725 are located in Zone 1. Radionuclide concentration ranges found in Zone 1 are uranium-238 from 1.69 to 21.5 pCi/g, radium-226 from 0.7 to 1.65 pCi/g, and radium-228 from 0.5 to 20.8 pCi/g.

Borehole 502 was drilled to 1.5 m (5 ft) and its associated soil samples were analyzed for uranium-238, radium-226, and radium-228. An above reference-level uranium-238 concentration was found to a depth of 46 cm (1.5 ft) with all other results indicating near background concentrations of uranium-238, radium-226, and radium-228. Near-surface site 725 was drilled to 30 cm (1 ft), and its soil samples were also analyzed for uranium-238, radium-226, and radium-228. An above reference-level uranium-238 concentration was found to 15 cm (0.5 ft), with all other results indicating near background concentrations of uranium-238, radium-226, and radium-228.

The estimated depth of above reference-level radionuclide concentrations in Zone 1 is 30 cm (1.0 ft) based on an average of the depths indicated by borehole 502 and near-surface sample site 725. The method of contaminant deposition here is probably surface water sheet flow from an area east of the zone where photographs taken during feed materials plant operation show storage of barrels containing ore concentrates. This storage area has been included in Zone 2 of Region 5.

The boundaries of Zone 1 were drawn by following the roadway on the north side, by splitting the linear distance between boreholes 502 and 253—which is the borehole in Zone 2 lying closest to Zone 1—and by splitting the distance between near-surface samples 725 and 720, which lie southeast of Zone 1 and contain no above reference-level concentrations of uranium-238, radium-226, or radium-228. Site topography was also considered in boundary placement to ensure the inclusion of local drainage features into Zone 1. The absence of elevated in situ measurements immediately outside the zone provides further confidence in the choice of boundary placement. Zone 1 is estimated to contain 687 m^3 (898 yd^3) of soils containing above reference-level radionuclide concentrations.

Zone 2, Region 5

Zone 2 lies immediately southeast of Zone 1 and occupies 10,884 m^2 (117,033 ft^2) in the northern section of Region 5. Much of Zone 2 encompasses an area where drums containing uranium ore concentrates were stored during the operation of the feed materials plant. This zone also falls in the path of natural drainage from Region 5 to the Frog Pond area. Borehole 253 and three near-surface sample sites, numbers 712, 715, and 716, are located in Zone 2. Radionuclide concentration ranges found in this zone are uranium-238 from 0.3 to 12.9 pCi/g, radium-226 from 1.6 to 4.3 pCi/g, and radium-228 from 1.4 to 2.1 pCi/g.

Borehole 253 was drilled to 2.4 m (8 ft) and its associated soil samples were analyzed for uranium-238. An above reference-level uranium-238 concentration was estimated to a depth of 15 cm (0.5 ft) here by assuming all uranium-238 activity in the 0-to-30-cm (0-to-1-ft) soil sample resided in the upper 15 cm (0.5 ft). Soil samples from all three near-surface sample sites were analyzed for uranium-238, radium-226, and radium-228. Sample sites 712 and 716 were drilled to 15 cm (0.5 ft), and both showed above mixture-rule concentrations to this depth. Sample site 715 was drilled to 30 cm (1 ft) and indicated an above mixture-rule concentration to a depth of 15 cm (0.5 ft). All individual radionuclide concentrations found in these sample sites were above background but below reference levels. Above reference-level uranium-238, radium-226, and radium-228 concentrations would be expected here since uranium ore concentrates contain these radionuclides.

The estimated average depth of above reference-level radionuclide concentrations in Zone 2 is 15 cm (0.5 ft) based on borehole 253 and near-surface site 715 results. The above reference-level radionuclide concentrations found here are probably due to spills from drums of uranium ore concentrates. The boundaries of this zone follow the roadway on the north and exclude boreholes 148 and 241 on the south and east which indicated near-background uranium-238 concentrations. The absence of elevated in situ measurements immediately outside of this zone provides further confidence in the choice of boundary placement. Zone 2 is estimated to contain 1,658 m^3 (2,167 yd^3) of soils containing above reference-level radionuclide concentrations.

Zone 3, Region 5

Zone 3 lies west of building 406 and the three railroad track spurs. This area lies in a small depression about 91 cm (3 ft) below the surrounding grade. There is no known radioactive material storage or disposal history in this area. Borehole 194 is located in this zone. Uranium-238 concentrations found in this borehole range from 2.0 to 20.2 pCi/g.

Borehole 194 was drilled to 1.5 m (5 ft), and its associated soil samples were analyzed for uranium-238. Above reference-level concentrations were found in the upper 15 cm (0.5 ft) and at 91 cm (3 ft) to 1.2 m (4 ft). Results also indicate an erratic uranium-238 concentration gradient with depth which could be due to unknown burial activity in this area. Further characterization efforts are required in this area to better determine the nature and extent of above reference-level radionuclide concentrations here. Until this occurs, borehole 194 results will be used yielding an estimated above reference-level uranium-238 concentration depth of 1.2 m (4 ft) in Zone 3. Site topography was used to demarcate Zone 3, which includes the deepest part of the area surrounding borehole 194. Based on available data, Zone 3 is estimated to contain 747 m^3 (977 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 4, Region 5

Zone 4 occupies 2,463 m^2 (26,486 ft^2) immediately west of building 401, the steam plant. The ash produced from burning coal in this building was slurried to Ash Pond in a pipe running through this zone. Ash is present on the surface of this zone and may have come from leaks or breaks in the slurry pipe during building 401 operation. A small incinerator which was used to burn radiologically contaminated material is also located in the zone. Surveys performed by the PMC indicate above background concentrations of gamma-emitting radionuclides in the incinerator and in two nearby hoppers containing assorted refuse. Radionuclide concentration ranges found in Zone 4 are uranium-238 from 1.7 to 18.5 pCi/g, radium-226 from 1.0 to 5.5 pCi/g, and radium-228 from 1.0 to 2.8 pCi/g.

Near-surface sample site 720 was drilled to 15 cm (0.5 ft) in Zone 4 and its associated soil sample was analyzed for uranium-238, radium-226, and radium-228. An above reference-level radium-226 concentration was found as well as an above mixture-rule concentration of uranium-238 and radium-228. These above reference-level and mixture-rule concentrations may be due to the ash present in Zone 4.

Since no radionuclide concentration data are available beyond 15 cm (0.5 ft) in this area, the depth of above reference-level radionuclide concentrations in Zone 4 is estimated at 15 cm (0.5 ft). The actual depth can be easily determined during remedial action because of the presence of radium-226, which is detected at below reference-level concentrations by both in situ measurements and soil sample analyses. Boundaries of Zone 4 include all areas near building

401 where ash is present. The absence of elevated in situ measurements immediately outside this zone provides further confidence in the choice of boundary placement.

Borehole 125 and near-surface sample site 695 are located southwest of Zone 4 in an area where no ash is present and no known burial activity occurred. Borehole 125 samples were analyzed for uranium-238 and exhibit an above reference-level concentration between 30 cm (1.0 ft) and 61 cm (2 ft) and a near reference-level concentration from 0 to 1 cm (0 to 0.4 in) and from 61 cm (2 ft) to 91 cm (3 ft). Samples from near-surface site 695 were analyzed for uranium-238, radium-226, and radium-228, and indicated approximately one-half the reference-level uranium-238 concentration and near background radium-226 and -228 concentrations to 30 cm (1 ft). The absence of near reference-level radium-226 concentrations discounts the possibility that ash produced the near surface-level uranium-238 concentrations found. Borehole 125 uranium-238 concentrations may indicate the possibility of unknown burial activity; further minor characterization is required to better determine the extent of above reference-level concentrations.

Zone 5, Region 5

Zone 5 occupies 4,827 m^2 (51,908 ft^2) and encompasses the three railroad track spurs running from north of building 101 to the south edge of building 406. These tracks were used to transport uranium and thorium ore concentrates to the storage area north of building 101. Five boreholes, numbers 197, 201, 205, 207 and 225, and three near-surface sample sites, numbers 683, 689, and 705, were located in this zone. All soil samples from boreholes were analyzed for uranium-238, while all near-surface soil samples were analyzed for uranium-238, radium-226, and radium-228. In addition, borehole 205 samples were all analyzed for thorium-230 along with the 1.5-to-1.8-m (5-to-6-ft) sample from borehole 201. Radionuclide concentration ranges found in this zone are uranium-238 from 0.3 to 131.1 pCi/g, radium-226 from 0.4 to 1.5 pCi/g, radium-228 from 1.9 to 26.9 pCi/g, and thorium-230 from 0.5 to 1.7 pCi/g.

Borehole 225, located in the northern end of the zone, was drilled to 1.8 m (6 ft) and exhibited no above reference-level uranium-238 concentrations. Borehole 207 was drilled to 1.5 m (5 ft) in an area northwest of building 108, and soil sample analyses indicated above reference-level uranium-238 concentrations to a depth of 46 cm (1.5 ft). Borehole 205 was drilled southwest of building 108 to a depth of 1.5 m (5 ft), and sample results indicate above reference-level uranium-238 concentrations to 46 cm (1.5 ft), a concentration gradient and magnitude to 61 cm (2 ft) similar to those of borehole 207, and near background concentrations beyond 61 cm (2 ft). These data suggest similar contaminant deposition methods in these two locations. All thorium-230 analyses from borehole 205 samples indicated near background-level concentrations. Soil samples from boreholes 201 and 197 indicated no above reference-level uranium-238 concentrations and near background concentrations beyond 61 cm (2 ft).

Near-surface sample site 705 was drilled to 15 cm (0.5 ft) and the 131.1 pCi/g uranium-238 concentration found here is the highest in this zone. A radium-228 concentration slightly above the surface reference level was also found. Sample site 689 was drilled approximately 1.8 m (6 ft) from borehole 207 and exhibited no above reference-level or above mixture-rule concentrations of uranium-238 or radium-228 and near background radium-226 concentrations.

The large difference in uranium-238 concentrations between borehole 207 and sample site 689, which were taken within 1.8 m (6 ft) of each other, suggest spotty contamination in this area. Spotty contamination combined with the known history of ore transport in this area suggests the mode of contaminant transport to be inadvertent spills from rail cars carrying ore concentrates or refined uranium or thorium.

Near-surface sample 683 was drilled to a depth of 30 cm (1 ft). Results indicate an increasing concentration gradient with depth for both uranium-238 and radium-228 along with near background radium-226 concentrations. An above reference-level uranium-238 concentration was found between 15 cm (0.5 ft) and 30 cm (1 ft), while above reference-level radium-228 concentrations were found to 30 cm (1 ft). The increased uranium-238 and radium-228 concentrations found in the 15-to-30 cm (0.5-to-1.0-ft) sample suggest that cover material may have been placed over spills in this area.

Based on the uranium-238 concentrations found in boreholes 205 and 207, the estimated depth of above reference-level concentrations in Zone 5 is 46 cm (1.5 ft). The mode of contaminant deposition here is probably spillage, evidence of which comes from historical operations in this zone and the presence of spotty contamination. Boundaries of Zone 5 were chosen to include the area surrounding the three track spurs since spills could have occurred anywhere that drums containing ore concentrates were handled. Zone 5 is estimated to contain 2,206 m^3 (2,884 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 6, Region 5

Zone 6 occupies 2,575 m^2 (27,683 ft^2) and contains soils lying west of building 105 and east of building 413 outside of Zone 5. Three boreholes, numbers 203, 206 and 211, were drilled to 1.8 m (6 ft), 1.5 m (5 ft), and 1.5 m (5 ft), respectively. Soil samples from these boreholes were analyzed for uranium-238, and all three boreholes are estimated to contain above reference-level concentrations to a depth of 15 cm (0.5 ft) by assuming all uranium-238 activity resided in the upper 15 cm (0.5 ft) of the 0-to-30-cm (0-to-1-ft) sample. Uranium-238 concentrations ranged from 1.0 to 11.3 pCi/g in these boreholes.

A 15-cm (0.5-ft) depth of above reference-level radionuclide concentrations is estimated in this zone based on the borehole sample results discussed above. The suspected methods of contaminant transport are surface sheet water flow from Zones 5 and 8 and/or airborne deposition from nearby process building emissions. Zone 6 boundaries were chosen to abut buildings and paved areas and to exclude borehole 214 which contains no above reference-level uranium-238 concentrations. Zone 6 is estimated to contain approximately 392 m^3 (513 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 7, Region 5

Zone 7 is located north of the reserve water facilities (Area 429) and was delineated to include near-surface site 682 which contains above reference-level uranium-238 concentrations to at least 15 cm (0.5 ft) for reasons not presently understood. The area between Zone 7 and borehole 125 (discussed in the Zone 4 presentation) is relatively flat and relatively far from both process buildings and other zones, making surface water flow and airborne contaminant deposition unlikely. There is also no known burial history in this area. Possible explanations for the 33.4 pCi/g uranium-238 concentration found at sample site 682 are unknown surface spill or burial activity. As was discussed in the Zone 4 presentation, further characterization is required in the area from Zone 7 north to borehole 125 to better determine the nature and extent of above reference-level-radionuclide concentrations.

Zone 8, Region 5

Zone 8 occupies 2,171 m^2 (23,349 ft^2) and contains the soils surrounding buildings 103 and 105, the refinery buildings of the feed materials plant. These areas were merged into one zone because the suspected mode of contaminant transport, inadvertent spills from these process buildings and/or airborne deposition, is the same. Radionuclide concentration ranges in Zone 8 are uranium-238 from 0.3 to 380.7 pCi/g, radium-226 from 3.1 to 22.3 pCi/g, and radium-228 from 0.4 to 5.1 pCi/g.

Three boreholes, numbers 198, 212, and 412, and two near-surface sample sites, numbers 670 and 690, were drilled within Zone 8. All borehole soil samples were analyzed for uranium-238, and all near-surface soil samples were analyzed for uranium-238, radium-226, and radium-228.

Boreholes 198 and 212 were drilled to 1.5 m (5 ft), and both contained near reference-level uranium-238 concentrations in the 0-to-30-cm (0-to-1-ft) samples and below reference-level concentrations beyond, suggesting airborne deposition as a method of contaminant deposition at both locations. Above reference-level concentrations were found to 15 cm (0.5 ft) and 30 cm (1.0 ft) in boreholes 198 and 212, respectively.

Borehole 412 was drilled to 1.5 m (5 ft) and exhibited a relatively high uranium-238 concentration of 380.7 pCi/g in the 0-to-30-cm (0-to-1-ft) sample followed by a decreasing concentration gradient with depth. Above reference-level concentrations were found to 61 cm (2 ft) in borehole 412.

Sample sites 670 and 690 were both drilled to 30 cm (1 ft), and both exhibited uranium-238 concentrations on the same order of magnitude as the 0-to-30-cm (0-to-1-ft) sample from borehole 412, which suggest similar contaminant deposition methods at these locations, possibly spills of concentrated uranium-containing compounds. Sample site 670 also contained above background, but below reference-level, radium-226 concentrations and near background radium-228 concentrations. Sample site 690 contained an above surface-reference-level radium-228 concentration and an above subsurface-reference-level radium-226 concentration. The relatively high uranium-238 concentrations at maximum depth in these sample sites indicates the possibility of above reference-level concentrations extending beyond 30 cm (1 ft).

The estimated average depth of above reference-level radionuclide concentrations in Zone 8 is 30 cm (1 ft) based on averaging the depths of above reference-level uranium-238 concentration found in boreholes 212, 412, and 198. Excavation control measurements will be taken during remedial action which will determine the depths of above reference-level concentrations extending beyond this average depth in localized areas.

Buildings 103 and 105 both processed various chemical compounds containing uranium-238, radium-226, radium-228, thorium-232, thorium-230, and daughter radionuclides. Spills which could have occurred anywhere in these buildings along with airborne deposition could have produced the varying radionuclide concentrations and concentration gradients exhibited in the boreholes and near-surface samples taken within this zone. These varying concentrations and gradients probably exist in localized areas throughout the zone. Zone 8 contains all soils surrounding buildings 103 and 105 in order to include all areas where spills could have occurred but were not detected during the radiological characterization. Zone 8 contains an estimated 1,323 m^3 (1,730 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 9, Region 5

Zone 9 is a former raffinate neutralization pit located immediately south of building 105. Blueprints indicate that the dimensions of this pit were approximately 2.4 m (8 ft) by 5 m (16.5 ft) by 3.4 m (11 ft) deep. The neutralization pit was backfilled to the existing grade at some point in the past and is now indistinguishable from the surrounding terrain except for a concrete slab along the south edge.

Borehole 213 and near-surface sample site 684 were drilled within the former raffinate neutralization pit. Borehole 213 was drilled to 3.4 m (11 ft), and its associated soil samples were analyzed for uranium-238 only. Above reference-level uranium-238 concentrations extend the entire depth of this borehole. Near-surface sample site 684 was drilled near borehole 213 to a depth of 30-cm (1-ft) and contained two 15-cm (0.5-ft) soil samples, which were both analyzed for uranium-238, radium-226, and radium-228. The 0-to-15-cm (0-to-0.5-ft) sample contains an above mixture-rule concentration of uranium-238 and radium-228, while the 15-to-30-cm (0.5-to-1.0-ft) sample contains an above reference-level uranium-238 concentration.

Uranium-238 and radium-226 concentrations are seen to increase with depth in these two samples, indicating possible above reference-level radium-226 concentrations beyond 30 cm (1 ft). Radium-228 concentrations decrease slightly with depth at sample site 684 but are above background concentrations.

The estimated depth of above reference-level radionuclide concentrations is 3.4 m (11 ft), corresponding to the original pit depth. A 30-cm- (1-ft-) thick concrete slab on the pit floor could have prevented above reference-level radionuclide concentrations from reaching deeper soil. The boundaries of Zone 9 follow the 2.4-m by 5-m (8-ft by 16.5-ft) areal dimensions of the neutralization pit. The uranium concentrations found below 91 cm (3 ft) in this borehole are on the order of those found in raffinate sludge (MKF and JEG 1989e) which indicates the possibility of raffinate sludge remaining in the former neutralization pit at depths beyond 91 cm (3 ft).

Zone 10, Region 5

Zone 10 is a rectangular area occupying 88 m^2 (948 ft^2). The area has a gravel-lined floor approximately 61 cm (2 ft) below existing grade with a surrounding concrete wall to grade level. Assorted debris items are located within this zone.

Near-surface sample 775 was taken in this zone to 15 cm (0.5 ft). The sample was analyzed for uranium-238, radium-226, and radium-228. Only uranium-238 concentrations were found to be above the reference-level. A relatively high uranium-238 concentration (461 pCi/g) was detected here. Surveys performed by the PMC indicated above background concentrations of gamma-emitting radionuclides within the debris which could be the source of the high uranium-238 concentrations. The estimated depth of above reference-level radionuclide concentrations is 15 cm (0.5 ft) based on near-surface sample site 775 results. The boundaries of this area are placed along the concrete wall that surrounds the zone. This area is estimated to contain 13 m^3 (17 yd^3) of soil with above reference-level radionuclide concentrations.

Zone 11, Region 5

Zone 11 is an approximately 233 m^2 (2,505 ft^2) area east of Ash Pond containing two stainless steel process tanks which hold a total of approximately 45,420 liters (12,000 gallons) of tributyl phosphate. Samples from each of the tanks were taken and analyzed by PMC personnel. Uranium-238 concentrations of 670 and 866 pCi/g and radium-228 concentrations of 24.7 and 40 pCi/g were detected in these samples.

The existence of this zone is based on a known accidental spill from these tanks occurring during collection of the samples mentioned above. This spill involved less than 500 ml of liquid which affected the area immediately under the tanks. The actual boundaries and depth of this small zone can be easily identified during remedial action via the excavation control process.

5.2.2.6 Region 6 - Northeast Buildings Area. Region 6 lies in the northeast corner of the chemical plant and contains soils surrounding buildings 403, 404, 407, and 410. Buildings 403 and 404 were designed to perform pilot-scale natural uranium processing operations but also processed enriched and depleted uranium and natural thorium in the later stages of feed materials plant operations. Building 407 was used to assay incoming uranium ore and provide for plant process research. Building 410 housed the cafeteria, laundry facilities, locker rooms, showers, and office space for various plant departments.

Region 6 was characterized by 21 boreholes containing a total of 117 borehole soil samples, 7 near-surface sample sites containing a total of eight near-surface soil samples, 48 surface and 1-meter exposure rate measurements, 21 spectrometer measurements, and 32 FIDLER measurements. Analysis of these measurements identified six zones containing above reference-level radionuclide concentrations. These zones are shown on Plate 2.

<u>Zone 1, Region 6</u>

Zone 1 lies north of Buildings 403 and 405. Precipitation runoff from the northern section of the chemical plant flows across this zone toward the Frog Pond inlet. Near-surface sample site 709 was drilled in this zone to a depth of 30 cm (1 ft). The two samples taken from this location were analyzed for uranium-238, radium-226, and radium-228 and contained an above reference-level uranium-238 concentration of 44.7 pCi/g to 15 cm (0.5 ft) and a below reference-level concentration beyond. All radium-226 and radium-228 concentrations in this sample site were near background levels.

The shallow depth (15 cm or 0.5 ft) of above reference-level uranium-238 concentrations found in this zone could be due to airborne deposition of uranium-238 emissions from nearby process buildings and/or surface water sheet flow transferring uranium-238 concentrations from the northern section of the chemical plant. The depth of above reference-level radionuclide concentrations in Zone 1 is estimated at 15 cm (0.5 ft) based on near-surface sample 709 results. Zone 1 occupies approximately 1,922 m^2 (20,667 ft^2) and is bounded by roadways on the west, south, and east. The north boundary was drawn by splitting the linear difference between sample 709 and sample 713, which contains below reference-level concentrations of uranium-238, radium-226, and radium-228. The absence of elevated in situ measurements immediately outside Zone 1 provides further confidence in the choice of boundary placement. Zone 1 contains approximately 293 m^3 (383 yd^3) of soils with above reference-level radionuclide concentrations.

<u>Zone 2, Region 6</u>

Zone 2 occupies 6,133 m^2 (65,947 ft^2) and includes soils lying immediately east, south, and west of buildings 403 and 404. Soil sample analyses indicate uranium-238 to be the primary above reference-level contaminant with similar concentrations and depths found in most sample locations here. Radionuclide concentrations found in this zone were uranium-238 from 3.6 to 44.7 pCi/g, radium-226 from 1.2 to 1.4 pCi/g, and radium-228 from 1.5 to 1.7 pCi/g.

Four boreholes were drilled within Zone 2. Boreholes 215, 216, and 218 were drilled to a depth of 1.5 m (5 ft) each, and 219 to a depth of 2.7 m (9 ft). Associated soil samples analyzed for uranium-238 only indicated above reference-level concentrations to 30 cm (1 ft) in all four boreholes. Three near-surface sample sites, numbers 696, 697, and 707, were drilled in this zone to depths of 15 cm (0.5 ft) each. The soil samples from these sites were analyzed for uranium-238, radium-226, and radium-228, and results indicated above reference-level uranium-238 concentrations at sample sites 696 and 708 and an above mixture-rule concentration of uranium-238, radium-226, and radium-228 at sample site 697. The above mixture-rule concentration found at sample site 697 is due mainly to the 13.2 pCi/g uranium-238 concentration. The radium-226 and radium-228 concentrations found at these sample sites were near background levels, making uranium-238 the primary contaminant here. Three of the four 0-to-30-cm (0-to-1-ft) borehole samples and all of the near-surface samples contained uranium-238 concentrations in the range of 13.2 to 26.1 pCi/g. This narrow concentration range and similar depths of above reference-level concentrations could be indicative of similar contaminant deposition methods.

The estimated depth of above reference-level radionuclide concentrations in Zone 2 is 30 cm (1 ft) based on soil sample analyses from the four boreholes taken. The source of these concentrations could be airborne deposition and/or surface water sheet flow from the chemical plant, especially from the building 403/404 area. Zone 2 includes all soils surrounding the building 403/404 area, except those abutting the north and west walls of building 403 where above reference-level radium-228 concentrations were found. Soils along the north and west wall of building 403 are included in Zone 6. The absence of elevated in situ measurements outside this zone provides further confidence in the choice of boundary placement. Zone 2 contains approximately 934 m^3 (1,221 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 3, Region 6

Zone 3 occupies 833 m^2 (8,955 ft^2) and lies north of Zone 2 and directly northeast of building 405. Zone 3 lies in the path of natural drainage from the northeast section of the chemical plant to Frog Pond. Borehole 223 was drilled here to a depth of 3.1 m (10 ft). Soil samples from this borehole were analyzed for uranium-238 only, and the results indicated an above reference-level concentration of 26.1 pCi/g in the 30-to-61-cm (1-to-2-ft) sample. This concentration is in the range reported in the Zone 2 presentation, but it is unclear why the concentration was not found in the 0-to-30-cm (0-to-1-ft) sample as was the case in the Zone 2 boreholes. Sample analyses do indicate below reference-level uranium-238 concentrations at all other sample depths which implies above reference-level concentrations extending to 61 cm (2 ft) in Zone 3.

Zone 3 boundaries follow roadways and a concrete pad north of building 404. The absence of elevated in situ measurements outside this zone provide further confidence in the choice of boundary placement. Zone 3 is estimated to contain 507 m^3 (663 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 4, Region 6

Zone 4 occupies 13,055 m^2 (140,379 ft^2) and contains soils on the north, west, and south sides of building 410. Borehole 196 and near-surface sample site 679 were drilled in this zone to depths of 1.5 m (5 ft) and 15 cm (0.5 ft), respectively. The borehole samples were analyzed for uranium-238 while the near-surface sample was analyzed for uranium-238, radium-226, and radium-228. An above reference-level uranium-238 concentration was estimated to 15 cm (0.5 ft) in borehole 196 by assuming all uranium-238 activity resided in the upper 15 cm (0.5 ft) of the 0-to-30-cm (0-to-1-ft) sample. All samples beyond 30 cm (1 ft) indicated below reference-level uranium-238 concentrations. Near-surface sample site 679 contained a 54.9 pCi/g uranium-238 concentration with near background radium-226 and -228 concentrations.

The depth of above reference-level radionuclide concentrations in Zone 4 is estimated to be 15 cm (0.5 ft) based on borehole 196 results. Airborne deposition is the probable method of contaminant deposition here due to the proximity of Zone 4 to the process buildings. The boundaries of Zone 4 include all soils surrounding the north, west, and south sides of building 410 since airborne deposition could have produced above reference-level uranium-238 concentrations in the entire area. Zone 4 is estimated to contain 1,989 m^3 (2,600 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 5, Region 6

Zone 5 occupies 2,275 m^2 (24,466 ft^2) west of building 407. Borehole 208 was drilled here to a depth of 1.5 m (5 ft), and associated soil samples were analyzed for uranium-238. An above reference-level concentration was estimated to 15 cm (0.5 ft) by assuming that all uranium-238 activity resided in the upper 15 cm (0.5 ft) of the 0-to-30-cm (0-to-1-ft) sample. All samples beyond 15 cm (0.5 ft) indicated below reference-level uranium-238 concentrations.

The estimated depth of above reference-level radionuclide concentrations in Zone 5 is 15 cm (0.5 ft) based on borehole 208 results, and the probable contaminant deposition method is airborne deposition due to the proximity of the process buildings to this zone. Boundaries of Zone 5 include surrounding borehole 209 which contains no above reference-level uranium-238 concentrations. Zone 5 is estimated to contain 347 m^3 (453 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 6, Region 6

Zone 6 occupies 544 m^2 (5,851 ft^2) and includes soils along the western edge and on the north side of building 403. Near-surface sample site 706 was drilled to 15 cm (0.5 ft) in this zone and the associated soil samples were analyzed for uranium-238, radium-226, and radium-228. An above reference-level radium-228 concentration was found, along with below reference-level concentrations of uranium-238 and radium-226. The 6.5-pCi/g radium-228 concentration found here may be due to thorium-232 processing which occurred in this building.

The estimated depth of above reference-level radionuclide concentrations is 15 cm (0.5 ft) based on the soil sample results. The boundaries of Zone 6 include all soils areas on the west and north edges of building 403. This zone is estimated to contain 83 m^3 (108 yd^3) of soils with above reference-level radionuclide concentrations.

5.2.2.7 Region 7 - Administration Area. Region 7 lies in the extreme eastern section of the chemical plant. This region is east of building 408 and 410 and extends to the DOE property fence. Two parking lots, the plant access road, and two open plots of grassland are located here.

Region 7 was characterized by six boreholes containing a total of 23 soil samples, four near-surface sample sites each containing one 0-to-15-cm (0-to-0.5-ft) sample, 32 surface and 1-meter exposure rate measurements, and 32 FIDLER measurements.

Boreholes 227, 229, and 432 were drilled to 61 cm (2 ft). Borehole 226 was drilled to 1.5 m (5 ft), and boreholes 228 and 427 were drilled to 1.8 m (6 ft). All borehole soil samples were analyzed for uranium-238, and all near-surface soil samples were analyzed for uranium-238, radium-226, and radium-228. All Region 7 borehole soil samples exhibited near background uranium-238 concentrations. All near-surface samples contained radium-226 and radium-228 concentrations near background levels, and sample sites 672 and 710 also contained near background uranium-238 concentrations. The uranium-238 concentrations found in sample sites 671 and 685 were above background levels but below the uranium-238 reference-level concentration (15 pCi/g).

All surface and 1-meter exposure rate measurements taken in Region 7 were near the background level of 11 μR/h. No readings above 13 μR/h were found here which, along with the near-surface sample results, confirms the improbability of above reference-level concentrations of radium-226 and radium-228.

Soil sample analyses and in situ measurements did not detect above reference-level radionuclide concentrations and none were expected since there is no historical evidence of radioactive material storage or burial here. Based on these results, Region 7 does not contain zones of above reference-level radionuclide concentrations.

5.2.2.8 Region 8 - West Raffinate Pits Area. Region 8 is located in the southwest section of the site and contains raffinate pits 3 and 4 and an open area to the south. Aerial photographs taken in the mid-1970s show equipment and debris stored on the surface of Zones 2, 3, and 4 of the region. This equipment was removed from buildings 101, 103, and 105 by the DA during chemical plant decontamination operations. The equipment was removed some time after the photograph was taken and probably deposited in raffinate pit 4, where large quantities of equipment are currently visible. Zones 2, 3, and 4 are presently free of equipment on the surface.

This region was characterized by 36 boreholes containing a total of 92 soil samples, 37 near-surface sample sites containing a total of 107 near surface soil samples, and 105 surface and 1-meter exposure rate measurements. Extensive walkover scans also were performed by the PMC in some areas where above reference-level radionuclide concentrations were found. Analysis of these measurements identified four zones of above reference-level radionuclide concentrations as shown on Plate 2.

Zone 1, Region 8

Zone 1 occupies 1,523 m^2 (16,380 ft^2) in the southeast section of Region 8. Sample site 635 was drilled to 15 cm (0.5 ft), and its associated soil sample was analyzed for uranium-238, radium-226, and radium-228. Soil sample analyses indicated an above reference-level uranium-238 concentration of 266 pCi/g, along with near background radium-226 and -228 concentrations. The proximity of a site roadway to this sample location suggests the possibility of an inadvertent spill from a vehicle carrying uranium-contaminated material.

The depth of above reference-level radionuclide concentrations in Zone 1 is estimated at 15 cm (0.5 ft) based on the near-surface sample results. Boundaries of this zone were determined based on a walkover scan of the area performed by the PMC. This scan identified the areal extent of above background concentrations of gamma-emitting radionuclides. Zone 1 is estimated to contain 232 m^3 (303 yd^3) of soils containing above reference-level radionuclide concentrations.

Zone 2, Region 8

Zone 2 occupies 1,532 m^2 (16,475 ft^2) in the southwest portion of Region 8. Aerial photographs taken in the mid-1970s show equipment and debris in this zone and also in Zones 3 and 4. This equipment and debris came from buildings 101, 103, and 105 and were placed in this area by the DA during chemical plant decontamination activities. Radionuclide concentration ranges found in Zone 2 were uranium-238 from 3.7 to 2,259.3 pCi/g, radium-226 from 0.4 to 2.0 pCi/g, and radium-228 from 0.4 to 2.0 pCi/g.

One borehole, number 377, and four near-surface sample sites, numbers 617, 623, 625, and 624, are located in Zone 2. All soil samples taken from these locations were analyzed for uranium-238, radium-226, and radium-228, except for samples from borehole 377 which were analyzed for thorium-230 only. Sample location 617 was drilled to 76 cm (2.5 ft) and contained a relatively high uranium-238 concentration of 226.0 pCi/g in the 0-to-15-cm (0-to-0.5-ft) sample, followed by a decreasing uranium-238 concentration gradient to maximum depth with an above reference-level concentration extending to 46 cm (1.5 ft). All radium-226 and radium-228 concentrations were near background levels. The high surface concentration and decreasing gradient are probably due to surface deposition from uranium-contaminated equipment previously stored at ground level. Sample location 623 was drilled to 1.2 m (4 ft) and contained an erratic uranium-238 concentration gradient with a high (2,259.3 pCi/g) 0-to-15-cm (0-to-0.5-ft) concentration which decreased to 76 cm (2.5 ft), followed by an increasing concentration with depth. The high surface concentration is probably due to surface storage of contaminated equipment. The erratic concentration gradient with depth may be due to burial of radioactive material, though there is no burial history in this area. Radium-226 and -228 concentrations were near background levels in all samples, as was the case for all samples in this zone that were analyzed for radium isotopes.

Near-surface sample sites 624 and 625 contained above reference-level uranium-238 concentrations to depths of 15 cm (0.5 ft) and 30 cm (1 ft), respectively. Both locations contained near reference-level concentrations to these depths, probably due to uranium-238 transport via surface water flow from nearby areas of high near-surface level uranium-238 concentrations. Borehole 377 was drilled to 1.5 m (5 ft) and all associated soil samples indicated background concentrations of thorium-230 which, along with the radium data, provide further evidence of uranium being the only radiological contaminant here. Based on the above reference-level depth of 1.2 m (4 ft) in borehole 623 and the above reference-level depths found at locations 617, 624, and 625, contamination in Zone 2 is estimated to average 61 cm (2 ft) in depth. Boundaries of Zone 2 include all nearby elevated in situ measurements. Zone 2 is estimated to contain 933 m^3 (1,220 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 3, Region 8

Zone 3 occupies 2,697 m^2 (29,000 ft^2) in the southwest section of Region 8 where material and debris were previously stored on the surface. Four near-surface sample sites, numbers 611, 612, 613, and 615, and two boreholes, numbers 373 and 616, were drilled in this zone. Soil samples from locations 611, 612, 613, 615, and 616 were all analyzed for uranium-238, radium-226, and radium-228, while samples from location 373 were analyzed for thorium-230. Radionuclide concentration ranges found in Zone 3 were uranium-238 from less than 2.4 to 171.2 pCi/g, radium-226 from less than 0.4 to 5.8 pCi/g, radium-228 from 0.8 to 5.1 pCi/g, and thorium-230 from 1.1 to 2.1 pCi/g.

Sample sites 612 and 613 were drilled to 61 cm (2 ft) and 15 cm (0.5 ft), respectively, and contained relatively high uranium-238 concentrations of 103.2 and 149.7 pCi/g, respectively, in the 0-to-15-cm (0-to-0.5-ft) samples. Sample site 612 contained above reference-level uranium-238 concentrations to 30 cm (1 ft) and a decreasing uranium-238 concentration gradient from the surface to 61 cm (2 ft) deep. The relatively high surface concentrations in both locations and the decreasing concentration gradient at sample site 612 could be due to surface spills containing high uranium concentrations arising from previous storage of equipment and debris on the surface. All radium-226 and radium-228 concentrations were near background levels in these locations, further suggesting that the main radiological contaminant here is uranium.

Near-surface sample sites 611 and 615 and borehole 616 were drilled to 15 cm (0.5 ft), 30 cm (1 ft), and 1.5 m (5 ft), respectively, and contained similar surface uranium-238 concentrations ranging from 11.2 to 43.6 pCi/g. Sample site 615 and borehole 616 contained above reference-level uranium-238 concentrations to 15 cm (0.5 ft) and 30 cm (1 ft), respectively, with below reference-level uranium-238 concentrations in all other samples. All samples in these three locations contained near background radium-226 and -228 concentrations. The uranium-238 concentrations found at these locations could have been due to spills containing low uranium concentrations or surface water flow from areas of higher surface uranium concentrations. Borehole 373 contained near background thorium-230 concentrations in all samples which, along with the near background radium concentrations observed in all other soil samples, indicates uranium to be the primary contaminant in Zone 3.

The depth of above reference-level radionuclide concentrations in Zone 3 is estimated to 30 cm (1 ft) based on an average of the depths found in near-surface sites 612, 615, and 616. Zone 3 boundaries were based on a walkover scan performed by the PMC which identified the areal extent of above background concentrations of gamma-emitting radionuclides. Zone 3 is estimated to contain approximately 822 m^3 (1,075 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 4, Region 8

Zone 4 occupies 2,962 m^2 (31,847 ft^2) and lies immediately south of Zone 3. The mid-1970s aerial photographs show equipment and debris stored on the surface of this zone at that time. Boreholes 370 and 371 and near-surface sample sites 600, 601, 603, 605, 606, and 607 are located in Zone 4. Soil samples from boreholes 370 and 371 were analyzed for thorium-230 and all other samples were analyzed for uranium-238, radium-226, and radium-228. Radionuclide concentration ranges found in Zone 4 were uranium-238 from 2.4 to 231.7 pCi/g, radium-226 from 0.7 to 3.8 pCi/g, radium-228 from 0.5 to 2.6 pCi/g, and thorium-230 from 0.8 to 2.4 pCi/g.

Sample locations 601 and 607 were both drilled to 1.5 m (5 ft). Location 601 contained an above reference-level uranium-238 concentration in the 0-to-15-cm (0-to-0.5-ft) sample and below reference-level uranium-238 concentrations beyond. Location 607 contained an above mixture-rule concentration in the 0-to-15-cm (0-to-0.5-ft) sample due mainly to uranium-238 since all radium-226 and -228 concentrations found in these borehole samples were near background levels. Erratic uranium-238 concentration gradients, which could be indicative of radioactive material burial, were not found in these boreholes.

Boreholes 370 and 371 were also drilled to 1.5 m (5 ft), and all associated soil samples from these boreholes contained near background thorium-230 concentrations. The presence of near background radium-226, radium-228, and thorium-230 concentrations in the borehole soil samples analyzed for these nuclides, along with the observed uranium-238 concentrations, indicates uranium to be the primary contaminant.

Near-surface sample sites 600, 603, 605 and 606 were drilled to 15 cm (0.5 ft), and all samples were analyzed for uranium-238, radium-226, and radium-228. Sample sites 600, 603 and 605 contained uranium-238 concentrations in the narrow range of 11.0 to 17.9 pCi/g, while sample site 605 contained a high uranium-238 concentration of 199.7 pCi/g. Sample site 606 may be near concentrated uranium deposition resulting from equipment previously stored on the surface, while sites 600, 603, and 605 may be near spills of lower uranium concentrations or where surface water flow transfers uranium from areas such as site 606. All near-surface soil samples contained near background radium-226 and -228 concentrations, again indicating uranium to be the primary contaminant.

The depth of above reference-level radionuclide concentrations in Zone 4 is estimated at 15 cm (0.5 ft), based on sample results from boreholes 601 and 607. The boundaries of this zone were based on a walkover scan performed by the PMC which identified the areal extent of above background concentrations of gamma-emitting radionuclides. Zone 5 is estimated to contain 451 m^3 (590 yd^3) of soils with above reference-level radionuclide concentrations.

5.2.2.9 Region 9 - East Raffinate Pits Area. Region 9 is a rectangular-shaped area located directly east of raffinate pit 3. This region was characterized by 52 boreholes containing a total of 246 borehole soil samples, 10 near-surface sample sites containing a total of 14 soil samples, 55 surface and 1-meter exposure rate measurements, eight spectrometer measurements, and eight FIDLER measurements. Results of soil sample analyses, exposure rate measurements, and spectrometer measurements identified two zones containing soils with above reference-level radionuclide concentrations. The region and zone boundaries, as well as most sample locations, are shown on Plate 2.

Zone 1, Region 9

Zone 1 occupies 25,794 m^2 (277,350 ft^2) and contains most of the soils area within Region 9. Radionuclide concentration ranges found in samples from Zone 1 are uranium-238 from less than 0.3 to 17.2 pCi/g, radium-226 from 0.4 to 7.5 pCi/g, radium-228 from 0.6 to 8.9 pCi/g, and thorium-230 from 0.8 to 8.9 pCi/g. Thirty-three boreholes were drilled within the zone to depths ranging from 61 cm (2 ft) to 6.1 m (20 ft). Soil samples from 28 of the 33 boreholes were analyzed for thorium-230. Samples from seven of the boreholes were analyzed for uranium-238, and samples from borehole 503 were analyzed for radium-226 and radium-228, in addition to uranium-238. Nineteen boreholes contained above reference-level thorium-230 concentrations to 15 cm (0.5 ft); four other boreholes contained above reference-level uranium-238 concentrations to 15 cm (0.5 ft). Samples from borehole 503 indicated near background concentrations of radium-226 and -228.

Seven near-surface samples were taken within this zone to depths ranging from 15 cm (0.5 ft) to 3.1 m (10 ft). All soil samples from these locations were analyzed for uranium-238, radium-226, and radium-228. Near-surface location 664 contained above reference-level concentrations of radium-226 and -228 to the maximum sampling depth of 15 cm (0.5 ft). Near-surface location 665 contained above reference-level uranium-238 and radium-228 concentrations to the maximum sampling depth of 15 cm (0.5 ft). The five remaining near-surface sample locations did not contain any above reference-level radionuclide concentrations.

A possible mode of contaminant transport in Zone 1 is airborne deposition of raffinate particulates originating from the pits during dry periods. Raffinate pits 1 and 2 have, at times, been void of surface water. This would allow for surrounding soils to become contaminated via windblown raffinate sludge. This mode of contaminant transport is consistent with the finding of low radionuclide concentrations confined to the surface soil.

The average depth of above reference-level radionuclide concentrations in Zone 1 is 15 cm (0.5 ft), based on results from the 23 boreholes and two near-surface locations containing above reference-level concentrations. Boundaries of Zone 1 were drawn to include the natural drainage between raffinate pits 1, 2, and 3 since runoff could have dispersed above reference-level radionuclide concentrations throughout soils in the drainage. Zone 1 is estimated to contain 3,929 m^3 (5,136 yd^3) of soils with above reference-level radionuclide concentrations.

Zone 2, Region 9

Zone 2 is an 1,724 m^2 (18,539 ft^2) area adjacent to the northern berm of raffinate pit 1. The average depth of above reference-level radionuclide concentrations for Zone 2 is estimated to be 2.4 m (8 ft). This zone is estimated to contain 4,208 m^3 (5,500 yd^3) of soil with above reference-level radionuclide concentrations. This zone was characterized by sample locations 294, 295, 296, and 653. Location 653 actually represents subsequent analyses of samples collected at location 294. Radionuclide concentration ranges found in Zone 2 are uranium-238 from 0.7 to 2.3 pCi/g, radium-226 from 1.2 to 26.6 pCi/g, radium-228 from 1.2 to 2.2 pCi/g, and thorium-230 from 0.8 to 17.2 pCi/g. Above reference-level concentrations of uranium-238 were not found at location 294, the only location where uranium-238 analyses were performed. Above reference-level concentrations of thorium-230 were found at locations 294, 295, and 296 to depths of 30 cm (1.0 ft), 15 cm (0.5 ft), and 30 cm (1.0 ft), respectively. Additionally, location 653 exhibited above reference-level concentrations of radium-226 between 91 cm (3.0 ft) and 2.4 m (8.0 ft) along with near background uranium-238 and radium-228 concentrations. The radium-226 concentration returned to background levels below 2.4 m (8 ft).

The south boundary of this zone is defined by the northern berm of pit 1. The north boundary of Zone 2 is defined by locations 300 and 301. The east and west boundaries are primarily defined by topography.

The initial conclusion might be that location 653 indicates raffinate pit 1 to be leaking. However, this conclusion is not supported by samples at locations 294, 295, and 296. These three locations do not show elevated uranium-238 or thorium-230 at the same depth interval as the elevated radium-226 in borehole 653. Raffinate from pit 1 contains an average total uranium concentration of 840 pCi/g and an average thorium-230 concentration of 27,000 pCi/g. It would be expected that uranium-238 and thorium-230 would also be elevated if pit 1 were leaking. Further analyses will be performed on archived samples from location 295 and 296 to determine uranium-238, radium-226, and radium-228 concentrations at these locations.

5.2.2.10 Region 10 - South Buildings Area. Region 10 is located in the middle of the site and contains soil areas surrounding process buildings 201 and 301 and non-process buildings 408, 414 and 417, as well as soils surrounding four railroad track spurs west of building 301. There is no known history of burial activity in this region.

Region 10 was characterized by 30 boreholes containing a total of 148 soil samples, 11 near-surface sample sites containing a total of 11 soil samples, 69 surface and 1-meter exposure rate measurements, 39 spectrometer measurements, and 30 FIDLER measurements. Analysis of these measurements indicates 14 zones containing above reference-level radionuclide concentrations as shown on Plate 2.

Boreholes 165 and 177, indicated on Plate 2 as containing above reference-level radionuclide concentrations to 76 cm (2.5 ft) and 61 cm (2 ft), respectively, were drilled on a paved area. Soils underlying paved areas are not characterized, so these boreholes are not included in any of the zones.

Characterization was not performed in a small drainage southeast of building 417 which combines with the southeast drainage off site. Characterization of this small drainage is required to determine the nature and extent of radionuclide concentrations here.

Zone 1, Region 10

Zone 1 occupies 1,039 m^2 (11,175 ft^2) in the northwest section of Region 10. Borehole numbers 189 and 190 were drilled to a depth of 1.5 m (5 ft). Associated soil samples from both boreholes were analyzed for uranium-238 and above reference-level concentrations were found to depths of 46 cm (1.5 ft) and 15 cm (0.5 ft) in boreholes 189 and 190, respectively. The uranium-238 concentration magnitudes and relatively shallow above reference-level concentration depths found suggest airborne deposition as the probable method of contaminant deposition in this zone. The estimated depth of above reference-level concentrations is 30 cm (1 ft) based on the average of these results.

Exposure rate measurements were used to create the boundaries of this zone. An estimated 317 m^3 (414 yd^3) of soils with above reference-level uranium-238 concentrations are in Zone 1.

Zone 2, Region 10

Zone 2 lies directly west of building 201 and occupies 1,353 m^2 (14,552 ft^2). Building 202 is surrounded by this zone as well as a portion of the easternmost railroad spur.

Boreholes 182 and 186 were drilled in this zone, both to depths of 1.5 m (5 ft). Associated soil samples were analyzed for uranium-238, and above reference-level concentrations were found to 15 cm (0.5 ft) in both boreholes. The magnitude and shallow depth of near reference-level uranium-238 concentrations, along with the proximity of the process building, suggest airborne deposition as the probable method of contaminant deposition in this zone. The estimated depths of above reference-level uranium-238 concentrations is 15 cm (0.5 ft) based on borehole sampling results. Exposure rate measurements and physical features (the roadway and building 202) were used to create the boundaries of this zone. An estimated 207 m^3 (270 yd^3) of soils with above reference-level uranium-238 concentrations are in Zone 2.

Zone 3, Region 10

Zone 3 occupies 803 m^2 (8,636 ft^2) outside the northwest corner of building 408. Borehole 191 was drilled to 1.5 m (5 ft) and associated soil samples were analyzed for uranium-238. Soil sample results indicate an above but near reference-level concentration of 20.5 pCi/g in the 0-to-30-cm (0-to-1-ft) sample with near background concentrations beyond 30 cm (1 ft).

As is the case with Zones 4, 8, 12, and 13, which together contain all soils along the north and west sides of building 408, the uranium-238 concentration magnitudes found and the shallow depth of above reference-level concentrations along with the proximity of the process buildings suggests airborne deposition as the probable method of contaminant deposition here.

The depth of above reference-level concentrations in Zone 3 is estimated at 30 cm (1 ft) based on borehole 191 results. Boundaries of Zone 3 follow paved areas and the walls of building 408. An estimated 245 m^3 (320 yd^3) of soils with above reference-level concentrations are in Zone 3.

Zone 4, Region 10

Zone 4 occupies 2,356 m^2 (25,331 ft^2) between building 408 and the main access road. Near-surface sample site 668 was drilled to 15 cm (0.5 ft), and its associated soil sample was analyzed for uranium-238, radium-226, and radium-228. An above reference-level uranium-238 concentration of 33.8 pCi/g was found along with near background radium-226 and -228 concentrations. The uranium-238 concentration found here and the proximity of the process buildings suggest airborne deposition as the probable method of contaminant transport.

The estimated depth of above reference-level concentrations in Zone 4 is 15 cm (0.5 ft), based on the available data from sample site 668. The boundaries of Zone 4 follow paved areas and the north wall of building 408. An estimated 359 m^3 (469 yd^3) of soils with above reference-level uranium-238 concentrations are in Zone 4.

Zone 5, Region 10

Zone 5 occupies 1,192 m^2 (12,819 ft^2) in the western portion of Region 10 and lies immediately north of a magnesium chip storage area. Borehole 175 was drilled to 1.5 m (5 ft), and associated soil samples were analyzed for uranium-238. The analyses indicated an above reference-level concentration to 46 cm (1.5 ft) and below reference-level concentrations beyond this depth.

The depth of above reference-level concentrations is estimated at 46 cm (1.5 ft) based on borehole 175 results. Boundaries of this zone were drawn to follow the roadway and the railroad track spur on the west and east, respectively, and to exclude borehole 180 on the north which contained near background uranium-238 concentrations and borehole 169 to the south which contains above reference-level uranium-238 concentrations to 1.2 m (4 ft) and is included in Zone 6. An estimated 545 m^3 (712 yd^3) of soils with above reference-level radionuclide concentrations are in Zone 5.

Zone 6, Region 10

Zone 6 occupies 1,510 m^2 (16,233 ft^2) south of Zone 5 and includes the magnesium chip storage area. Borehole 169 was drilled in this zone and associated soil samples were analyzed for uranium-238. A near reference-level concentration of 12.2 pCi/g was found in the 30-to-61-cm (1-to-2-ft) sample, and an above reference-level concentration of 26.5 pCi/g was found in the 91-cm-to-1.2-m (3-to-4 ft) sample. Samples from all other depths contained below reference-level concentrations. The depth of above reference-level concentrations in Zone 6 is estimated at 1.2 m (4 ft) based on borehole 169 results. The boundaries of this zone were drawn to follow the roadway and railroad track spur and to exclude borehole 167 which contains below reference-level uranium-238 concentrations. An estimated 1,840 m^3 (2,405 yd^3) of soils with above reference-level concentrations are in Zone 6.

Zone 7, Region 10

Zone 7 occupies 529 m^2 (5,688 ft^2) near the northwest corner of building 301. No soil samples were taken in this area. Two elevated exposure rate measurements of 13 and 14 μR/h were taken here and are assumed to result from above reference-level radionuclide concentrations. The estimated depth of above reference-level concentrations is 15 cm (0.5 ft) to correspond to the depth estimated in Zone 10, which is also close to building 301. The boundaries were drawn to include all soils surrounding the northeast wall of building 301. An estimated 80 m^3 (105 yd^3) of soils are assumed to contain above reference-level concentrations within Zone 7.

Zone 8, Region 10

Zone 8 occupies 934 m^2 (10,042 ft^2) surrounding the southwest corner of building 408. Borehole 171 and near-surface site 662 were sampled in this zone. Borehole 171 was drilled to 1.5 m (5 ft), and associated soil samples were analyzed for uranium-238. An above reference-level concentration of 51.6 pCi/g was detected in the 0-to-30-cm (0-to-1-ft) sample, along with below reference-level concentrations beyond 30 cm (1 ft). Near-surface site 662 was drilled to 15 cm (0.5 ft), and its associated soil sample, analyzed for radium-226 and -228, contained near-background concentrations. Airborne deposition is the probable method of contaminant deposition here because of the uranium-238 concentration magnitudes, the shallow depth of above reference-level uranium-238 concentrations, and the proximity of the process buildings.

The depth of above reference-level uranium-238 concentrations in Zone 8 is estimated at 30 cm (1 ft) based on borehole 171 sampling results. The boundaries of this zone follow paved areas and the walls of building 408. An estimated 285 m^3 (372 yd^3) of soils with above reference-level concentrations are in Zone 8.

Zone 9, Region 10

Zone 9 occupies 1,524 m^2 (16,384 ft^2) southwest of building 301. Borehole 170 and near-surface sample site 655 were drilled in this zone to depths of 1.5 m (5 ft) and 15 cm (0.5 ft), respectively.

Soil samples from borehole 170 were analyzed for uranium-238, and above reference-level concentrations were found to 61 cm (2 ft) with near background concentrations beyond. Near-surface sample 655 was analyzed for uranium-238, radium-226, and radium-228, and above reference-level radium-226 and -228 concentrations were found along with a near reference-level uranium-238 concentration. The spectrometry measurement taken above sample location 170 indicated above background radium-226 and -228 concentrations, and an elevated exposure rate measurement of 23 μR/h was also detected.

The depth of above reference-level concentrations is estimated at 61 cm (2 ft) based on borehole 170 sampling results. The boundaries of this zone contain all soils between the railroad track spur and surrounding paved areas. An estimated 929 m^3 (1,214 yd^3) of soils with above reference-level concentrations are in Zone 9.

Zone 10, Region 10

Zone 10 occupies 2,144 m^2 (23,050 ft^2) and contains soils surrounding the southeast corner of building 301. Near-surface locations 657 and 660 were drilled to 15 cm (0.5 ft), and near-surface location 768 was drilled to 30 cm (1 ft) within the zone. All soil samples from these locations were analyzed for uranium-238, radium-226, and radium-228. Sample locations 657 and 660 both contained relatively high uranium-238 concentrations of slightly less than 100 pCi/g, which may be due to residue originating from surface storage of uranium metal here. Both sample sites also contained near background concentrations of radium-226 and -228. The soil sample taken from location 768 contained a uranium-238 concentration of approximately 2,000 pCi/g, one of the highest concentrations found in soils at the site, which again was probably caused by surface storage of uranium metal. Near background radium-226 concentrations were found at location 768. The 4.1 pCi/g radium-228 concentration found here may be due to thorium processing in building 301 during feed materials plant operation.

Borehole 430 was drilled to 6.1 m (20 ft) in Zone 10, but only the 0-to-30-cm (0-to-1-ft) sample and samples below 4.9 m (16 ft) were recovered during sample collection. The 0-to-30-cm (0-to-1-ft) sample was analyzed for uranium-238; the other recovered samples were analyzed for uranium-238 and thorium-230. Below reference-level uranium-238 and near background thorium-230 concentrations were detected in these samples.

The estimated depth of above reference-level concentrations here is 30 cm (1 ft), based on the near-surface sample site results. The boundaries follow paved areas and include all soils immediately southeast of building 301. An estimated 653 m^3 (854 yd^3) of soils with above reference-level concentrations are in Zone 10.

Zone 11, Region 10

Zone 11 occupies 5,223 m^2 (56,156 ft^2) south of building 417 and contains equipment used during uranium feed materials plant operation. Surveys performed by the PMC have identified above background concentrations of beta-gamma emitting radionuclides on some of this equipment. Borehole 163 and near-surface sites 661 and 658 were drilled in this zone. Borehole 163 was drilled to 1.5 m (5 ft), and associated soil samples were analyzed for uranium-238. An above reference-level concentration was found to 30 cm (1 ft) with near background concentrations beyond 30 cm (1 ft). Near-surface sites 661 and 658 were both drilled to 15 cm (0.5 ft), and the associated soil samples were analyzed for uranium-238, radium-226, and radium-228. Both of these locations contain above reference-level uranium-238 concentrations (65.2 pCi/g and 70.2 pCi/g in locations 658 and 661, respectively), along with near background radium-226 and -228 concentrations.

Surface deposition arising from contaminated equipment within the zone and/or airborne deposition from the nearby process buildings are the most likely methods of contaminant deposition here. The depth of above reference-level concentrations is estimated at 30 cm (1 ft) based on borehole 163 results. Boundaries of Zone 11 were drawn to follow all surrounding roadways and paved areas. An estimated 1,591 m^3 (2,080 yd^3) of soils with above reference-level concentrations are in Zone 11.

Zone 12, Region 10

Zone 12 occupies 456 m^2 (4,904 ft^2) on the west side of building 408. Near-surface site 663 was taken to 15 cm (0.5 ft) and the associated soil sample, analyzed for radium-226 and -228, contained near background concentrations. The exposure rate measurement taken above sample site 663 corresponded to 15 μR/h. This elevated reading could be due to the presence of above reference-level uranium-238 concentrations. The uranium-238 concentration at sample site 663 is unknown since the soil sample was not analyzed for this radionuclide. However, the proximity of the process buildings to this area suggests the possibility of airborne deposition, which is also suggested by soil sample analyses from Zone 8 immediately to the south. An exposure rate of 16 μR/h was found above borehole 171 in Zone 8, which is similar to that detected above sample site 663.

The depth of above reference-level concentrations in Zone 12 is estimated at 30 cm (1 ft) to correspond to the depth estimated in Zone 8, where samples were analyzed for uranium-238. The boundaries follow paved areas on the south and west, the wall of building 408, and exclude soils surrounding borehole 183 which contains near background uranium-238 and thorium-230 concentrations to 1.5 m (5 ft) and a near background exposure rate of 10 μR/h. An estimated 139 m^3 (182 yd^3) of soils with above reference-level concentrations are in Zone 12.

Zone 13, Region 10

Zone 13 occupies 288 m^2 (3,099 ft^2) on the northwest side of building 408. Near-surface site 666 was drilled to 15 cm (0.5 ft), and one soil sample, analyzed for radium-226 and -228, contained near background concentrations. Therefore, the depth of above reference-level concentrations shown on Plate 2 for sample site 666 is zero. However, an exposure rate measurement taken above sample site 666 indicated an elevated reading of 18 μR/h, which could be due to the presence of above reference-level uranium-238 concentrations. The similarities in location and exposure rate measurements found in Zones 8 and 12 were used to estimate a 30 cm (1 ft) depth of above reference-level concentrations in Zone 12. This depth corresponds to the 30 cm (1 ft) depth estimated in Zone 8 on the basis of uranium-238 soil sample analyses. The boundaries of this zone follow paved areas to the north, south, and west and the west wall of building 408. An estimated 88 m^3 (115 yd^3) of soils with above reference-level concentrations are in Zone 13.

Zone 14, Region 10

Zone 14 occupies 1,038 m^2 (11,162 ft^2) on the east side of building 408. This area was characterized by four near-surface soil samples (756, 758, 760, and 761), all drilled to a 15-cm (0.5-ft) depth. All samples were analyzed for uranium-238, radium-226, and radium-228. Sample 758 contained a high uranium-238 concentration (204 pCi/g), which is not characteristic of airborne deposition, along with an unusually high radium-226 concentration of 452 pCi/g and an above reference-level radium-228 concentration. Location 758 was drilled near a wash pad where plant equipment was washed before being repaired in building 408 (Meyer 1989). Loose contamination removed from plant equipment during washing may be the source of the above reference-level radionuclide concentrations found here. The other samples showed rather low above reference-level uranium-238 concentrations averaging 14 pCi/g, which may have been due to airborne deposition in this area. Sample locations 756 and 761 contained near background radium-226 and -228 concentrations. Sample location 760 contained a near background radium-226 concentration and an above reference-level radium-228 concentration of 6.8 pCi/g, which may be due to an inadvertent spill from a vehicle based on the proximity of location 760 to a site roadway.

This area is estimated to contain above reference-level radionuclide concentrations to a depth of approximately 15 cm (0.5 ft) based on these soil sample results. Boundaries were determined using exposure rate measurements and follow the fence line on the east side of building 408 and the fence line on the east. Sample locations 757 and 759, drilled to 15 cm (0.5 ft) along this fence, both contained below reference-level concentrations of uranium-238, radium-226, and radium-228. These results were used to justify the fence line as the eastern boundary of this zone. An estimated 158 m^3 (207 yd^3) of soils with above reference-level radionuclide concentrations are in Zone 14.

5.2.2.11 Region 11 - Southeast Area. Region 11 includes the southeast section of the chemical plant. This region contains non-process buildings 302, 432, 427, 434, 435, and 436. Buildings 434, 435, and 436 were used for storage space. Building 302 was used for magnesium storage. Building 432 housed the proof sampler associated with the process sewer system.

Region 11 was characterized by 12 boreholes from which 68 borehole soil samples were collected, 10 near-surface soil sample sites, 56 surface and 1-meter exposure rate measurements, 14 spectrometer measurements, and 15 FIDLER measurements. There are two zones in this area where the soil residue concentrations are above the reference level for uranium-238 and thorium-230.

Zone 1, Region 11

Zone 1 occupies 8,493 m^2 (91,321 ft^2) just east of the raffinate pits 1 and 2; three boreholes were drilled in this area. Borehole 388 and 390 were drilled in this area to a depth of 1.5 m (5 ft). Borehole 391 was drilled to a depth of 2.1 m (7 ft). Soil samples collected from borehole 388 were analyzed for uranium-238 only. Soil samples from boreholes 390 and 391 were also analyzed only for thorium-230. Near-surface sample site 652 was also collected in Zone 1 to a depth of 15 cm (0.5 ft) and analyzed for uranium-238, radium-226, and radium-228.

Near-surface sample site 652 results indicated a uranium-238 concentration of 18.5 pCi/g, which is slightly above the reference level, to a depth of 15 cm (0.5 ft). Radium-226 and -228 results were at background levels. Borehole 390 and 391 results indicated that thorium-230 concentration is above the reference level as deep as 15 cm (0.5 ft).

Borehole 388 was only analyzed for uranium-238 and the results indicated that uranium-238 concentrations were above the reference level to depths of approximately 15 cm (0.5 ft). Area photographs taken during the mid-1970s indicate that pits 1 and 2 had no standing water. Wind from a westerly direction could therefore have resuspended dry surficial waste in the raffinate pits and deposited it in Zone 1. On the basis of this information, this area was determined to have an above reference-level concentration mixture of thorium-230 and uranium-238 to a depth of 15 cm (0.5 ft) which is due to wind-blown deposition.

Discussion with a former Mallinckrodt employee who was a maintenance worker at the feed materials plant revealed that the central portion of Zone 1 was a drainage area and received bricks and other debris from building 103 which could possibly be contaminated (Meyer 1989). This area was probably then covered with soil and brought up to the surrounding grade. A site fill map indicates that a maximum of 3.1 m (10 ft) of material was added to this area in Zone 1.

No boreholes have been drilled in this area to determine if above reference-level radionuclides are present below the surface. This area will require further investigation to determine if radiologically contaminated material is buried in this area and, if so, the volume of soil affected.

Zone 2, Region 11

Zone 2 occupies 4,365 m^2 (46,938 ft^2) in the southwestern section of Region 11 in the areas surrounding buildings 435 and 436 (storage facilities). This zone contains equipment and debris that was removed from buildings 101, 103, and 105 (Meyer 1989). These materials are surficially radiologically contaminated and include drinking fountains, stainless steel piping, forklifts, steel tables, 55-gallon drums, wooden pallets, and gasoline engines.

Borehole 376 was drilled along the west side of building 436. This borehole was drilled to 2.4 m (8 ft), and the samples were analyzed for thorium-230 only. Results indicated near background concentrations in all samples. Borehole 622 was drilled to 1.5 m (5 ft) and was analyzed for uranium-238, radium-226, and radium-228. Results indicated an above reference-level uranium-238 concentration to 15 cm (0.5 ft) and near background radium-226 and -228 concentrations.

Surveys performed by the PMC have identified above background levels of beta-gamma emitting radionuclides on the equipment and debris stored in this area. Since this equipment originally came from process buildings 101, 103, and 105, loose contamination on the equipment surface could have been removed by precipitation and transported to the ground surface below. The shallow depth of above reference-level uranium-238 concentrations found in borehole 622 may be due to surface deposition occurring in this manner.

The depth of above reference-level concentrations is estimated at 15 cm (0.5 ft) based on borehole 622 results. The boundaries of Zone 2 include all equipment and debris stored outside of buildings 435 and 436. An estimated 665 m^3 (869 yd^3) of soils with above reference-level radionuclide concentrations are in Zone 2.

5.2.3 Vicinity Properties

This subsection summarizes the extent and levels of soil contamination resulting from previous AEC operations and continuing waste storage on properties surrounding the chemical plant and raffinate pits. For comparative purposes, contamination is defined as soils containing radionuclides in excess of the reference levels defined in Section 5.2.2. Several soil contamination surveys have been completed on these off-site properties which include the August A. Busch Wildlife Area, Weldon Spring Wildlife Area, Army Reserve Property (Weldon Spring Training Area), and several small tracts belonging to St. Charles County (Francis Howell High School and Annex, Highway Maintenance Department, and two water treatment plants - one active, the other no longer in service). For convenience, and to correspond to the formats used in the previous assessment reports, this section is divided into a discussion of vicinity properties including the DA properties and the Missouri Department of Conservation (MDOC) wildlife areas and remaining properties.

5.2.3.1 Department of the Army. A radiological survey of the DA property adjacent to the chemical plant was performed by the ORAU radiological site assessment program from March through July 1985. The survey identified seven areas of uranium-238, radium-226, and/or thorium-232 soil contamination which exceeded DOE guidelines established at that time. These seven locations are designated as DA 1, DA 2, etc., in this report and are shown in Figure 5.2-32. Between June and August 1987, DA locations 1, 2, 3, and 7 were resurveyed by the PMC to determine the appropriate remedial action effort necessary to clean up the individual locations. The remaining locations on the DA property were not resurveyed because they are affected by continued surface water discharge from the chemical plant. A brief discussion of each of the seven contaminated areas follows. The methods and procedures utilized in the ORAU and PMC surveys are summarized in Sections 3.2.3 and 3.3.2, respectively.

DA 1

DA 1 (Figure 5.2-33) is located on approximately 2.8 ha (7 ac) of wooded field surrounded by a barbed-wire fence. The contaminated area consists of a soil-covered mound and surrounding area, an approximately 1.2-m-wide (4-ft-wide) ditch adjacent to a railroad track east of the wooded field, and a drainage ditch which flows to the northwest toward a swamp located in the central part of the wooded field. Although the historical use of the property is not known, all of the contamination on the wooded field probably results from the mound of buried scrap metal, wood, slag, and other debris (MKF and JEG 1987j). The mound is raised approximately 46 cm (18 in) above surrounding grade and measures approximately 12.2 m (40 ft) in the north-south direction and approximately 21.4 m (70 ft) in the east-west direction. Contamination detected along the railroad tracks may have been caused by yellowcake spills or washing of rail cars carrying feed materials to the chemical plant (MKF and JEG 1987j).

During the ORAU survey (ORAU 1986a), gamma radiation exposure rate measurements were taken at the surface and at 1 m (3.28 ft) above the surface. Beta-gamma dose measurements at the surface and soil, water, and sediment samples were also collected.

At grid intersections, gamma exposure rates measured 1 m (3.28 ft) above ground in the area of the mound ranged from 7 to 52 μR/h. Surface contact gamma exposure rates and beta-gamma dose rates ranged from 6 to 56 μR/h, and 6 to 1,280 μrad/h, respectively. In the outlying areas surrounding the mound, gamma exposure rates 1 meter above the surface and at surface contact ranged from 4 to 9 μR/h and 4 to 11 μR/h, respectively. Beta-gamma dose rates at the surface ranged from 4 to 44 μrad/h in the outlying areas surrounding the mound.

In the areas of elevated surface radiation identified by the walkover survey, contact gamma exposure rates and beta-gamma dose rates ranged from 15 to 660 μR/h and 610 to 60,460 μrad/h, respectively.

Surface soil samples collected by ORAU obtained from a 10-m (32.8-ft) grid area associated with the mound contained radium-226 concentrations ranging from 0.42 to 18.1 pCi/g. The concentration of uranium-238 ranged from 0.60 to 1,100 pCi/g, and thorium-232 concentrations ranged from 0.13 to 4.82 pCi/g. Radionuclide concentrations from surface soil samples collected from 20-m (65.6 ft) and 40-m (131.2-ft) grid sections in outlying areas from the mound were within the range encountered in background soil samples collected by ORAU for radium-226 and thorium-232. The uranium concentrations were generally slightly above background levels and ranged from less than 0.5 to 7.3 pCi/g.

Radionuclide concentrations in borehole samples collected by ORAU in areas identified by the walkover scan of the mound area as having elevated gamma radiation levels indicated uranium-238 concentrations ranging from 2.76 to 29,530 pCi/g. Radium-226 concentrations ranged between 0.70 and 40.1 pCi/g. Concentrations of thorium-232 ranged from less than 0.46 to 450 pCi/g. Uranium-238 contamination was noted to at least 91 cm (3 ft) below the soil surface at four locations.

Sediment samples obtained by ORAU in the drainage ditch revealed radionuclide concentrations ranging from 1.09 to 781 pCi/g for uranium-238, 0.6 to 1.27 pCi/g for radium-226, and 0.48 to 11.40 pCi/g for thorium-232.

PMC personnel surveyed DA 1 in June 1987 (MKF and JEG 1987j). During the survey, 73 beta activity measurements, 206 in situ gamma activity measurements, and 142 soil samples at 75 locations were collected. Soil samples were analyzed for uranium-238, radium-226, and radium-228.

Two attempts were made by the PMC to drill through the mound of debris, but large pieces of scrap halted the drilling at each location. A third sample point was located on the northern edge of the mound at surrounding grade elevation and revealed contamination to 76 cm (2.5 ft). Since the mound is raised approximately 46 cm (1.5 ft) above the surrounding grade and since the depth of contamination at the northern edge of the mound is 76 cm (2.5 ft), the depth of contamination under the entire 260 m^2 (2,800 ft^2) mound is estimated to be 122 cm (4 ft). This yields a volume estimate of 317 m^3 (415 yd^3) of contaminated material under the mound surface. The estimated average uranium-238 concentration from this area is 676 pCi/g ± 257 at one Standard Error of the Mean (SEM) based on the average of nine samples. The highest concentration of radium-226 from this area is 3.5 pCi/g. Radium-228 concentrations are at background levels.

Three locations were sampled by the PMC in an area to the north and west of the mound perimeter as shown on Figure 5.2-33. The depths of contamination at these locations were determined to be 76 cm (2.5 ft), 1.1 m (3.5 ft), and 46 cm (1.5 ft). The average of these depths is approximately 76 cm (2.5 ft). Using this 76 cm (2.5 ft) contamination depth, the total volume of contaminated material in this 442-m^2 (4,755-ft^2) perimeter area is 337 m^3 (440 yd^3), based on the PMC data. The estimated average uranium-238 concentration is 75 pCi/g ± 20 at one SEM, based on the average of 11 samples. Radium-226 and -228 concentrations are at background levels.

An exterior zone of contaminated material is identified on Figure 5.2-33. Six of the 17 PMC sampling locations had contamination depths of 15 cm (0.5 ft), one location had a depth of contamination of 46 cm (1.5 ft), and 10 locations had surface uranium-238 concentrations less than 15 pCi/g. The locations where no contamination above 15 pCi/g was found were randomly interspersed throughout the exterior zone. A volume estimate of 138 m^3 (180 yd^3) for this 901 m^2 (9,703 ft^2) outer zone of contamination is based on a contamination depth of 15 cm (0.5 ft). The estimated average uranium-238 concentration of this material is 22 pCi/g ±7.2 at one SEM, based on 22 PMC samples. Radium-226 and radium-228 concentrations were equivalent to background levels.

The contamination east of the wooded field extends 91.5 m (300 ft) eastward along the railroad tracks. Six PMC sampling locations spaced 15.3 m (50 ft) apart in the east-west direction characterize this approximately 1.2-m-wide (4-ft-wide) ditch. The walkover survey indicated that the contamination is confined to the ditch. The depth of contamination ranges from 30 cm (1 ft) to 76 cm (2.5 ft).

A volume of 85 m^3 (111 yd^3) for this area is estimated based on excavating the entire 1.2-m-wide (4-ft-wide) by 91.5-m-long (300-ft-long) ditch to a depth of 76 cm (2.5 ft). The estimated average uranium-238 concentration is 38 pCi/g ± 6.7 at one SEM, based on 20 PMC samples. Radium-226 and radium-228 are at background levels.

The small drainage ditch flowing from the contaminated southeast corner of the wooded field ranges in width from approximately 61 cm (2 ft) to 4.6 m (15 ft) with an average width of approximately 1.5 m (5 ft) (Figure 5.2-33). Contamination levels are highest in the southern (upstream) reach of the ditch and are greatly reduced as the ditch fans out in its south to northwest traverse across the wooded field. By the time the ditch reaches 61 m (200 ft) from its origin, the flow gradient is so gentle that the ditch becomes imperceptible from the surrounding grade. At this point, the contamination in the ditch is at background levels.

Samples were taken by the PMC at two locations in the ditch. One location was uncontaminated and the other was contaminated to a depth of 30 cm (1 ft). Since about 61 m (200 ft) of the approximately 1.5-m-wide (5-ft-wide) ditch is contaminated, the volume of contamination is estimated to be 15 m^3 (19 yd^3), based on an average contamination depth of

15 cm (0.5 ft). No average uranium-238 concentration is estimated for this material due to the limited number of samples collected from the ditch.

On the basis of the results of PMC and ORAU measurements, it is estimated that the depth of contamination on the wooded field ranges from 15 cm (0.5 ft) to 1.2 m (4 ft). The deepest contamination is under the approximately 12.2 m (40 ft) by 21.4 m (70 ft) contaminated mound of buried debris. The shallower contamination is located to the north and west of the mound.

Table 5.2-5 summarizes the radiological contamination found in DA 1 during the PMC survey. The volumes of contaminated material are based on the reference level of 15 pCi/g uranium-238.

A comparison of the PMC and ORAU surveys shows generally good agreement between the defined areas of contamination. The only significant discrepancies are along the drainage ditch in the wooded field and along the railroad tracks. In both areas the PMC survey defined larger zones of contaminated material. The discrepancy is due to the fact that ORAU used a comparative guideline of 60 pCi/g for uranium, while the PMC used a comparative reference level of 15 pCi/g for uranium.

DA 2

DA 2 (Figure 5.2-34) is located adjacent to a railroad track in a grass field approximately 122 m (400 ft) north of the Weldon Spring Training Area entrance road and about 1,159 m (3,800 ft) from the entrance off of State Route 94. The area is rectangular in shape measuring approximately 21.4 m (70 ft) in the north-south direction by 79.3 m (260 ft) in the east-west direction. Debris, consisting mostly of small pieces of metal, was uncovered during the radiological surveys. This debris may be the source of the contamination detected at DA 2 (MKF and JEG 1987f).

During the ORAU survey, surface beta-gamma dose rate measurements, surface gamma exposure measurements, and surface and subsurface soil samples were collected and a walkover scan was performed. ORAU implemented a 9.2-m (30-ft) grid system when surveying DA 2.

Contact gamma exposure and beta-gamma dose rates at grid intersections ranged from 6 to 13 μR/h and 7 to 120 μrad/h, respectively. Gamma exposure rates at 91 cm (3 ft) ranged from 6 to 14 μR/h. In areas of elevated radioactivity identified by the walkover scan contact gamma exposure and beta-gamma dose rates ranged from 17 to 150 μR/h and 92 to 4,950 μrad/h, respectively. Gamma exposure rates at 91 cm (3 ft) ranged from 7 to 21 μR/h.

The concentrations of uranium-238 in surface soil samples ranged from less than 0.97 to 97.4 pCi/g. Thorium-232 concentrations in surface soil samples ranged from less than 0.49 to 1.91 pCi/g, while radium-226 concentrations ranged from 0.64 to 1.84 pCi/g.

Subsurface soil samples were also obtained in shallow boreholes during the ORAU survey at areas of elevated radioactivity identified by the walkover scan. Uranium-238 concentrations in shallow borehole soil samples ranged from less than 1.94 to 1,350 pCi/g. Concentrations of radium-226 and thorium-232 ranged from 0.99 to 38.8 pCi/g and less than 0.31 to 2.28 pCi/g, respectively.

Two small "hot spots" were also identified during the ORAU survey in an area 22.9 m (75 ft) west of where the main sample grid was located. These isolated spots were designated as Zone 5 by the PMC. Uranium-238 and radium-226 concentrations in soil samples collected by ORAU from the hot spots ranged from 10.1 to 390 pCi/g and 2.78 to 36.2 pCi/g, respectively. Thorium-232 concentrations were at background levels.

PMC personnel resurveyed DA 2 in July 1987 (MKF and JEG 1987f). The PMC survey obtained 25 soil samples at 17 locations and 160 in situ gamma radiation measurements. Soil samples were analyzed for uranium-238, radium-226, and radium-228. The PMC survey divided DA 2 into five separate zones of contamination based on similar contamination characteristics. A summary of the average radiological contamination and estimates of the volume of contaminated material in each of these zones is shown in Table 5.2-6.

In Zone 1 of DA 2, 12 surface gamma measurements and soil samples from two boreholes were obtained by PMC personnel. Subsurface soil sample data from the PMC and ORAU surveys indicate that the contamination is 30 cm (1 ft) deep. The estimated average uranium-238 concentration within this 30-cm (1-ft) layer is 20 pCi/g with an SEM of 1.9 pCi/g based on 12 measurements obtained by the PMC. Background levels of radium-226 and thorium-232 were present at the PMC sample locations. Two hot spots sampled by ORAU, however, revealed radium-226 concentrations of 38.8 pCi/g and 2.78 pCi/g and uranium-238 concentrations of 34.6 and 625 pCi/g, respectively, in this zone. Radium-228 concentrations are at background levels. The estimated volume of material for Zone 1 is 24 m^3 (31 yd^3).

In Zone 2 of DA 2 there are several isolated hot spots. Nineteen surface gamma measurements and soil samples from three boreholes were obtained by the PMC. Subsurface soil sample data from PMC and ORAU surveys indicate the contamination is 15 cm (0.5 ft) deep in this zone. The estimated average uranium-238 concentration within this surface layer is 18 pCi/g with an SEM of 2.7 pCi/g based on PMC measurements. One of the PMC sample locations indicated slightly elevated radium-226 and -228 results of 2.5 pCi/g and 2.2 pCi/g, respectively. All other sample locations indicated background levels of radium-226 and -228. The estimated volume of material is 20 m^3 (26 yd^3).

In Zone 3 of DA 2, 18 surface gamma measurements and soil samples from three boreholes were obtained by the PMC. Subsurface soil sample data from PMC and ORAU surveys indicate the contamination is 30 cm (1 ft) deep. Using the PMC data, the estimated average uranium-238 concentration within this 30-cm (1-ft) layer is 96 pCi/g with an SEM of 21 pCi/g, based on 18 measurements. Radium-226 and -228 concentration were slightly above background levels. The estimated volume of material is 38 m^3 (50 yd^3).

In Zone 4 of DA 2, the PMC collected 45 surface gamma measurements and soil samples from 7 boreholes. Subsurface soil sample data from the PMC and ORAU surveys indicate the contamination is 15 cm (0.5 ft) deep. The estimated average uranium-238 concentration within this surface layer is 26 pCi/g, with an SEM of 4.2 pCi/g, based on the 45 PMC measurements. Two surface samples collected by the PMC in Zone 4 have slightly above background radium-226 concentrations of 1.8 pCi/g and 1.9 pCi/g. All radium-228 concentrations are at background levels. The estimated volume of material is 54 m^3 (71 yd^3).

In Zone 5 of DA 2, the PMC did not collect soil samples but did perform gamma radiation walkover scans in order to delineate the surface area of contamination. ORAU soil sample data indicate the contamination is 46 cm (1.5 ft) deep. The estimated average uranium-238 and radium-226 concentration within this 46 cm (1.5 ft) layer is 76 and 18 pCi/g, respectively. The SEM for uranium-238 and radium-226 concentrations are 60 and 8.9 pCi/g, respectively. Thorium-232 concentrations are at background levels. The estimated volume of material is 4.6 m^3 (6 yd^3).

The ORAU and the PMC data are in good agreement for the easternmost zones (Zones 3 and 4); while in the westernmost zones (Zones 1 and 2), ORAU data shows more concentrated areas of contamination (i.e., hot spots). Zones 1 and 2 have many isolated hot spots of contamination, whereas Zones 3 and 4 consist of a single rather large area of contamination. The reasons for the discrepancies are that ORAU, in general, obtained data showing the need for further study of areas of elevated contamination; hence, maximum areas of radionuclide concentrations are sampled and represented in the data. The PMC, in general, obtained data for boundaries and extent of contamination; hence, average concentrations were obtained to determine the volume of material. Therefore, the discrepancy is a result of biased versus systematic sampling efforts.

DA 3

DA 3 (Figure 5.2-35) is a wooden loading dock located approximately 75 m (245 ft) to the south of the Weldon Spring Training Area entrance road and 1,380 m (4,525 ft) from the entrance off of State Route 94. The dock rises approximately 4.6 m (15 ft) above an abandoned railroad track.

During the ORAU survey, surface gamma measurements, mixed soil and debris, and subsurface soil samples were collected. Gamma exposure rates of 33 μR/h and 22 μR/h were measured beneath the loading dock and on the southeast corner on top of the dock, respectively. The concentration of uranium-238 in the mixed soil and debris sample collected at the southeast corner of the top of the loading dock was 1,042 pCi/g, and the radium-226 concentration was 4.46 pCi/g. One shallow borehole was dug by ORAU at the northeast corner lower level of the loading dock. Radium-226 concentrations ranged from 0.82 to 3.14 pCi/g. The uranium-238 concentration ranged from 2,640 pCi/g in the top 15 cm (0.5 ft) of soil to 477 pCi/g in the sample obtained from 46 cm (1.5 ft) to 61 cm (2 ft) below the soil surface. All thorium-232 concentrations were below the minimum detectable activity.

PMC personnel resurveyed this vicinity property and defined two contaminated areas (MKF and JEG 1987g). One area is on top of the dock at the southeast corner. This area covers about 6 m (20 ft) in the north-south direction and about 3 m (10 ft) east-west (see Figure 5.2-34). The contamination here generally consists of uranium-contaminated soil and leaves lying loose on the dock surface. Two samples were taken of the loose material in this area. Uranium-238 concentrations of 349.9 and 775.0 pCi/g were measured. Radium-226 concentrations of 2.1 and 3.4 pCi/g were measured, and radium-228 concentrations were at background levels. At six locations in the contaminated region of the dock surface, the loose material was scraped away and direct alpha measurements were made. The results of these measurements ranged from zero to 600 alpha disintegrations per minute per 100 square centimeters (dpm/100 cm^2), with an average of approximately 380 dpm/100 cm^2.

The second area of contamination defined in the PMC survey is beneath the dock at ground level on the east side of the dock. This area extends from the outer railroad rail, 2.4 m (8 ft) east of the outer edge of the dock to a line about 2.1 m (7 ft) under the dock. The north-south dimension of the contaminated region is 16.8 m (55 ft). The area of contamination was determined by noting where the gamma count rate (counts per minute) decreased to background levels.

Five soil samples were collected in the contaminated region by PMC personnel to depths of 30 cm (1 ft), 30 cm (1 ft), 61 cm (2 ft), 46 cm (1.5 ft), and 15 cm (0.5 ft). The respective uranium-238 concentrations at these depths were 34.8, 27.6, 9.2, 14.4, and 24.3 pCi/g. The radium-226 and radium-228 concentrations were at background levels. The depths of radiological contamination below the dock were found to be greater than 30 cm (1 ft) at five of the six PMC sample locations. On the basis of this soil data, an average contamination depth of 46 cm (1.5 ft) is estimated using a reference level uranium-238 concentration of 15 pCi/g.

The estimated volume of contaminated material is 35 m^3 (46 yd^3) based on the 46 cm (1.5 ft) depth of contamination for the entire 77 m^2 (825 ft^2) area. The average uranium-238 concentration of this material is estimated to be 62 pCi/g on the basis of the 12 PMC soil samples collected. Radium-226 and -228 concentrations are at background levels. The volume of contaminated dirt and leaves on the top of the dock is negligible.

DA 4

DA 4 is a short segment of the southeast drainage running from the Imhoff tanks within the Weldon Spring chemical plant to the Missouri River. Soil contamination in this area is described in Section 5.2.3.3, Southeast Drainage Area.

DA 5

DA 5 (Figure 5.2-36) is a surface drainage ditch leading westward from the raffinate pits across a part of the Weldon Spring Training Area to drainage ditch no. 4. The ORAU survey of this area included direct radiation measurements and sediment and surface water samples (ORAU 1986a).

Direct radiation levels measured at 100-m (328-ft) intervals along the drainage ditch showed gamma exposure rates from 6 to 18 μR/h at the surface and 6 to 13 μR/h measured about 1 m above the surface. Direct measurements were made from three areas of elevated surface readings identified in the walkover scan. The highest surface gamma exposure rate of 45 μR/h was measured approximately 201.3 m (660 ft) from the chemical plant perimeter fence.

Radionuclide concentrations were measured in sediment samples collected at 100-m (328-ft) intervals. Uranium-238 concentrations range from less than 1.05 to 6.00 pCi/g; radium-226 and thorium-232 concentrations are from 0.61 to 8.22 pCi/g, and 0.61 to 1.24 pCi/g, respectively.

Concentrations of radionuclides were measured in sediment from areas of elevated surface contamination identified by the walkover scan. Radium-226 concentrations range from 0.94 to 62.6 pCi/g. Uranium-238 and thorium-232 concentrations are at the levels normally encountered in background samples.

The results of the ORAU scans indicate radium-226 as the primary contaminant and that the contamination could extend the full length of the drainage from the raffinate pit fence line to the main ditch (no. 4), a distance of approximately 244 m (800 ft). By estimate using ORAU data, a cross section 3 m (10 ft) wide by 91 cm (3 ft) deep may be contaminated. This is approximately 680 m^3 (889 yd^3). An average radium-226 concentration was not estimated for this volume of material but should be below 30 pCi/g based on the ORAU data. Contamination limits are shown on Figure 5.2-36. Due to the biased sampling (hot spots) performed by ORAU this estimate is probably high. The PMC believes that several areas of the drainage, but not the entire length, may be contaminated to the above estimated boundaries.

The PMC did not survey the DA 5 drainageway because it is subject to further influence from the raffinate pits. This drainage will be more fully characterized by the PMC after major site remedial actions are completed.

DA 6

DA 6 (Figure 5.2-37) consists of about 201 m (660 ft) of a drainage ditch beginning at Ash Pond which crosses a portion of the Weldon Spring Training Area. During the ORAU survey, surface gamma measurements and subsurface soil samples were collected.

Direct radiation levels were measured at locations of elevated activity identified in the gamma walkover scan. The surface gamma exposure rates were approximately 14 μR/h measured at approximately 95 m (310 ft) and 160 m (525 ft) from the site fence line. The exposure rate did not change significantly after a 1-kg (2.2-lb) surface soil sample was removed. This indicates that contamination extends beyond 15 cm (0.5 ft) in depth at the sample locations.

The radionuclide concentrations were measured in two boreholes also at 95 m (310 ft) and 160 m (525 ft) from the site fence line. Uranium-238 concentrations range from less than 3.38 to 123 pCi/g. The contamination extends beyond the sampling depths of 61 cm (2 ft) and 30 cm (1 ft) in each borehole, respectively. Thorium-232 and radium-226 concentrations are within the range normally encountered in background samples.

From the results of the survey, ORAU indicated that the contamination could extend approximately 201 m (660 ft) from the chemical plant fence line and has a width of 3 m (10 ft). Based on the limited ORAU sample data, the contamination probably extends to an average of approximately 91 cm (3 ft) which would yield about 536 m^3 (700 yd^3) of contaminated material. This volume estimate is based on a concentration of 15 pCi/g uranium-238. The depth of contamination is estimated at the area of highest activity which would tend to give a greater average contamination depth.

The PMC did not survey this drainageway because it is subject to further influence from the chemical plant. This drainage will be more fully characterized by the PMC after the major site remedial actions are completed.

DA 7

DA 7 (Figure 5.2-38) was an isolated area located about 91 cm (3 ft) north of the Weldon Spring Training Area entrance road about 1,156 m (3,790 ft) from the entrance off of State Route 94. The area was rectangular, measuring roughly 2.1 m (7 ft) by 1.5 m (5 ft).

In January 1988, DA 7 was remediated by excavating a 3.3 m^2 (35 ft^2) area to a depth of about 30 cm (1 ft) (MKF and JEG 1988h). The excavated soil, about 1.1 m^3 (1.5 yd^3), was deposited in five 55-gallon drums which were placed in building 434 at the chemical plant for interim storage. The excavation was backfilled with soil from the Weldon Spring Training Area and graded to the original elevation. The area was then radiologically surveyed by the PMC and by ORAU. These surveys confirmed that the cleanup was effective.

5.2.3.2 Wildlife Areas and Remaining Properties. A radiological survey of the vicinity properties, exclusive of the Army Reserve property, was performed by ORAU from July through September 1985 (ORAU 1986b). The ORAU report identified 10 locations of contamination, all within either the Weldon Spring or August A. Busch Wildlife Areas (Figure 5.2-39). Six of these 10 locations were designated as requiring remediation by exceeding DOE residual contamination guidelines that were current at the time of the survey (Locations 1, 3, 4, 5, 7, and 9). According to the ORAU survey, Locations 2, 6, 8, and 10 did not exceed the DOE residual soil guidelines that were applicable at the time of the survey; however, ORAU suggested further investigation of Locations 6 and 8 to verify their compliance with DOE guidelines.

In February 1986, BNI conducted a remedial action at Location 1. A radiological survey has verified that the remedial action was satisfactorily completed (Nelson 1986).

ORAU survey results indicated that Locations 2 and 10 were cleaned up as a result of sampling efforts. PMC personnel resurveyed Location 10 in May 1989. The results indicated a small area of elevated gamma radiation. A surface soil sample collected in the area revealed that thorium-230 concentrations were above DOE residual soil guidelines.

PMC personnel resurveyed Location 6 in October 1987. The results indicated the area was larger than ORAU had indicated and that it exceeded the present DOE guidelines. The PMC decided that Location 6 should be resurveyed and remediated during the cleanup of the Weldon Spring quarry, since they are close together.

Locations 7 and 9 will be characterized and remediated at a later date because they are affected by surface and groundwater discharge from the Weldon Spring chemical plant and quarry, respectively. Location 7 is the main drainage area which extends from the southwest corner of the chemical plant to the Missouri River. This location will be discussed separately in Section 5.2.3.3, Southeast Drainage Area. Location 9 (Femme Osage Slough) is located approximately 152.5 m (500 ft) south-southeast of the quarry and is hydraulically connected to the quarry sump. Location 9 will not be reviewed as part of this remedial investigation report due to its association with the quarry.

In October 1987, Locations 3, 4, 5, and 8 were resurveyed for radiological contamination by PMC personnel. This second survey was performed in order to determine the appropriate remedial action effort necessary to clean up these four properties. The results of this second survey were reported in May 1988 (MKF and JEG 1988k). For the purpose of this report, the contaminated areas designated by ORAU in the wildlife areas managed by the Missouri Department of Conservation are referred to as DOC 1, DOC 2, etc. A brief discussion of the radiological contamination present in each of these areas follows. The estimated areas, depths, volumes, and average contaminant concentrations for these vicinity properties and those of the DA are summarized in Table 5.2-7.

DOC 1

DOC 1 was an area of radium-226 contamination on the west side of State Route 94 just north of the entrance to the Missouri Highway Department property (ORAU 1986b). This area was located on the outside of a sharp curve in the highway and was apparently contaminated as a result of an accident involving a truck hauling contaminated residues to the chemical plant (Berger 1986).

On February 24, 1986, BNI remediated this area. The contamination covered approximately 167 m^2 (1,800 ft^2). During remediation, the area was found to be contaminated to depths ranging from 15 cm (0.5 ft) to 76 cm (2.5 ft). The contaminated material was deposited in raffinate pit 4 on the chemical plant site. ORAU verified that the remedial action was effective in reducing contamination to within the DOE residual contamination guidelines (Berger 1986).

DOC 2

DOC 2 was a small piece of pipe on the surface located approximately 91 cm (3 ft) off State Route 94 to the east and about 3,498.4 m (11,470 ft) from U.S. Highway 40/61 (ORAU 1986b). Analysis identified the contaminant in the pipe as radium-226 with a concentration of approximately 82 pCi/g. Because removal of the pipe eliminated the source of elevated radioactivity, no further sampling or measurements were performed by ORAU at this location. The PMC has not conducted any further investigation at this location.

DOC 3

DOC 3 consists of two small isolated areas of contamination (Location 3A and 3B), south of Highway D at the 7,462.1 m (24,466 ft) reference marker (Figure 5.2-40). There are no obvious features which indicate the reason for this contamination. Contact exposure rate measurements and surface and subsurface soil samples were collected by ORAU. Gross gamma radiation measurements and surface and subsurface soil samples were collected by the PMC.

There is a discrepancy between the boundaries of the two contaminated spots reported by the two studies. The PMC found the larger area of contamination (3A) was closer to the road and that the smaller area was several feet to the south. ORAU reported the reverse of this.

It is suspected the contamination boundaries were mistakenly switched on a map provided in the ORAU report.

To delineate the horizontal boundary of contamination at Location 3A, the PMC measured gross gamma radiation levels on the surface of the ground in 30-cm (1-ft) increments from the approximate center of the contaminated area in four directions. Measurements continued until a background reading was obtained with the scintillation detector. The results indicate a contaminated area that is 2.7 m (9 ft) x 2.4 m (8 ft) in diameter in the north-south and east-west directions, respectively. Ground surface exposure rates as measured by ORAU ranged up to 54 μR/h.

Radionuclide concentrations in soil samples collected at Location 3A contained high levels of uranium-238. Surface soil samples collected by ORAU and by the PMC contained uranium-238 concentrations of 2,170 and 289 pCi/g, respectively. One ORAU surface sample indicated slightly elevated radium-226 and thorium-232 at 1.78 and 2.06 pCi/g, respectively. PMC results were at background concentration for radium-226 and -228. Subsurface soil samples collected by ORAU indicated contamination to a depth greater than 91 cm (3 ft) where sample collection ceased. The PMC collected soil samples to a depth of 46 cm (1.5 ft), where results indicated contamination to a depth of 30 cm (1 ft).

While there is a discrepancy between subsurface information obtained by the two studies, the recent data obtained by the PMC was used to estimate contaminated volumes. The quantity of contaminated material is estimated to be 2.3 m^3 (3 yd^3) with an average uranium-238 concentration of 161 pCi/g with an SEM of 128 pCi/g based on two PMC samples.

To define the horizontal boundary of contamination at Location 3B, the PMC measured gross gamma radiation levels on the surface of the ground using the same procedure as for Location 3A. The results indicate a contaminated area 2.1 m (7 ft) x 1.8 m (6 ft) in the north-south and east-west directions, respectively. Contact surface exposure rate measurements taken by ORAU ranged up to 70 μR/h.

Radionuclide concentrations in soil samples collected at Location 3B also contained high levels of uranium-238. Surface soil samples collected by ORAU and by the PMC contained uranium-238 concentrations of 3,020 and 1,004 pCi/g, respectively. Radium-226 and thorium-232 are at background levels. Subsurface soil samples collected by ORAU indicated contamination at a depth greater than 30 cm (1 ft), where sample collection ceased. The PMC collected soil samples to a depth of 1.1 m (3.5 ft), where subsurface gamma radiation measurements decreased or approached background levels. Analytical results from soil samples indicated concentrations of uranium-238 above the reference level in the sampling interval of 91 cm (3 ft) to 1.1 m (3.5 ft).

Although neither ORAU nor the PMC characterized the depth of contamination, this can be determined during remedial action. If the contamination is assumed to extend an additional 30 cm (1 ft) (1.4 m [4.5 ft] total), the quantity of contaminated material is estimated to be 5.4 m^3 (7 yd^3). The average uranium-238 concentration is 228 pCi/g with an SEM of 130 pCi/g, based on seven PMC samples.

DOC 4

DOC 4 is situated near an access road to the radio tower (Road C) and the DA property perimeter fence (Figure 5.2-41). The area contains several mounds of soil and miscellaneous wood, metal, and other debris. ORAU measured gamma exposure rates at the surface and at about 91 cm (3 ft). They also measured surface beta-gamma dose rates and collected surface and subsurface soil samples. The PMC measured gross gamma radiation levels and collected surface and subsurface soil samples.

Surface soil samples were collected from DOC 4 at 40-m (131-ft) grid line intersections and analyzed for radionuclide constituents during the ORAU survey. Radium-226 ranged from 0.51 to 1.23 pCi/g. Levels of uranium-238 ranged from less than 0.46 to 6.58 pCi/g. Background levels of thorium-232 were noted. These sampling mechanisms and a gamma walkover scan identified one general area of contamination (Location 4C) and two isolated hot spots (Locations 4A and 4B).

At Location 4A, the contamination is associated with a mound of white, powder-like material (possibly gypsum) covered with soil (MKF and JEG 1988k). The mound measures 6.4 m (21 ft) x 2.4 m (8 ft) north-south and east-west, respectively. Gamma exposure rates at the surface and at 91 cm (3 ft) above surface were 19 and 10 μR/h, respectively. The beta-gamma dose rate at the surface was 71 μrad/h. Radionuclide concentrations in soil samples collected at this location contained elevated levels of uranium-238 and radium-226. Subsurface soil samples collected to a depth of 30 cm (1 ft) by ORAU revealed radium-226 and uranium-238 results of 36.3 pCi/g and 29.2 pCi/g, respectively, which indicates that the contamination exists at depths greater than 30 cm (1 ft) where their sampling ceased. The PMC collected subsurface soil samples to a depth of 68 cm (2.25 ft) with analytical results indicating contamination to a depth of 46 cm (1.5 ft).

The PMC soil samples were composited and analyzed for thorium-230. The results indicated an average concentration of 15 pCi/g. The average radium-226 and thorium-230 concentrations indicate that the radionuclides were not chemically separated and are still in a near equilibrium state.

The quantity of contaminated material is estimated to be 6.9 m^3 (9 yd^3) with an average radium-226 and uranium-238 concentration of 23 and 15 pCi/g, respectively, and an SEM of 7 and 5 pCi/g, respectively, based on three PMC samples. Radium-228 concentrations are at background levels.

At Location 4B, the contamination is associated with a spill of black cylindrical material (possibly graphite) (MKF and JEG 1988k). The spill area measures 7.9 m (26 ft) x 1.5 m (5 ft) in the north-south and east-west directions, respectively. A surface soil sample was collected by the PMC. Analytical results indicated radionuclide concentrations in the soil at background concentrations. ORAU collected a surface soil sample which indicated radium-226, uranium-238, and thorium-232 results of 6.49, 6.08, and 1.34 pCi/g, respectively. Thus, the contamination seems to be confined to the spill material. The debris is confined to the surface (top 15 cm or 0.5 ft); therefore the estimated volume of material is 1.5 m^3 (2 yd^3).

At Location 4C, the contamination is associated with a gravel area adjacent to a secondary road. The area measures 20.1 m (66 ft) by 29.9 m (98 ft) in the north-south and east-west directions, respectively. Subsurface soil samples were collected at eight locations by ORAU and one location by the PMC. Radionuclide concentrations in soil samples collected at Location 4C contained elevated levels of uranium-238 and radium-226. Laboratory analysis of samples collected by ORAU indicated radium-226 levels from 0.53 to 430 pCi/g. Levels of uranium-238 ranged from less than 1.16 to 80.9 pCi/g. Concentrations of thorium-232 were in the range of background levels.

ORAU and PMC data indicate the depth of contamination at 30 cm (1 ft) for this location; the estimated volume of material is 184 m^3 (240 yd^3). Based on ORAU data, the average radium-226 and uranium-238 concentrations are 118 and less than 13 pCi/g, respectively. Analytical results of the PMC samples indicate an average thorium-230 concentration of 44.0 pCi/g.

DOC 5

DOC 5 is 471.2 m (1,545 ft) from the intersection of Highway D and State Route 94 (Figure 5.2-42) and is in a drainageway along an eroded gravel road. When the PMC resurveyed the location, an additional two barrels with elevated gamma radiation readings were discovered adjacent to the original one barrel found by ORAU. There are several pieces of scrap metal, debris, and deteriorated barrels along this roadway, but they are not radiologically contaminated.

Radionuclide concentrations in soil samples collected by ORAU adjacent to the drums indicate that levels of radium-226, uranium-238, and thorium-232 are generally in the range of background levels. ORAU collected sediment samples in the drainage at 9 and 615 meters (30 and 2,000 ft) below the drums and analyzed them for radium-226, uranium-238, and thorium-232. The results indicated that radionuclide concentrations were at background levels.

To remediate the location, the PMC excavated the drums in May 1988. A dike was built in the drainage to prevent the spreading of contamination. At that time, a fourth drum was discovered in DOC 5.

During the excavation, liquid leaked out of holes in the drums. The soil which came in contact with the liquid was excavated until readings slightly above background were obtained with a hand-held gamma scintillation probe. The material was removed and deposited in twenty 55-gallon drums, three of which were overpack drums. The drums were placed in building 434 at the chemical plant for controlled, interim storage.

Two of the drums were opened and sampled. The samples were analyzed for uranium-238, radium-226, radium-228, and thorium-230. The analytical results of both drums were similar to raffinate sludge with the predominant radionuclide being thorium-230 at concentrations of 13,900 and 52,900 pCi/g.

Immediately following the cleanup, the PMC collected samples in the excavated area. A composite of these samples revealed elevated concentrations of 214 pCi/g for thorium-230 and 5.6 pCi/g for radium-226. The following day, ORAU performed an independent verification survey of DOC 5. Soil samples were collected from the excavation and from the undisturbed area around the excavation. Soil samples from within the excavation contained thorium-230 concentrations ranging from 400 to 3,100 pCi/g. ORAU indicated that there was no evidence of elevated radionuclide concentrations on the surface surrounding the excavation.

In November 1988, the PMC resurveyed Location No. 5 to determine if thorium-230 contamination, which cannot be detected by in situ gamma measurements, had washed down the drainage. Soil samples were collected in the center of the drainage from 3.1 m (10 ft) upstream to 132.7 m (435 ft) downstream of the previously excavated area. Samples were collected with a hand-held auger sampling tool in 15-cm (0.5-ft) increments to a depth of 46 cm (1.5 ft) or until auger refusal. Samples were collected at 7.6 m(25 ft), 15.3 m (50 ft), 30.5 m (100 ft), 39.7 m (130 ft), 61 m (200 ft), 122 m (400 ft), and 132.7 m (435 ft) downstream from the original location. The samples were sent to a PMC subcontractor laboratory for thorium-230 analysis. The only results that were above reference-levels were surface samples (15 cm or 0.5 ft) at 30.5 m (100 ft) and 39.7 m (130 ft) downstream. The thorium-230 concentrations were 8.0 and 110 pCi/g, respectively. Based on the PMC data, the volume of contaminated material remaining is estimated to be approximately 0.8 m^3 (1 yd^3). Further characterization, however, is warranted.

DOC 6

DOC 6 is an isolated spot of contamination adjacent to the quarry perimeter fence as shown on Figure 5.2-43. This contamination probably resulted from a spill during disposal activities at the quarry.

ORAU obtained contact gamma exposure rate measurements and surface soil samples at this location. The PMC collected surface and subsurface soil samples and measured gross gamma radiation.

ORAU measured contact gamma exposure rates at one location with a result of 51 μR/h. Radionuclide concentrations in the single surface soil sample collected from this location contained radium-226, 8.35 pCi/g; uranium-238, 18.3 pCi/g; thorium-232, 25.7 pCi/g; and thorium-230, 350 pCi/g.

The PMC collected soil samples in 15 cm (0.5 ft) increments to a depth of 91 cm (3 ft) at one sample location. The results revealed thorium-230 as the primary contaminant with a maximum concentration of 294 pCi/g in the 0-to-15-cm (0-to-0.5-ft) sample. The remaining thorium-230 values for five subsurface samples were below the detection limits. Radium-226 concentration ranged from 1.6 to 7.9 pCi/g. Radium-228 concentrations ranged from 1.5 to 12.6 pCi/g. Uranium values were below the detection limits. In situ gross gamma radiation levels measured in the borehole indicated that the contamination extends to 76 cm (2.5 ft) in depth.

To delineate the horizontal boundary of contamination at this location, the PMC measured gross gamma radiation levels on the surface of the ground in 30-cm (1-ft) increments from the approximate center of the area in the north-south and east-west directions until background readings were detected. The measurements indicated a 91 cm (3 ft) by 91 cm (3 ft) area of contamination.

The quantity of contaminated material is estimated to be less than 0.8 m^3 (1 yd^3). Average radionuclide concentrations were not calculated for this small volume of material.

DOC 7

DOC 7 is the main southeast drainage area running from the Department of Conservation perimeter fence through the Weldon Spring Wildlife Area to the Missouri River (Figure 4.2-4). Contamination in this area is discussed in Section 5.2.3.3, Southeast Drainage Area.

DOC 8

DOC 8 contained three isolated spots (8A, 8B, 8C) of elevated levels of radioactivity near a railroad bridge spanning the Little Femme Osage Creek (Figure 5.2-44). Rail cars were reportedly washed in this area after leaving the quarry (ORAU 1986b). This area of contamination was located on DOE property and therefore is not technically a vicinity property but is part of the DOE site responsibility.

ORAU measured exposure rates on the surface and about 91 cm (3 ft) above the surface and performed soil sampling at each of the three locations of elevated radioactivity. Walkover gamma scans and sediment sampling were also performed by ORAU along the Little Femme Osage Creek. No locations of elevated activity were noted in the creek by the walkover scan. Levels of radionuclides in the sediment were not significantly different from background levels. The PMC sampled soils and measured gross gamma at two of the three spots of elevated activity. Soil samples were analyzed for uranium-238, radium-226, and thorium-232 during both the ORAU and PMC surveys.

At Location 8A gross gamma was measured by the PMC to delineate the horizontal extent of contamination. Measurements were taken in four directions at 30 cm (1 ft) increments from the center of the hot spot and continued until a background count rate was obtained. The area of contamination measured 61 cm (2 ft) by 91 cm (3 ft) in the east-west and north-south directions, respectively. Subsurface soil sampling by ORAU to a depth of 20 cm (8 in) did not go beneath the layer of contamination. The PMC collected subsurface soil samples to a depth of 46 cm (18 in), where auger refusal prevented sampling beneath the layer of contamination.

Surface and subsurface soil samples collected by both surveys indicated that radium-226 was the predominant contaminant. Average radium-226 and uranium-238 concentrations were 53 and 35 pCi/g respectively with an SEM of 34 and 14 pCi/g, respectively, based on three PMC samples.

At location 8B gross gamma radiation was measured by the PMC to delineate the horizontal extent of contamination as described above. The surface contamination measured 91 cm by 91 cm (3 ft by 3 ft).

Subsurface soil sampling by ORAU to a depth of 46 cm (1.5 ft) did not go beneath the layer of contamination. The PMC collected soil samples to a depth of 2 ft where auger refusal, due to railroad bed gravel, prevented sampling beneath the layer of contamination.

Surface and subsurface soil samples collected by ORAU and the PMC indicated that radium-226 was the predominant radionuclide at location 8B. The average radium-226 and uranium-238 concentrations were 78 and 41 pCi/g, respectively with an SEM of 69 and 53 pCi/g based on four PMC samples. Radium-228 concentrations were below the detection limits. A surface soil sample collection by the PMC was analyzed for thorium-230 and indicated a concentration of 4.5 pCi/g.

At Location 8C, the PMC measured gross gamma radiation to delineate the horizontal extent of contamination as described for Location 8A. The area of contamination measured 91 cm by 91 cm (3 ft by 3 ft) east-west and north-south directions, respectively.

The PMC did not collect soil samples at location 8C. Surface and subsurface soil samples collected by ORAU indicated elevated concentrations of radium-226 and uranium-238. Average radium-226 and uranium-238 concentrations were 52 and 4 pCi/g, respectively, with an SEM of 5 and 1 pCi/g, respectively, based on two ORAU samples. Thorium-232 concentrations were at background levels. Subsurface soil sampling by ORAU to a depth of 25 cm (0.83 ft) did not go beneath the layer of contamination.

DOC 8 was remediated on August 1, 1990, during quarry staging area construction activities. The final verification of remediation will be performed to a level consistent with unrestricted use in that area as part of the follow-on quarry cleanup after bulk waste removal.

DOC 9

DOC 9 is located between the abandoned Missouri-Kansas-Texas Railroad and the Femme Osage Slough, south of the Weldon Spring quarry. The slough is hydraulically connected to the quarry sump and is affected by subsurface migration. Because of this, the slough was not characterized by the PMC and is not reviewed as part of this report. The slough will be characterized and evaluated for remediation strategies after the quarry bulk waste has been excavated.

DOC 10

DOC 10 is an old DA disposal area located along Highway D adjacent to an access road leading to Busch Wildlife Area Lake 21. ORAU performed a walkover gamma scan and identified two small area of elevated radiation (ORAU 1986b). Surface soil samples collected in these spots had elevated radium-226 concentrations of 6.36 and 8.53 pCi/g, uranium-238 concentrations of 6.20 and 38.1 pCi/g, and thorium-232 concentrations of 17.3 and 27.7 pCi/g, respectively. ORAU reported that sampling at these two locations was effective in removing the contaminants, and no further action is required.

The PMC performed a cursory gamma walkover survey of these two location in June 1989 which revealed slightly elevated above background gamma radioactivity at one location. In April 1990, the PMC collected a surface soil sample in the center of the area which exhibited elevated gamma radiation levels. The sample was analyzed on site for uranium-238, radium-226, and radium-228. The results of the analysis revealed no concentration above reference levels. The sample was sent off site for thorium-230 analysis. The results of this analysis revealed a thorium-230 concentration of 36 ± 1 pCi/g. On the basis of the thorium-230 concentrations and the gamma radiation levels in the soil, the total volume of contaminated material at this location is estimated to be 0.15 m^3 (0.2 yd^3).

5.2.3.3 Southeast Drainage Area. The southeast drainage area runs from the Weldon Spring chemical plant boundary to the Missouri River (Figure 5.2-45). The runoff flows through a 20-cm- (8-in-) diameter underground pipe and surfaces approximately 200 m (650 ft) southeast of the chemical plant property fence line. The drainage ditch continues above ground for approximately 305 m (1,000 ft) across the southeast corner of the Weldon Spring Training Area to the perimeter fence between the DA property and the Weldon Spring Wildlife Area. From there, the drainage ditch continues in a southeasterly direction across the wildlife area to the Missouri River.

The southeast drainage area was previously surveyed for radiological soil contamination by ORAU both as part of the Army Reserve Weldon Spring Training Area assessment (ORAU 1986a) and as part of the Weldon Spring Wildlife Area assessment (ORAU 1986b). The drainage area is identified as location DA 4 on the Weldon Spring Training Area and as location DOC 7 on the Weldon Spring Wildlife Area property.

Direct radiation measurements at the surface and 91 cm (3 ft) above the surface were obtained at various locations along the length of the drainage area crossing the DA. Gamma exposure rates at the surface ranged from 7 to 120 μR/h, and gamma exposure rates at 91 cm (3 ft) above the surface ranged from 8 to 29 μR/h.

Both surface soil and shallow borehole soil samples were collected from the southeast drainage area on the Weldon Spring Training Area. In surface soil samples, concentrations of uranium-238 ranged from less than 0.76 to 42.0 pCi/g. Radium-226 and thorium-232 concentrations ranged from 0.76 to 8.36 pCi/g and 0.43 to 2.69 pCi/g, respectively. In areas of elevated gamma activity identified by the gamma walkover scan, five of the six boreholes sampled contained elevated uranium-238 concentrations ranging up to 1,010 pCi/g. Radium-226 concentrations ranged from 2.04 to 210 pCi/g, and thorium-232 levels ranged from 0.88 to 69.1 pCi/g. One sample location at 195.2 m (640 ft) from the outfall was analyzed for thorium-230 with results of 11.5 pCi/g for the 15-to-30-cm (0.5-to-1-ft) sample depth and 4.15 pCi/g for the 30-to-46-cm (1-to-1.5-ft) sample depth. Contamination extends to at least 61 cm (2 ft) below the soil surface in most of the borehole locations.

Concentrations measured in sediment samples collected at 100-m (328-ft) intervals showed uranium-238 from less than 1.56 to 39.7 pCi/g, and radium-226 concentrations ranged from 4.34 to 6.57 pCi/g. The concentrations of thorium-232 ranged from 1.41 to 2.18 pCi/g.

Direct radiation measurements at the surface and about 91 cm (3 ft) above the surface were obtained at various locations along the length of the drainage area crossing the Weldon Spring Wildlife Area (DOC 7). In areas of elevated radioactivity identified by the gamma walkover scan, gamma exposure rates at the surface ranged from 24 to 300 μR/h and gamma exposure rates at 91 cm (3 ft) above the surface ranged from 7 to 46 μR/h.

Surface sediment and shallow borehole soil samples were also collected by ORAU along the southeast drainage area through the Weldon Spring Wildlife Area. In surface soil and sediment samples, concentrations of uranium-238 ranged from less than 28.6 to 720 pCi/g. Radium-226 and thorium-232 concentrations ranged from 2.57 to 110 pCi/g and from less than 0.51 to 240 pCi/g, respectively. Five of the surface samples were analyzed for thorium-230, resulting in an average concentration of 5,610 pCi/g with a maximum concentration of 10,100 pCi/g. Shallow borehole soil samples contained uranium-238 concentrations ranging from 9.58 to 810 pCi/g. Radium-226 concentrations ranged from 2.82 to 130 pCi/g, and thorium-232 levels ranged from 0.51 to 150 pCi/g. All samples were collected in areas of elevated radioactivity identified by the gamma walkover scan. Samples from shallow boreholes indicated contamination to depths exceeding 30 cm (1 ft). In most cases, however, the drilling depth was restricted by subsurface rocks. Contamination was detected up to 11 m (36 ft) from the ditch centerline.

The PMC did not survey the southeast drainage area because it is subject to further influence from the chemical plant. This drainage will be more fully characterized by the PMC after major site remedial actions are completed and will be the subject of a separate decision-making process regarding future remedial actions.

Much of the 2,440-m (8,000-ft) drainage contains contamination. The lateral extent and depth varies. Bedrock is further below the surface in the upper reaches, and based on ORAU data contamination, could extend beyond a depth of 91 cm (3 ft) in some areas. In the downstream section much of the drainage bed is solid bedrock. Here, the average depth of contamination is probably not over a 30 cm (1 ft) except at the mouth which is contaminated to 61 cm (2 ft) in some locations. The estimate of the volume of material is based on an assumption that the drainage is contaminated along its entire length to an average depth of 61 cm (2 ft) and an average width of 4.6 m (15 ft). This is approximately 6,800 m^3 (8,900 yd^3). Average radionuclide concentrations have not been estimated for this volume.

5.2.4 Quarry Construction Staging Area and Water Treatment Plant Site

The PMC surveyed the quarry construction staging area in the summer of 1988 and determined that the gravel access road and railroad spur that enters the quarry are contaminated. The predominant radionuclide present on the gravel access road is thorium-230 and extends to a maximum depth of 76 cm (2.5 ft). Radium-226 is the primary contaminant on the railroad spur and extends to a maximum depth of 15 cm (0.5 ft). The total amount of contamination is approximately 842 m^3 (1,100 yd^3). These areas of contamination were cleaned up in order to allow construction of the water treatment plant which will be used in support of bulk waste removal at the quarry. Results of the survey are detailed in the *Radiological and Chemical Characterization Report* (MKF and JEG 1989n) for the planned quarry construction staging area and water treatment plant.

5.3 Surface Water and Sediment

The surface waters that are affected by the site can be divided into three major drainage systems according to the flow pathway leaving the site: Ash Pond and raffinate pits, Frog Pond, and southeast drainage. These drainage basins are shown in Figure 4.4-1. The Ash Pond and raffinate pits drainage system includes surface water from the Ash Pond drainage basin flowing off site through NPDES outfall NP-0003 at the northwest corner of the site, and the drainage from the raffinate pit area flowing through a separate, more southerly outfall NP-0004 (Figure 5.3-1). Both of these drainages feed unnamed tributaries of Schote Creek which flow to Lake 35 and on to Dardenne Creek. Seepage run studies have indicated that both of these tributaries lose water to the subsurface; dye studies have determined that at least part of this lost water resurfaces at Burgermeister Spring (SW-2008/SP-6301) and two wet weather springs, SW-2009/SP-6302 and SP-6303, which are all believed to be hydrologically connected (Section 4.4, Figure 4.4-4). Burgermeister Spring (SW-2008/ SP-6301) and the nearby wet weather spring (SW-2009/SP-6302) were sampled as surface waters and as springs. Outflow from Lake 34 enters an unnamed tributary of Dardenne Creek and eventually flows into the Mississippi River.

Frog Pond receives runoff from the northeastern portion of the chemical plant and storm water from most of the chemical plant area. The Frog Pond outlet, NPDES outfall NP-0002, flows into an unnamed tributary of Schote Creek, which flows to Lake 36. Overflow from Lake 36 enters Schote Creek, which flows into Lake 35. A portion of the water from Lake 35 is lost to the subsurface; dye trace studies have determined that some of the lost water resurfaces at Lake 34 and SP-6306, north of Lake 34 (Section 4.4). Overflow from Lake 35 enters Schote Creek, which joins Dardenne Creek and eventually enters the Mississippi River.

The southeast drainage system receives most of its water from the chemical plant process and sanitary sewer system. NPDES outfall NP-0001 discharges precipitation flow intercepted by the process sewer system at the chemical plant. Water that enters various building sumps and drains due to disrepair of some of the building roofs also eventually discharges from NP-0001. NPDES outfall NP-0005 is the point at which overland flow leaves the southeastern portion of the site. Discharges from the wastewater treatment plant for the new administration building flow through NPDES outfall NP-0006 to the southeast drainage. Six springs have been identified within southeast drainage 5300 (Section 4.4). Other 5000 series surface water drainages and springs will also be discussed.

The hydrology and water quality of the surface water features within each drainage basin have been studied to evaluate the role of surface water in the migration of contaminants and as receptors for contaminants (MKF and JEG 1987d, 1987o, 1988r). Sediments in the lakes and streams were also evaluated to assess existing contamination (MKF and JEG 1989h). Surface drainage features that may permit the migration of contaminants from the site are described in Section 4.4. Sources of contaminants on site that may contribute to surface water are discussed in Section 5.1.

The nature and extent of radiological and chemical contamination for the three drainage systems have been evaluated using data from the chemical analyses of surface water, NPDES outfall, spring, and sediment samples collected during 1987 and 1988 by the PMC (MKF and JEG 1987o, 1988r, 1989h). Spring and seep sample locations, surface water and NPDES sample locations, and sediment sample locations are presented in Figure 4.4-4, Figure 5.3-1 and Figure 5.3-4, respectively.

The comparison summarized in Table 5.3-1 includes data from the chemical analysis of surface water and springs by the PMC from first quarter 1987 through first quarter 1990. The analytical data for each chemical was compared against the detection level, background concentration, and water quality standards. The sampling locations with chemical analyses above the criteria of comparison were used to describe a generalized distribution of the chemical component in the surface water and springs.

Background concentrations were determined from chemical data for SW-2007, a sample location on Dardenne Creek upstream from where the drainage systems of Ash Pond, the raffinate pits, and Frog Pond enter Dardenne Creek. This location was sampled to assess background water quality (MKF and JEG 1988t). The chemical analyses of surface water samples were performed on unfiltered samples. The results, therefore, represent the total concentrations in the dissolved and suspended phases. Consequently, a direct comparison of the data in Table 5.3-1 for surface water reported in total concentrations with the calculated background levels in Appendix B for groundwater, which were reported in dissolved concentrations from filtered samples, was not appropriate. Thus, the water quality measured at SW-2007 was considered to be representative of background water quality for surface water.

Figures 5.3-2 through 5.3-9, excluding Figure 5.3-7, show the minimum, maximum, and average values of uranium, nitrate, and detectable nitroaromatic compounds for the surface water, NPDES outfall, spring, and sediment locations sampled in the vicinity of the site. The arithmetic mean of all data collected has been calculated and is displayed with the minimum and maximum values below each sample location. Single values are displayed for locations sampled once. Tables 5.3-2 through 5.3-9 correspond directly to the values presented in Figures 5.3-2 through 5.3-9, excluding 5.3-4 and 5.3-7. For each sample location in Tables 5.3-2 through 5.3-9, the following information is listed: the number of data values used to calculate the average, the minimum and maximum values (concentration range) existing in the data set, the average, and the standard deviation. Outliers were removed from the data and calculations in this report are based on the following conditions. Values that were significantly impacted by documented laboratory contamination were removed from the data presented in this report. A few values were also removed due to problems such as analyzing a preserved sample or because analytical results were obviously not representative of actual conditions.

In addition to outlying values, no duplicates, matrix spikes, or matrix spike duplicate values were included in the data presented on the figures.

The comparison of the surface water chemical analysis with detection limits, standards, and background values presented in Table 5.3-1 indicates that uranium, nitrate, and nitroaromatic compounds are the contaminants which occur consistently in concentrations greater than background in off-site receptors. Uranium and nitrate contamination originated from the uranium processing activities conducted on the site. The nitroaromatic compounds are the major contaminants from the ordnance works. The uranium in surface waters is exhibited primarily in the dissolved form based upon the studies comparing total versus dissolved (unfiltered vs. filtered) in samples from the southeast drainage. On average, greater than 90% of the measurable uranium is evident in samples filtered to 0.45 μm as compared to unfiltered replicates.

Results of random sampling of sediments in the lakes and drainages show that the sediments contain uranium contamination (MKF and JEG 1989h). Analysis of sediment samples from the southeast drainage, which were identified as hot spots by a walkover radiation scan, showed concentrations of radium, thorium, and uranium above background levels (ORAU 1986a). The isolated occurrences of radium and thorium in the sediments as compared to the widespread occurrence of uranium suggests different pathways of transport. Whereas uranium in the sediments is probably an accumulation of uranium transported via surface water discharge, radium and thorium were probably transported off site in a solid phase during operations (Section 6.1.2).

Section 5.3 focuses on the evaluation of uranium, nitrate, and nitroaromatic contamination in surface water features on or in the vicinity of the site. However, in addition to the presence of uranium, nitrate, and several nitroaromatic compounds, occasional water samples showed greater than background concentrations of thorium-230, sulfate, chloride, sodium, aluminum, chromium, zinc, and nickel. These concentrations were generally below drinking water standards as shown in Table 5.3-1.

5.3.1 Uranium

Total uranium concentrations for surface water, NPDES outfalls, springs, and sediments are presented in Figure 5.3-2, Figure 5.3-3, Table 5.3-2, and Figure 5.3-4. Total uranium analysis of samples from surface water, NPDES outfalls, and springs is expressed in pCi/l. Total uranium analysis of sediments is expressed in pCi/g. To assess potential contamination, detected concentrations of total uranium are compared to background values. For surface water, the average background level measured at SW-2007 is 1.45 pCi/l (Table 5.3-1). The background value for uranium in sediment is 2.4 pCi/g (UNC 1988). Water of Ash Pond, SW-2010, contained an average uranium value of 1,355 pCi/l (Figure 5.3-2). A surface drainage flowing into Ash Pond (SW-2013) was sampled in addition to the five NPDES sampling sites during the NPDES sampling effort and had an average uranium concentration of 210 pCi/l. Data from this inlet suggest that an on-site uranium source contributes total uranium to Ash Pond during precipitation events. Section 5.2.2.4 identifies uranium-contaminated soil in the Ash

Pond and south dump area. A drainage extending from east of raffinate pit 3 through a culvert under the roadway to Ash Pond, where SW-2013 is located, acts as a surface water pathway for uranium.

The Ash Pond NPDES outfall NP-0003, the raffinate pits outfall NP-0004, Burgermeister Spring SW-2008, and Lake 34 (SW-2004), which is part of the Ash Pond and raffinate pits drainage system, contained average total uranium concentrations of 1,082 pCi/l, 6 pCi/l, 74 pCi/l, and 21.5 pCi/l, respectively. These data suggest that uranium migrates off site in surface water and is discharged into losing streams which emerge at Burgermeister Spring. Concentrations of uranium measured in the wet weather spring were 24 pCi/l (SW-2009) and 10 pCi/l (SP-6302). These values are lower than the average value (84 pCi/l) measured in the nearby perennial Burgermeister Spring due to the wet weather spring's dependence on precipitation events. All other springs in the 6000 series drainage contained values less than the detection limit or slightly above the background range (Figure 5.3-3).

Uranium contamination also exists along the Frog Pond drainage. One water sample collected from Frog Pond during the first quarter of 1987 had a total uranium value of 240 pCi/l (Figure 5.3-2). The Frog Pond outfall NPDES NP-0002 and the inflow to Lake 36 (SW-2002) contained average uranium activities of 147 pCi/l and 105 pCi/l, respectively.

Lake 36 (SW-2005), the inflow to Lake 35 (SW-2003), the spring north of Lake 34 (SP-6306) and the junction of Dardenne Creek and Schote Creek (SW-2001) had average activities of 17 pCi/l, 18 pCi/l, 6 pCi/l, and 2 pCi/l, respectively (Figures 5.3-2 and 5.3-3). These measurements support the observation that the source of uranium is the surface water runoff via NP-0002 and the drainage to Lake 36. During high flow events, Lake 35 also receives flow from other sources of uranium, Ash pond and the raffinate pits. The data from lakes and streams suggest that uranium migrates from the site with the surface flow and decreases in concentration downstream.

Lake 10 (SW-2006) contained an average uranium concentration of 2 pCi/1, slightly above the background level measured in Dardenne Creek. Lake 10 does not receive surface water discharge from the site, so the measured value of 2 pCi/1 is likely within the background range.

Samples from NPDES outfalls NP-0005 and NP-0001, located within the southeast drainage, contained average uranium values of 436 pCi/l and 506 pCi/l, respectively (Figure 5.3-2). Significant uranium contamination in site soil and structures is contributing elevated levels of total uranium to the surface water discharge, NP-0005. Significant uranium contamination also appears in the chemical plant process and sanitary sewer system and possibly various building sumps and drains. These sources contribute elevated levels of uranium off site through NP-0001.

Samples from four of the six springs in the southeast drainage area contained uranium concentrations above the background level of 1 pCi/l. These were SP-5301 at 310 pCi/l, SP-5302 at an average of 312 pCi/l, SP-5303 at 224 pCi/l, and SP-5304 at 125 pCi/l (Figure 5.3-3). These four springs each receive some of their flow from the losing stream segments of the southeast drainage. SP-5303 and SP-5304 are the only perennial springs in the southeast drainage easement, suggesting a groundwater contribution to flow and possibly additional chemical contamination from another source (MKF and JEG 1988r). The uranium concentration in SP-5306 was below the detection limit. Spring SP-5305 was not sampled. Spring SP-5203 in drainage 5200 directly east of drainage 5300 had a total average uranium value of 5 pCi/l. Spring SP-5503 west of drainage 5400 had an average uranium value of 4 pCi/1. All other springs in the 5000 series drainages contained uranium values below detection limit or slightly above background.

Accumulation of uranium in the sediments in the Ash Pond and raffinate pits drainage system appears to be significant (Figure 5.3-4). Sediment sample locations SD-4002 downstream of NP-0003, SD-4013 downstream of Burgermeister Spring, and Lake 34 contained average uranium concentrations of 160 pCi/g, 7 pCi/g, and 47 pCi/g at 0 to 15 cm (0 to 6 in) in depth (MKF and JEG 1989h). Evaluation of the geochemistry of the surface water suggests that uranium is transported in the carbonate-rich water in the oxidized form as uranium bi- and tri-carbonate complexes. Precipitation in the lake and stream sediments is probably a result of chemical reduction to uraninite (Section 6.2 and Appendix C) and adsorption on the sediment material. In addition, sediments containing uranium may be transported off site and deposited in the streams and lakes.

Sediment samples from locations SD-4001, Lake 36, SD-4006, SD-4007, and Lake 35 contained average activities of 31 pCi/g, 30.3 pCi/g, 11 pCi/g, 26 pCi/g, and 23.6 pCi/g at the 0- to 15-cm- (0- to 6-in-) depth interval (Figure 5.3-4). The values decrease from locations SD-4001 and Lake 36 to location SD-4006 along the Frog Pond surface water pathway. The SD-4006 uranium activity may be lower due to sediment deposition in Lake 36.

The unnamed tributaries of both the Ash Pond and raffinate pits discharge system and the Frog Pond drainage system feed Schote Creek upstream of Lake 35. Contaminants along Schote Creek and Lake 35 may originate from one or both drainage systems. Samples from location SD-4007 had a slightly higher level of total uranium than SD-4006, which may suggest that both drainage systems are supplying uranium contamination.

Sediment samples collected along the southeast drainage were analyzed for total uranium (refer to Figure 5.3-4 for 1988 data and to Section 6.1.2 for ORAU 1986 data). Samples from all six locations had total uranium values above the background level of 2.4 pCi/g (MKF and JEG 1989h). These were SD-4061 at 6 pCi/g, SD-4062 at 12 pCi/g, SD-4063 at 20 pCi/g, SD-4064 at 10 pCi/g, SD-4065 at 12 pCi/g, and SD-4006 at 11 pCi/g. The 20 pCi/g measured at SD-4063, which is located downstream of SP-5303, may be due to the contribution of uranium from another source perhaps unrelated to the surface water discharge of drainage 5300. However, upon comparison of the average uranium concentrations measured for the four springs, the source of uranium measured in the sediment at SD-4063 is more likely the water discharging from the perennial spring of SP-5203. A greater volume of contaminated water flowing from the perennial spring would deposit greater quantities of uranium in the sediment.

5.3.2 Thorium-230

Average thorium-230 concentrations were less than or equal to the background value of 2 pCi/l in the surface water samples. A sample from Burgermeister Spring (SP-6301) contained 8 pCi/l of thorium-230 for the first quarter of 1987. Analyses of eight subsequent samples from Burgermeister Spring did not detect thorium. All other sample locations were below the detection limit.

Transport of thorium from the contaminated soils and sediments by surface water does not appear to be occurring because the detectable thorium values in the surface water do not exceed the background value measured at Dardenne Creek upstream of drainages from the site.

5.3.3 Nitrate

Nitrate contamination detected in surface water, NPDES outfalls, and springs is presented in Figure 5.3-5, Figure 5.3-6, and Table 5.3-3. The average of the data collected has been calculated and is displayed with the minimum and maximum values for each sample location. Nitrate concentrations are expressed in mg/l. The evaluation of contamination by nitrate in the surface water of the three drainage systems is based upon a comparison between the data and the average background level of 2.8 mg/l and the EPA primary drinking water standard of 10 mg/l nitrogen (44 mg/l nitrate) (Table 5.3-1).

Samples from Ash Pond (SW-2010), NPDES outfall NP-0003, Burgermeister Spring (SP-6301), and the wet weather spring (SP-6302) contained average nitrate concentrations of 19 mg/l, 728 mg/l, 740 mg/l, and 15 mg/l, respectively. The average nitrate concentration measured in SP-6303 is 37 mg/l. NP-0004 contained an average nitrate value of 30 mg/l. The higher nitrate concentration in Burgermeister Spring and in the nearby wet weather spring relative to the lower concentrations in the surface discharge suggests an additional nitrate source from groundwater flow in the subsurface connection between the site and springs. Figure 5.3-7 illustrates the concentration of nitrate (in mg/l) as a function of the discharge in cubic meters per second at Burgermeister Spring. The nitrate concentration appears to be inversely proportional to the volume of discharge, which may suggest a dilution mechanism due to an increase in the surface water contribution. Dye trace studies have demonstrated a hydrological connection between springs SP-6301 and SP-6302 and the surface discharge from the site. Ash Pond drainage and contaminated groundwater flow appear to be contributing elevated nitrate concentrations to Burgermeister Spring and the nearby wet weather spring.

The inflow to Ash Pond (SW-2013) had a minimum nitrate value of 3.4 mg/l and a maximum of 363 mg/l. The large variation in the measured concentrations suggests an intermittent source of nitrate in the surface water which is dependent upon the flow rate.

Nitrate levels for Lake 34 and SW-2001 were slightly above background, whereas springs SP-6304, SP-6306, SP-6501, SP-6601 had slightly higher levels of average nitrate ranging from 3 mg/l to 6 mg/l. However, all values are below the EPA primary drinking water standard of 10 mg/l nitrogen (44 mg/l nitrate).

Average nitrate levels for Frog Pond (SW-2011), Lake 10, Lake 36, the inflow to Lake 35 (SW-2003), the inflow to Lake 36 (SW-2002), and the outflow of Lake 35 (SW-2012) were below the background concentration. The spring north of Lake 34 (SP-6306) contained a nitrate concentration range from 4.2 mg/l to 14.5 mg/l. This range of nitrate concentrations, which is greater than the nitrate value measured in Lake 34, suggests a contribution of nitrate-contaminated groundwater flowing from the site. All nitrate values measured along the Frog Pond drainage were below the EPA primary drinking water standard. Nitrate contamination does not appear to be migrating along the surface water pathway of the Frog Pond drainage to Schote Creek and Lake 35.

NPDES outfalls NP-0001 and NP-0005 had average nitrate levels of 4.0 mg/l and 206 mg/l, respectively (Figure 5.3-5). The elevated nitrate concentration in NP-0005 suggests a nitrate source within the southeastern portion of the site. The distribution of nitrate in the soils on the site is presented on Figure 5.2-2 (Section 5.2.1.2). Several areas with elevated nitrate concentrations are located in the southeastern portion of the site which may be contributing nitrate to the overland surface water flow sampled at NP-0005. The nitrate level for NP-0001 is below the background concentrations; the chemical plant process and sanitary sewer system does not appear to contribute nitrate contamination to the surface water discharge.

Most of the springs in the southeast drainage area as well as those in the other 5000 series drainages were above the background level for nitrate but below the EPA standard (Figure 5.3-6). Significant nitrate contamination does not appear to be migrating via groundwater flow to the springs in the Missouri drainage basin. The source of nitrate in the 5300 series springs appears to be the surface water discharge (NP-0005) from the site, which is lost into the stream bed at various locations along the drainage.

Surface water sediment samples have not been analyzed for nitrate; however, nitrate is very soluble and would not accumulate in surface sediments (Campbell Design Group and Geotech, Inc. 1987; Law Engineering, Inc. 1988).

5.3.4 Sulfate

Three surface water sample locations, Ash Pond (SW-2010), Frog Pond (SW-2011), and the inflow to Lake 36 (SW-2002), contained elevated sulfate concentrations at 40 mg/l, 57 mg/l, and 50 mg/l, respectively (see Figure 5.3-1 for sample locations). These are above the background level of 38 mg/l (Table 5.3-1), but below the EPA secondary drinking water standard of 250 mg/l and Missouri's standard of 125 mg/l. Sulfate-contaminated soil has been identified within the Ash Pond and Frog Pond areas (Section 5.2.1.2).

Burgermeister Spring (SW-2008, SP-6301) contained an average sulfate concentration of 44 mg/l. Sulfate-contaminated surface water runoff from Ash Pond lost to the subsurface as well as contaminated groundwater flowing off site may be contributing the elevated concentration.

Samples from seven springs within Missouri River drainage basin 5000 contained average sulfate concentrations above the background concentration: SP-5201 at 50 mg/l, SP-5203 at 64 mg/l, SP-5204 at 58 mg/l, SP-5301 at 64 mg/l, SP-5303 at 52 mg/l, SP-5601 at 47 mg/l, and SP-5602 at 41 mg/l. Along the eastern site boundary, sulfuric acid is believed to have been stored and used for ordnance works activities. Surface runoff over contaminated soil may transport sulfate along possible subsurface connections to these spring locations. Two springs in drainage 5600 contained values slightly above background: SP-5601 at 47 mg/l and SP-5602 at 41 mg/l. These springs are downgradient from a former wastewater lagoon used to store red water (sodium sulfite) during the ordnance works TNT manufacturing activities (MKF and JEG 1988r). It is likely this lagoon served as the source for sulfate contamination detected in the waters of these springs. All spring samples contained sulfate values well below the EPA and Missouri water quality standards.

5.3.5 Chloride

Elevated average levels of chloride, above the average background concentration of 27 mg/l (Table 5.3-1), were detected in samples along the Frog Pond drainage system: Frog Pond (SW-2011) at 367 mg/l, the inflow of Lake 36 (SW-2002) at 144 mg/l, and Lake 36 (SW-2005) at 67 mg/l. These concentrations can be attributed to runoff from the Missouri Highway Department's maintenance facility's salt pile located upstream of Frog Pond (MKF and JEG 1988r). Springs SP-5203 and SP-5204, immediately downgradient of the Missouri State Highway Department maintenance facility, also had elevated average levels of 90 mg/l for SP-5203 and 75 mg/l for SP-5204. With the exception of Frog Pond, all of the chloride concentrations measured in the surface water features were well below the EPA secondary drinking water standard of 250 mg/l.

5.3.6 Metals

Sodium concentrations above the background concentration of 11.5 mg/l (Table 5.3-1), were measured at the locations with elevated levels of chloride in the Frog Pond drainage: Frog Pond at 792 mg/l, the inflow of Lake 36 at 119 mg/l, Lake 36 at 55 mg/l, and springs SP-5203 and SP-5204 at 79 mg/l and 51 mg/l, respectively. As in the case of chloride, the concentrations of sodium appear to be due to runoff from the Missouri State Highway Department Maintenance Facility salt pile (MKF and JEG 1988r).

Chromium concentrations slightly above the background concentration of 25 μg/l (Table 5.3-1) were measured at several surface water sample locations: Ash Pond at 47 μg/l, Frog Pond at 31 μg/l, Burgermeister Spring at 26 μg/l, and the junction of Schote Creek and Dardenne Creek at 27 μg/l.

A primary or secondary EPA drinking water standard does not currently exist for nickel. However, the water quality standard established by *Quality Criteria for Water 1986* is 13.4 μg/l (EPA 1986b).

Sources for nickel and chromium are not known. These metals are typically associated with electroplating activities, which have not been identified as occurring at the site. The activities associated with buildings 301 and 404, referred to as the metals plant and metals pilot plant, have not been determined. Nickel and chromium are present in raffinate pit sludges, although they were not detected as dissolved species in the raffinate water available for transport (Section 5.1.2). Surface and subsurface soils of the coal storage area, southwest of Frog Pond, contained elevated nickel and chromium concentrations (Section 5.2.1.3). However, the extent of the contamination was limited.

Zinc concentrations above the detection limit were measured at SW-2001, SW-2003, SW-2005, and SW-2010. The elevated values ranged from 21 μg/l to 78 μg/l, all of which are well below the EPA secondary drinking water standard of 5000 μg/l. This narrow range of values may suggest a background concentration at most of the surface water and spring sample locations which is slightly above the zinc level measured at SW-2007 (representative of background water quality).

The higher zinc and other metal concentration ranges observed in the spring and seep samples relative to Dardenne Creek may be due to a greater quantity of suspended material in the spring and seep samples. The total concentration (dissolved and suspended phases) of a particular metal in a water sample is dependent upon the quantity of suspended particulate and colloidal material present in the sample. The spring and seep samples collected during the 1987 and 1988 sampling effort, as well as the surface water samples collected on or near the site, likely contained a larger amount of suspended sediment than the samples collected from the upstream Dardenne Creek location.

The elevated aluminum concentrations found at 10 spring sample locations (SP-5204, SP-5301, SP-5303, SP-5402, SP-5403, SP-5405, SP-6301, SP-6302, SP-6501, SP-6601) and four surface water sample locations (SW-2001, SW-2003, SW-2005, SW-2010) may also be due to a higher suspended sediment content in the samples analyzed. The aluminum values ranged from 205 μg/l to 1,530 μg/l with a background level of less than the detection limit (Table 5.3-1). Water quality standards do not currently exist for aluminum.

5.3.7 Nitroaromatic Compounds

The NPDES outfalls, several surface waters, and the springs including Burgermeister Spring and the wet weather spring were sampled and analyzed for the nitroaromatics, 1,3,5-trinitrobenzene (1,3,5-TNB), 1,3-dinitrobenzene (1,3-DNB), nitrobenzene (NB), 2,4,6-trinitrotoluene (2,4,6-TNT), 2,4-dinitrotoluene (2,4-DNT), and 2,6-dinitrotoluene (2,6-DNT) (Figure 5.3-8, Figure 5.3-9 and Tables 5.3-4 through 5.3-9). Nitroaromatic compound values are expressed in μg/l. The background concentrations of the nitroaromatic compounds are zero.

All nitroaromatic compounds in samples collected from NP-0001, 0002, 0003, 0004, and 0005 were below the detection limit with the exception of trace amounts of 2,4,6-TNT for NP-0004 and 1,3,5-TNB for NP-0001, 0002, and 0004. The low concentrations of the few compounds detected suggest that surface water may not be a primary pathway for nitroaromatic compound migration off site (Section 6.2.7).

Nitroaromatic concentrations at Burgermeister Spring (SP-6301) ranged from less than detectable to a value of 0.02 μg/l for 1,3,5-TNB, an average value of 0.71 μg/l for 2,4-DNT, and an average value of 3.62 μg/l for 2,6-DNT. Measured nitroaromatics in the nearby wet weather spring (SW-2009, SP-6302) ranged from less than detectable to 1.42 μg/l for 2,4-DNT. The wet weather spring (SP-6303) upstream of Burgermeister Spring contained a range of less than detectable to a maximum value of 3.30 μg/l for 2,4,6-TNT. These three springs are believed to be hydrologically connected. Since nitroaromatics are not transported significantly via surface water, the presence of nitroaromatic compounds in the springs suggests a groundwater transport pathway.

The presence of 1,3,5-TNB, 2,4,6-TNT, 2,4-DNT and 2,6-DNT in Burgermeister Spring and 2,4,6-TNT in SP-6303 and the absence of 1,3,5-TNB, 2,6-DNT, and 2,4,6-TNT in the surface water drainage at NP-0003 suggest that the source of nitroaromatics in Burgermeister Spring is primarily contaminated groundwater flowing from the site and the Weldon Spring training area west of the site (Campbell Design Group and Geotech, Inc. 1987; Law Engineering, Inc. 1988). The trace amounts of 1,3,5-TNB and 2,4,6-TNT at NP-0004 may contribute to the nitroaromatic contamination in Burgermeister Spring. However, degradation of some nitroaromatic compounds by photolysis does not support this possibility. A further discussion on contaminated groundwater is provided in Section 5.4.

Water samples from Frog Pond outfall NPDES NP-0002 contained an average value of 0.8 μg/l of 1,3,5-TNB and were below detection limits for the other nitroaromatics (Figure 5.3-8). Nitroaromatic compound values from SW-2002, SW-2012, and from the spring sampled north of Lake 34 (SP-6306) were below detection limits (Figure 5.3-9). SP-6306 is one of two springs documented to have been contaminated by red water during ordnance works production (Fishel and Williams 1944).

Samples from NPDES outfall NP-0005 were below detection limits for all nitroaromatics. NPDES outfall NP-0001 had one sample in eleven in which 1,3,5-TNB was detected. All other nitroaromatic parameters were below detection limits. SP-5303 and SP-5304 samples contained 2,4,6-TNT at a range of 11.9 μg/l to 110.0 μg/l and 0.98 μg/l to 4.8 μg/l (Figure 5.3-9). On the basis of these values, it appears that SP-5303 receives additional water from another source having 2,4,6-TNT contamination, which, subsequently, flows to SP-5304 (MKF and JEG 1988r). No other springs within the southeast drainage area have detectable levels of nitroaromatic compounds.

Samples from SP-5201 contained 1,3,5-TNB, 1,3-DNB, 2,4,6-TNT, and 2,6-DNT average values of 1.4 μg/l, 0.85 μg/l, 22.34 μg/l, and 0.8 μg/l, respectively. SP-5201 is downgradient and within the same surface drainage feature as a dump with known nitroaromatic contamination. The nitroaromatic contaminants are presumably contributing to the groundwater/surface water system within that drainage as a result of gaining/losing stream conditions similar to those existing in drainage 5300 (DOE 1987).

Samples from SP-5602 contained 2,4,6-TNT, 2,4-DNT, and 2,6-DNT at 1.8 μg/l, 0.5 μg/l, and 3.5 μg/l, respectively. SP-5602 resurges 91 m (100 yd), horizontally, and approximately 9 m (30 ft) lower than a former wastewater lagoon used to store red water during the ordnance works TNT manufacturing activities. It is likely this lagoon serves as the source of nitroaromatic contamination detected in the waters of this spring (MKF and JEG 1988r).

Nitroaromatic contamination in SP-5503 of 0.61 μg/l of 2,4,6-TNT has not been attributed to a specific point source, but may result from widespread contamination of both groundwater and soil by nitroaromatics across the area. This contamination could be associated with nitroaromatics known to exist in the Weldon Spring training area (MKF and JEG 1988r; Campbell Design Group and Geotech, Inc. 1987; Law Engineering, Inc. 1988).

Results for the nitroaromatic compounds analysis in lake and stream sediment samples collected by the PMC in 1988 were below detectable levels (MKF and JEG 1989h). Although these compounds are present in the site soils and have migrated with the groundwater, nitroaromatic compounds have not been transported in measurable quantities to the lake and stream sediments. The absence of detectable concentrations of nitroaromatic compounds in sediment samples is consistent with the indication from surface water sample data that surface water is not a primary transport mechanism for nitroaromatic compound contamination.

5.4 Groundwater Quality

This section presents results of the water quality analyses from sampling of the vadose zone and bedrock aquifers. Vadose zone data are available from lysimeters and overburden wells adjacent to the raffinate pits. Wells monitoring the shallow, weathered bedrock aquifer are distributed across the site and outside the site in close proximity to the boundary. Several of the shallow monitoring wells on site are paired with monitoring wells completed within the deeper, competent limestone aquifer.

Based on a comparison of measured concentrations with background values (discussed in Appendix B) nitrate, sulfate, nickel, chromium, and nitroaromatics are the contaminants of major concern in the groundwater. In general, contaminated groundwater is contained within the site boundaries. The data do suggest, however, that low levels of nitrate and nitroaromatics migrate off the site. Low levels of sulfate and nitroaromatics migrate into the deeper, competent aquifer on site. Uranium, in concentrations slightly above background, may migrate off site in groundwater toward the south, but is primarily transported off site toward the north and southeast in surface water released from NPDES discharge points on the site perimeter.

5.4.1 Vadose Zone

Vadose zone water quality was evaluated from lysimeters and monitoring wells installed in the perched water tables adjacent to the raffinate pits, as described in Section 4.5 (Figure 4.5-3). Of 10 lysimeters installed, six from three locations were successfully sampled. Wells MW-3013 and MW-3018 also monitor the quality of perched and mounded water within the overburden. The chemical composition of water collected from these lysimeters and monitoring wells represents a mixture of leachate from soils contaminated during operation of the ordnance works and seepage from the raffinate pits (Table 5.4-1). The raffinate pits were constructed over portions of TNT processing line no. 4 and soils contaminated by ordnance works operations were used in construction of the dikes (MKF and JEG 1988j).

Selected analyses of total constituents (dissolved and suspended) in water from the raffinate pits and the lysimeters are presented in Table 5.4-1. Complete interpretation of the contamination along the pathway of seepage from the raffinate pits requires analysis of both total and dissolved constituents. Suspended materials, which are included in an analysis for total elements, may not be transported with the groundwater. The elements most susceptible to significant differences between dissolved and total analysis are metals such as iron, manganese, and aluminum, which form amorphous hydrous oxides and trace metals such as chromium and nickel, which are associated with these hydrous oxides by adsorption or co-precipitation.

Concentrations of major cations (sodium, magnesium, calcium, and potassium) and anions (sulfate, nitrate, chloride, and bicarbonate/carbonate), as measured by analysis of total constituent, should not be very different from dissolved constituent concentrations. Therefore, the interpretation of contamination in the water within the vadose zone and the deduction of geochemical processes, based on analysis of total constituents, are limited to the major chemistry. Trace metal analyses presented in Table 5.4-1 are used to indicate the presence or absence of these elements. Contaminants in the vadose zone water provide a source term for leaching into the saturated zone.

5.4.2 Bedrock Aquifer

Primary constituents of the groundwater sampled from the limestone bedrock aquifer are calcium, magnesium, and carbonate with lesser concentrations of sodium, potassium, sulfate, and chloride. The measured pH range is generally between 6.5 and 7.5 with an inferred low redox potential (Eh) (indicating a chemically reducing environment). A pH less than 7 is unusual for a limestone system and may indicate impact from geochemical reactions between the groundwater and minerals within the bedrock. For example, a lowered pH may be the result of an increase in carbon dioxide partial pressure due to neutralization of acid by carbonate minerals or from hydrolysis of metals such as aluminum or silicon. Potential sources of acid may be spills of nitric or sulfuric acid during processing or in situ oxidation of reduced iron such as that contained in pyrite. A low redox potential is inferred from the relatively high soluble iron (Fe^{+2}) concentrations ranging from 0.01 to 5.1 mg/l with a median value of 0.15 mg/l, and total organic carbon ranging from 0.1 to 250 mg/l with a median value of 3.8 mg/l. Calculations using PHREEQE (described in Appendix C) substantiate the inference of a low redox potential. At pH values near 7, Eh values of less than 50 to 150 millivolts are generally considered reducing.

Table 5.4-2 lists the chemical analyses normally performed on groundwater samples from the site along with brief descriptions of element distribution in the groundwater compared to the analytical detection limits, water quality standards, and calculated background concentrations. Analyses for volatile and semivolatile organic compounds, PCBs, and pesticides were performed only once because the results were negative (MKF and JEG 1987o).

The comparison of the groundwater chemical data for the sampling which occurred between first quarter 1987 through fourth quarter 1988 with the analytical detection limits, water quality standards, and background values, indicates that nitrate and uranium are the primary contaminants from the uranium processing, and nitroaromatic compounds are the major contaminants from the ordnance works. This description of major contaminants reflects those constituents that were measured more than a few times at concentrations greater than background concentrations or water quality standards. In addition to nitrate, uranium, and nitroaromatic compounds, nickel, chromium, aluminum, and sulfate exceed background concentrations in several wells within the site.

Aluminum concentrations above background may indicate impact from acidic discharges of spills from former operations which caused leaching of aluminum from clay minerals in the overburden soils. High sulfate concentrations have been detected in water around the raffinate pits and along the eastern site boundary where sulfuric acid was believed to have been stored and used. Sulfate may also originate from oxidation of sulfite (SO_3^{-2}) from the sodium sellite (red water) discharged from the ordnance works. A few pH values less than 6.5 were measured in monitoring wells in the northeast portion of the site near where sulfuric acid was used for ordnance production.

Figures 5.4-1 through 5.4-21 show the spatial distributions in the weathered and competent limestone aquifers of uranium, nitrate, sulfate, and nitroaromatic compounds and in the weathered limestone aquifer for chromium, nickel, and aluminum. The overburden monitoring wells, MW-3013 and MW-3018, are included in the figures showing the wells in the weathered limestone aquifer. The arithmetic mean of all data collected has been calculated and is displayed with the concentration range and mean next to each monitoring well location. Single values are displayed for locations sampled once. Tables 5.4-3 through 5.4-14 correspond to values presented in Figures 5.4-1 through 5.4-21. For each sample location in Tables 5.4-3 through 5.4-14, the following data are listed: the number of data values used to calculate the mean, the minimum, and maximum values existing in the data set; the mean; and any outlying values within the data set which were not used to calculate the mean. Outlying values were determined as discussed in Section 5.3. In addition to outlying values, no duplicates, matrix spikes, or matrix spike duplicate values were included in the data analysis. Cases where the "less than detectable value" was used in the calculation of the mean are discussed in Section 5.3. All outlier, duplicate, matrix spike, and matrix spike duplicate values identified have been recorded on an archived data set.

5.4.2.1 Uranium. The distributions of uranium concentrations in the weathered and competent limestone aquifers are shown in Figures 5.4-1 and 5.4-2. A background concentration of approximately 5.5 pCi/l was calculated from the groundwater data set (Appendix B).

Uranium concentrations above background occur in monitoring wells completed in the weathered limestone located adjacent to the raffinate pits, southeast of the process buildings, and south of the raffinate pits (Figure 5.4-1). Significant quantities of uranium are apparently not migrating off site in the groundwater. Samples from wells around the northwestern, northern, and northeastern portions of the site perimeter show uranium concentrations below background. Uranium concentrations above background, at a value of 18.0 pCi/l, have been detected in MW-4021 to the east of the site.

Three sources of uranium appear to account for the groundwater contamination patterns. These sources are: 1) the raffinate pits and contaminated soils in the Ash Pond area, 2) contaminated soils near buildings 103 and 105 and the railroad tracks, and 3) contaminated soils south of the raffinate pits.

Uranium from the raffinate pits appears to have impacted groundwater in wells near the perimeter of the pits (MW-3008, MW-3009, MW-3007, MW-3003 and MW-3013). In general, these wells also show other raffinate constituents such as sodium, nitrate, and fluoride. The marked decrease of uranium concentrations away from the pits appears to be due to dilution and removal of uranium from groundwater by precipitation of uraninite and adsorption (see Section 6.2).

Uranium-contaminated soils near buildings 103 and 105 and the railroad tracks are in the vicinity of the groundwater divide (Figures 4.4-4 and 4.4-6) and may be the source of uranium in the groundwater to the southeast (MW-2017, MW-2020, and MW-4020). Water samples from these wells do not contain elements associated with the raffinate pits.

Uranium detected in soil south of the raffinate pits may contribute to the elevated uranium measured in the groundwater from MW-3019. Raffinate pits 1 and 2 may also contribute to contamination in this area because the well is down-gradient from these pits; however, nitrate, the element most characteristic of the raffinate pits, has not been detected above background in MW-3019.

5.4.2.2 Nitrate. Nitrate concentrations from monitoring wells screened in the weathered limestone range from less than the detection limit (0.10 mg/l) to 6,010 mg/l (Figure 5.4-3 and Table 5.4-4). The highest concentration was measured in MW-3008 located on the eastern side of raffinate pit 3. Concentrations decrease to below background toward the southwestern to southeastern periphery of the site. Values on the northwestern to northeastern periphery are generally greater than background, indicating off-site migration of nitrate.

Several apparent outliers in the nitrate database were identified during the preparation of Figure 5.4-3. In many instances, the first quarter 1987 nitrate values were one or two orders of magnitude higher than the other data reported for a given well, possibly due to a data or laboratory error. These outliers were not used to determine the range and average values listed on Figure 5.4-3. Another discrepancy exists between data from wells near the north edge of raffinate pit 4, MW-3007 and MW-3003. Historically, samples from well MW-3007 had high nitrate concentrations (2,650 to 5,560 mg/l) due to seepage from the raffinate pits. This well was grouted in 1988 because it was screened over a large monitoring interval (60 ft) and replaced with MW-3003 which is screened over 10 ft. MW-3003 was first sampled in third quarter 1988 and the analysis showed nitrate was less than the detection limit. Laboratory error is suspected because of the improbability of a less than detectable concentration of nitrate in this nitrate contaminated soil/water area. Data for first quarter 1989 indicate a nitrate concentration of 2,050 mg/l for MW-3003.

The background concentration for nitrate is approximately 9 mg/l as nitrate (NO_3)(Appendix B). The primary drinking water standard for nitrate is 44 mg/l. The estimated background level of 9 mg/l for the site is therefore well below the drinking water standard.

Potential nitrate sources on site include: the raffinate pits, Ash Pond, the nitric acid recovery plant (area 100), the digestion and denitration plant (building 103), the refinery tank farm (area 102), and process lines and sewer leaks. The raffinate pits and Ash Pond appear to be major contributors to the nitrate contamination observed in groundwater samples since high concentrations have been detected near these sources.

Monitoring wells MW-3007 and MW-3008 consistently show nitrate concentrations greater than 1,000 mg/l. These wells are located adjacent to the raffinate pits (Figure 5.4-3). Liquids from raffinate pits 1 and 3 have concentrations of nitrate ranging from 1,960 to 12,960 mg/l measured in samples taken periodically between 1979 and 1987 (Table 5.1-13). Nitrate concentrations in water from pits 2 and 4 are lower than nitrate concentrations in raffinate pits 1 and 3. Nitrate concentrations in the raffinate pits are sufficiently high to account for the concentrations seen in the adjacent wells assuming some dilution along the flow path from the pits to the monitoring wells.

The trend of high nitrate concentrations extends north from the raffinate pits and includes wells MW-2003 and MW-2002. Across the drainage from Ash Pond, the concentrations decrease dramatically, suggesting a groundwater dilution process or lack of hydraulic connection between wells on the south side of the drainage and those on the north side. The source of slightly elevated levels of nitrate in MW-2001 and MW-2005 located north of the Ash Pond drainage is probably Ash Pond rather than the raffinate pits.

Wells MW-3009 and MW-4001, west of raffinate pit 4, appear to be impacted by the pits. These wells typically show greater than 100 mg/l nitrate. These wells are in an area of high groundwater in the upper bedrock and/or residuum and are probably downgradient from the pits because of the localized mounding of groundwater beneath the pits.

Water from some wells along the northeast boundary shows large temporal fluctuations of nitrate concentrations (MW-2008 and MW-2016). These fluctuations could be associated with discrete recharge events leading to nitrate-contaminated slugs of groundwater moving through the weathered aquifer system.

The maximum measured nitrate concentration in the competent limestone is 6.1 mg/l in MW-2028 (Figure 5.4-4). This concentration is below background and indicates that this zone of the bedrock aquifer has not been impacted by nitrate contamination sources on site. This is expected since the vertical hydraulic conductivity of the bedrock is lower than the horizontal hydraulic conductivity in the upper aquifer.

5.4.2.3 Sulfate. Sulfate distributions in the weathered and competent limestone aquifers are shown in Figures 5.4-5, 5.4-6, and Table 5.4-5. A background concentration of approximately 55 mg/l was calculated (Appendix B). Samples from all but three wells around the perimeter of the site have sulfate concentrations below or near background levels. Wells

MW-2017, MW-2020, and MW-4020 are the wells with sulfate concentrations above background levels (Figure 5.4-5 and Table 5.4-5). These wells are located near the southeastern boundary of the site where sulfuric acid was used during operation of the ordnance works.

Initial review of the sulfate database indicated that analysis of at least one sample from each of six wells (MW-2005, MW-2008, MW-2014, MW-2015, MW-3007, and MW-3018) had a value which was several orders of magnitude higher or lower than the mean of the rest of the data set (Table 5.4-5). These outliers are typically from the first quarter of 1987 and were not used in the range and average value determinations.

Sulfate concentrations in the weathered limestone aquifer range from less than 1.0 mg/l to 1,830 mg/l (Figure 5.4-5). Wells having concentrations above background are located around the processing buildings on the eastern portion of the site and near the raffinate pits. Temporal fluctuations observed in many wells contaminated with sulfate suggest intermittent sources (e.g., contaminated soil leached by infiltration through the vadose zone) rather than continuous sources (e.g., seepage from raffinate pits). Like nitrate, sulfate concentrations in wells northeast of the raffinate pits decrease markedly across the drainage from Ash Pond.

The probable source of sulfate in the groundwater near the processing buildings is release of sulfuric acid and sellite (sodium sulfite) used in TNT production. Sulfate in the soils from sulfuric acid use during uranium processing could be associated with acid storage and handling facilities and process lines and sewers. An additional source of sulfate may be from the oxidation of sulfur in the coal which was stored north of the buildings.

Sulfate in groundwater near the raffinate pits is probably a mixture of contributions from raffinate pit seepage and leaching of sulfate-contaminated soils. Soil used to construct the pit berms could have been contaminated from ordnance works operations (MKF and JEG 1988j).

Sulfate concentrations above background levels were measured in four monitoring wells completed within the competent limestone (Figure 5.4-6). These wells are scattered across the site, again suggesting multiple sulfate sources.

5.4.2.4 Metals. Aluminum, antimony, chromium, and nickel were each measured in at least two wells at concentrations greater than background or greater than a water quality standard (Table 5.4-1). In general, wells in the weathered limestone with the higher concentrations are located near the raffinate pits or near the chemical plant process buildings.

Antimony concentrations greater than the EPA water quality standard of 146 μg/l were detected for MW-3007 at 231 μg/l and MW-3008 at 247 μg/l for the first quarter of 1987. Subsequent sampling of these two wells during the first quarter of 1988 resulted in less than detectable values for both wells.

The distribution of chromium, nickel, and aluminum in wells completed in the weathered limestone are shown in Figures 5.4-7 to 5.4-9 and Tables 5.4-6 to 5.4-8, respectively. The temporal variability is great, suggesting either intermittent sources or analytical errors.

Sources for nickel and chromium contamination of the soils and resulting groundwater contamination are not known. Nickel and chromium are typically associated with electroplating activities, which have not been documented at the site. The activities associated with buildings 301 and 404, referred to as the metals plant and metals pilot plant, have not been determined. Nickel was detected in various soil samples across the site, whereas chromium was rarely detected. Nickel and chromium are present in raffinate pit sludges and detected in total analyses of the pit waters (Table 5.4-1). However, nickel and chromium concentrations are less than detection limits in the dissolved fraction of water from the raffinate pits. Suspended solids detected in the total analyses of the pit waters cannot migrate through the soils beneath the pits, suggesting the raffinate pits are not the source of nickel and chromium contamination.

Chromium concentrations in the weathered limestone groundwater range from less than 10 μg/l to 137 μg/l (Table 5.4-7). Four wells located in the competent limestone groundwater contain chromium concentrations above the detection limit, but well below the background value: MW-2025 at 14.9 μg/l, MW-3006 at 37.2 μg/l, MW-4009 at 10.2 μg/l, and MW-4022 at 16.8 μg/l. The background value is approximately 55 μg/l (Appendix B). With the exception of MW-2020, wells with chromium concentrations greater than background are adjacent to the raffinate pits and along the inferred flow path to the north toward Ash Pond, similar to the trend of nitrate concentrations. Unlike the nitrate trend, however, the chromium trend does not reflect the apparent hydrogeologic discontinuity northwest of Ash Pond. This suggests that multiple sources of chromium may exist; however, the soils sampling programs did not identify significant chromium sources.

Nickel concentrations in the weathered limestone groundwater range from less than 40 μg/l to 172 μg/l. The background value is approximately 60 μg/l (Appendix B). Interpretation of nickel distribution is complicated by an analytical detection limit of generally 40 μg/l (Table 5.4-8). Many values which were less than the detection limit were not included in the background calculation, which may have skewed the upper background value to unrealistic higher values.

Wells having nickel concentrations above the background range are adjacent to the raffinate pits (MW-3007, MW-3008) and adjacent to and down-gradient from Frog Pond (MW-2006, MW-2010, and MW-4014). Nickel concentrations in the wells located in the competent limestone groundwater are all below the detection limit. The absence of nickel contamination in MW-2003 and MW-2002, north of the raffinate pits, and the presence of nickel contamination in the vicinity of the processing buildings and Frog Pond, suggest the major source is related to TNT production. Nickel was detected at greater than twice background level in 15 soil samples across the site (Section 5.2.1.3).

Aluminum concentrations in the weathered limestone groundwater range from less than 200 μg/l to 665 μg/l. Aluminum concentrations in the competent limestone groundwater are all below the detection limit. The upper background value is approximately 150 μg/l (Appendix B). As with the nickel background determination, the detection limit for aluminum (200 μg/l) is high relative to the calculated background. This could create the appearance of a higher background range than exists in reality.

Based on the upper background value of 150 μg/l, the distribution of elevated aluminum concentrations is similar to the distribution of chromium. The distribution of aluminum also does not show a discontinuity across the drainage from Ash Pond. The inferred source of aluminum is chemical reactions occurring in the vadose zone between water and alumino-silicate minerals. Aluminum is leached from these minerals by solutions with either an acidic or basic pH. The raffinate pit waters are basic, with pHs ranging from 8.5 to 9.4 (Table 5.4-1) and water associated with ordnance works operations was generally acidic.

5.4.2.5 Nitroaromatic Compounds. Distributions of nitroaromatics in the weathered and competent limestone aquifers are shown in Figures 5.4-10 through 5.4-21 and Tables 5.4-9 through 5.4-14. The background concentration for nitroaromatics is considered zero, because nitroaromatics do not occur naturally. The initial review of the nitroaromatics database indicated that three wells (MW-2009, MW-3018, and MW-4001) had outlying values which appeared extremely high. These values were not used in the range and average value calculations. In general, the distributions in the groundwater within the weathered limestone (Figures 5.4-10, 5.4-12, 5.4-14, 5.4-16, 5.4-18, and 5.4-20) show low concentrations pervasive throughout the wells on and off site and two areas with significantly elevated concentrations.

Statistics described in Appendix B were used to distinguish between the concentrations in groundwater near sources and the diffuse concentrations in groundwater away from the sources. The upper concentration of the diffuse nitroaromatics in the groundwater away from the sources are as follows: 2,4,6-TNT less than 2.4 μg/l; 1,3,5-TNB less than 1.2 μg/l; 2,6-DNT less than 1.2 μg/l; 2,4-DNT less than 0.7 μg/l; 1,3-DNB less than 1.8 μg/l; and nitrobenzene less than 1.8 μg/l. The differences among these values are probably a function of differences among source concentrations and geochemical properties unique to each species (e.g., solubility and susceptibility to adsorption and biodegradation).

Two apparent source areas of nitroaromatic compounds are 1) near Frog Pond and the TNT production lines directly south of Frog Pond and 2) along the process line west of raffinate pit 4. Wells near these apparent source areas contain several hundred micrograms per liter of the various nitroaromatic species. Concentrations near the detection limits in adjacent wells suggest that low concentrations are transported off site in the groundwater. MW-4013, located off site north of the burn area and Ash Pond, showed 1,3,5-TNB levels with an arithmetic mean of 51.6 μg/l, suggesting a third potential source in the burn area.

Compared with the number of detectable occurrences in the groundwater, the soils investigations encountered relatively little nitroaromatic contamination (Figure 5.2-1). The greatest number of samples with detectable concentrations of nitroaromatic compounds are from the Ash Pond area; however, the groundwater from the wells outside Ash Pond did not show concentrations elevated above the pervasive low levels across the site. The presence of nitroaromatics in the soils of Ash Pond as compared to the low concentrations in the groundwater indicates that the contaminated soils are not a major source to groundwater contamination. Soil samples were not collected in the immediate vicinity of Frog Pond and raffinate pit 4 which are the areas having the most highly contaminated groundwater. The contaminant source in the groundwater near raffinate pit 4 is likely nitroaromatic solids mixed in the soils at the time this raffinate pit was constructed. The origin of this nitroaromatic contaminated soil is probably similar to the contaminated soil known to be scattered throughout the Weldon Spring training area west of the raffinate pits (Campbell Design Group and Geotechnology, Inc. 1987 and Law Engineering, Inc. 1988).

The nitroaromatic species 1,3,5-TNB, 2,4-DNT, and nitrobenzene were detected in a few samples from monitoring wells completed in the competent limestone, whereas 2,4,6-TNT, 2,6-DNT, and 1,3-DNB were undetected (Figures 5.4-11, 5.4-13, 5.4-15, 5.4-17, 5.4-19, and 5.4-21). A clear distribution pattern is not apparent when comparing detectable concentrations in groundwater samples from weathered versus competent limestone wells. In some cases, the nearest wells cased in the weathered limestone show comparable levels of contamination; in other cases samples from the weathered limestone wells have no detectable contamination. These distribution patterns may be misleading because the detection limits are near the diffuse concentrations that are pervasive across the site (Appendix B). It does appear, however, that vertical movement of nitroaromatics through the aquifer is occurring at various locations across the site. Vertical movement is most likely occurring along fractures rather than by porous media flow.

The fact that only sulfate and certain nitroaromatic compounds, all of which can be traced to the ordnance works operations, have been detected in above background concentrations in the competent zone of the bedrock aquifer suggests that hydraulic communication between the weathered and competent zones may occur at a rate such that contaminants in groundwater in the weathered zone originating from the feed materials plant operations have not had sufficient time to migrate to the competent zone.

5.5 Ecology

The Weldon Spring site and the adjacent 16,000-acre Busch/Weldon Spring wildlife complex (Figure 5.5-1) are located on the Missouri and Mississippi River drainage divide along the boundary between the southern portion of the Dissected Till Plain physiographic province, and the northern subsection of the Ozark Uplift (Johnson 1987; Thom and Wilson 1980). The land form in the area varies from rolling hills to moderately sloped forested lands. Limestone bluffs along the Missouri River floodplain landscape have little relief, with elevations ranging from 137 m to 141 m (450 ft to 464 ft) National Vertical Geodetic Datum (NVGD). Elevations on the Busch and Weldon Spring wildlife areas range from 137 m (450 ft) NVGD at the base of the bluffs to 217 m (712 ft) NVGD on the uplands (MDOC 1989).

5.5.1 Terrestrial Habitats

5.5.1.1 Chemical Plant Area. While much of the chemical plant area consists of maintained grasslands and old fields that are periodically mowed (65.5 ha (162 acres)), upland and palustrine deciduous forests also occur within the site. Vegetation surveyed at the Weldon Spring site is listed in Table 5.5-1. The area immediately adjacent to the chemical plant buildings and roadways is mowed and maintained grassland. Vegetation in the chemical plant area includes grasses such as foxtail, big bluestem, and fescue, and shrubs and herbs such as mulberry, black locust, thistle, dandelion, and clover. The habitats around the raffinate pits and south dump area are old fields that are periodically cut, but not routinely mowed or maintained. Vegetation typical to old field habitats occur and include horse nettle, hedge bindweed, eastern red cedar, and goldenrod. Drainage areas located south along the edges of the chemical building perimeter include species such as common cattail and willow saplings.

The northwest portion of the chemical plant (approximately 22 ha (55 acres)), consists of relatively natural old field/forest habitat (Figure 5.5-2). The forest at the northwest corner of the site provides a continuum of the rich and diverse wildlife areas to the north and west. Deciduous tree species include red oak, shingle oak, and shagbark hickory. Understory species include wood sorrel, white avens, and violets. Coniferous species such as short-leaved pine and red cedar also exist within the forest areas. Ash Pond is lined to the east by palustrine vegetation including cottonwood and sycamore in the canopy and willow and mulberry in the understory. Herbaceous species include wild grape, thoroughwort, and nettle. Vegetation surveys will continue in 1992 to further document species present.

Although the perimeter of the chemical plant area is fenced, deer move on and off site by either jumping the fence or passing through it at the northwest opening. White-tailed deer have been observed feeding and resting around Ash Pond and in the forests north of it. Raccoon, opossum, and deer tracks have been sighted along the exposed sediments at raffinate pits 3 and 4, Ash Pond, and Frog Pond. Raccoon, muskrat, opossum, and short-tailed shrew were captured as part of the biouptake studies in 1977 (RETA 1978). The palustrine habitats surrounding Ash Pond and Frog Pond and their drainages support semi-aquatic species such as the bullfrog and the red-eared slider turtle.

Pigeons and sparrows roost among the chemical plant buildings and surrounding area. A few adult pairs of geese have been observed roosting on the roofs of the chemical plant buildings (Herron 1991a). Cottontail rabbits were collected during sampling surveys conducted in the buildings area in 1987 by the PMC and in 1977 by Ryckman, Edgerly, Tomlinson and

Associates (RETA). These studies show that few species occur in the immediate area of the chemical plant buildings.

Bird surveys were conducted at the raffinate pit area, Ash Pond, Frog Pond, and the old field habitat south of the chemical plant buildings. Table 5.5-2 lists the species of birds sighted at the Weldon Spring Chemical Plant area during these surveys. American goldfinches, orioles, and field sparrows were among those species sighted in the old field habitats. Bluejays, cardinals, and red-headed woodpeckers were observed in the forests surrounding Ash Pond and Frog Pond and in the northwest woods. Wild turkeys were observed gathering around Ash Pond and in the fields east of Ash Pond. Two Great-horned owls, have been observed in the cottonwood trees in Ash Pond. The quarry haul road survey documented 65 bird species which occur in forests and fields south of the chemical plant (MKF and JEG 1992d) (Table 5.5-3).

5.5.1.2 Busch and Weldon Spring Wildlife Areas. The August A. Busch Wildlife Area occupies much of the land adjacent to the Weldon Spring site. The wildlife area consists of three state-owned and operated wildlife areas, totaling 6,836 ha (16,890 ac), that are actively managed for wildlife and support as diverse biota. These areas are the August A. Busch Memorial Wildlife Area to the north of the site (2,828 ha [6,987 ac]), the Weldon spring Wildlife Area to the south and east of the site (2,977 ha [7,356 ac]), and Howell Island Wildlife Areas in the Missouri River to the southeast of the site (1,031 ha [2,547 ac]) (Figure 5.5-1). Although little information regarding species diversity and population sizes of resident biota is available, many of the species which occur in the county may also occur in the wildlife areas.

Habitat types in the area include open fields and pastures; upland, slope, and palustrine and riverine forests; and cultivated farmlands (MDOC 1989). Plant species common to the open fields and pastures include Indian mallow, crabgrass, ragweed, aster, thistles, mustard, fleabane, and goldenrod. Sixty-four percent (4,289 ha or 10,840 ac) of the entire Busch Area consists of upland, slope, and bottomland forests. The upland forests are primarily oak and oak-hickory forests. The slope forest species are primarily oak and hickory and include sugar maple, American elm, and black walnut. Palustrine forests occur within the Missouri River floodplain and riverine forests and slough, stream, and lake banks. The dominant species in these palustrine forests include willow, eastern cottonwood, silver maple, American elm, boxelder, red mulberry, pecan, oak (pin and burr), hackberry, and persimmon.

Habitats in the wildlife areas are actively managed for wildlife use. Openlands are managed to minimize soil erosion and provide forage and cover for wildlife. Some portions of the Busch and Weldon Spring Wildlife Areas are leased to sharecroppers for agricultural production. In these areas, a percentage of the crop is left for wildlife use. The farmed areas undergo required fallow rotation; fields remain unfarmed for at least one year before they are cultivated again. Cultivated fields are planted with corn, soybeans, milo, winter wheat, and legumes.

The Missouri Department of Conservation has identified 29 species of mammals in St. Charles County (Dickneite 1988). Twenty-two of these mammalian species have been sighted in the Weldon Spring Wildlife Area and include fox squirrel, gray squirrel, white-tailed deer, red fox, opossum, raccoon, skunk, eastern cottontail, and a variety of mice and other rodents (Table 5.5-4).

St. Charles County is populated with 47 reptile and 25 amphibian species which include softshell and map turtles, a variety of snakes, bullfrogs, spring peepers, slimy and eastern tiger salamanders, and Fowler's toads (Dickneite 1988). Three species of venomous snakes, Osage copperhead, eastern massasauga rattlesnake, and timber rattlesnake, are known to inhabit St. Charles County. Twenty-nine reptile and eighteen amphibian species have been sighted at the Busch area and are listed in Table 5.5-5.

St. Charles County is located along the Mississippi Flyway, a major north-south route for migratory North American birds. St. Charles County has reported 295 avian species (Dickneite 1988) including more than 100 species that breed in the area, and 43 which are common throughout three seasons of the year (MDOC 1981). Common birds occurring in the Weldon Spring site vicinity include warblers, sparrows, hawks, owls, thrushes, woodpeckers, and turkeys. Quail are found in forest-openland edge areas and agricultural fields within the Busch Wildlife Area. The Busch Wildlife Area has a reported 277 species of birds (MDOC 1981). The MDOC maintains a goose management program and provides suitable habitat for resident and migratory waterfowl and shorebirds.

Surface waters in the area, which include ponds, lakes, and streams, provide suitable habitat for a variety of waterfowl and shorebirds. Up to 30 species of waterfowl utilize the Mississippi River Flyway during spring and autumn migrations (MDOC 1976). Ten waterfowl species are common in the Weldon Spring area during area migratory periods. Several species, such as the Canada goose, mallard, and wood duck, nest or overwinter in the area.

5.5.2 Aquatic Habitats

Aquatic habitats in the immediate vicinity of the Weldon Spring site include intermittent and permanent streams, various sized ponds and lakes, the Missouri River, and portions of the Mississippi River that receive drainage from St. Charles County, the Busch Wildlife Area, and portions of the Weldon Spring site.

5.5.2.1 Chemical Plant Area. At the chemical plant area, aquatic habitats cover approximately 38 acres and include four raffinate pits, Ash Pond, Frog Pond, and drainages from these ponds. The impounded water and the sediment in these habitats are radioactively and chemically contaminated. Rooted aquatic vegetation are found in Ash Pond, Frog Pond, and raffinate pit 4.

Reptiles and amphibians, including snapping turtles, red-eared sliders and map turtles, have been observed sunning on debris in raffinate pit 4 and Frog Pond. Electrofishing efforts conducted on site in 1987 found only a few small sunfish in Frog Pond (MKF and JEG 1989l). Depending on water levels at the raffinate pits, Ash Pond, and Frog Pond, exposed sediment and sludge in these areas attract shorebirds. Killdeer and spotted sandpiper have been observed foraging in the sediment on raffinate pit 4. Waterfowl, including blue-winged teal, mallard, wood duck, and Canada goose have been observed on raffinate pit 4 and Ash Pond. Wood ducks, green-backed herons, and great blue herons have been sighted at Frog Pond. Ducks, primarily mallards, have been documented as summer residents at raffinate pit 4.

5.5.2.2 Busch and Weldon Spring Wildlife Areas. The aquatic habitats of the Busch Wildlife Area and Weldon Spring Wildlife Area include the Missouri River, several streams, two quarries, and numerous ponds and lakes. Warmwater fish species in the lakes and ponds include carp, black bullhead, bluegill, black and white crappie, bluntnose and fathead minnow, green sunfish, goldfish, rock bass, grass pickerel, buffalo, golden shiner, brook silversides, and rainbow trout (Missouri Botanical Gardens 1975; MDOC 1989).

The Busch Wildlife Area has 33 lakes and 60 ponds with areas totalling 209 and 8.9 surface ha (517 and 22 surface ac), respectively. Two shallow impoundments, created to attract shorebirds, cover 5.3 surface ha (13 surface ac). Major streams in the area are Dardenne Creek and Kraut Run. Many of the ponds and lakes in the Busch Wildlife Area are intensively managed as warm-water fisheries (Figure 5.5-3).

Aquatic habitats in the Weldon Spring Wildlife Area include the Missouri River, Femme Osage Slough, Prairie Lake, Little Femme Osage Creek, the southeast drainage, 12 ponds, several intermittent creeks, and five springs. Femme Osage Slough, Prairie Lake, and three ponds in the Weldon Spring Wildlife Area are managed as multiple species fishing waters (MDOC 1989). The Little Femme Osage Creek has stretches of permanent water, but does not flow throughout the year. The southeast drainage begins within the chemical plant area and flows to the Missouri River. Information on the fish fauna of Little Femme Osage Creek and the southeast drainage is not available. Resident fishes, if any, are probably restricted to species tolerant of low flow. Some of these species include the creek chub, bluntnose minnow, fathead minnow, and green sunfish.

The MDOC reports that 105 species of fish are present in St. Charles County (Dickneite 1988). Based on the habitats and distribution of Missouri fishes, the most common fish species that could occur in the streams in the site vicinity include carp, creek chub, redfin shiner, fathead minnow, white sucker, green sunfish, orange spotted sunfish, johnny darter, and fantail darter. Recent electrofishing surveys of the Missouri River, conducted approximately 10 miles upstream of the site, have shown a population typical of big river habitats. The species collected include freshwater drum, channel catfish, river carpsucker, carp, blue catfish, smallmouth buffalo, bigmouth buffalo, paddlefish, longnose gar, shortnose gar, flathead catfish, shorthead redhorse, blue sucker, white crappie, goldeye, and gizzard shad (Union Electric 1988, 1989, 1990). Largemouth bass, bluegill, and crappie are abundant in backwaters and oxbows (Pflieger 1975).

5.5.3 Wetlands and High-Quality Natural Communities

5.5.3.1 Chemical Plant Area. Identified wetlands at the Weldon Spring site include the raffinate pits, Frog Pond, and Ash Pond (U.S. Fish and Wildlife Service 1990). These wetlands are four man-made surface water impoundments and two man-made ponds. Two types of wetland classes exist on site. Raffinate pits 1, 2, and 3 are palustrine, unconsolidated bottom, excavated wetlands. Frog Pond and raffinate pit 4 are intermittently exposed, diked palustrine wetlands with unconsolidated bottoms. Ash Pond is a diked/impounded palustrine forested wetland (U.S. Fish and Wildlife Service 1990).

Hydric soil conditions were reviewed utilizing St. Charles County soil survey information (USDA 1982). Soils at the chemical plant area are considered part of the Armster-Mexico-Hatton association and consist of moderately well drained to poorly drained soils. The raffinate pits are saturated year round; some shoreline portions along raffinate pit 4, particularly in the north and southeast corners, are exposed during the late summer. Ash Pond is completely dry in late summer, and the water level in Frog Pond falls from 1 meter (3.28 ft) to 0.3 meters (0.98 ft).

The preliminary vegetation survey, conducted in August 1991, documents the existence of facultative wetland and obligate wetland species (Table 5.5-1). Facultative wetland species are usually found in wetlands (67%-99% occurrence). Obligate species are always found in wetlands under natural conditions. Federal guidelines require that facultative/obligate wetland species occur as dominant species in order to declare or delineate wetland boundaries. Spotted-touch-me-not, broadleaf arrowhead, and smooth hedge nettle were present in late summer in the exposed sediments. The vegetation survey will continue in 1992 in order to quantify species and dominance and to delineate wetland-upland boundaries.

5.5.3.2 Busch/Weldon Spring Wildlife Area. All lakes and ponds within the Busch and Weldon Spring Wildlife Areas are identified as wetlands by the U.S. Fish and Wildlife Service National Wetlands Inventory Map. The Weldon Spring Wildlife Area has a large area of riparian habitat. This type of habitat is associated with intermittent and perennial drainages and with shoreline areas of ponds and lakes (Cooperrider et al. 1986). These habitats are ecologically very important; they contain diverse plant species, are utilized by wildlife for foraging and breeding, function as an important food source for stream organisms, and play a major role in streambank stabilization. Two pools totaling 5.3 ha (13 ac) and portions of seven lakes in the Busch Wildlife Area are managed as wetland habitat, and 312 ha (772 ac) of Missouri River bottomlands in the Weldon Spring Wildlife Area are managed as wetland areas (MDOC 1989).

The MDOC has identified four high-quality natural communities in the area of the Weldon Spring site (Gaines 1988). These communities include a mesic forest and a dry-mesic chert forest located in the Weldon Spring Natural Area south of State Route 94 near the chemical plant, and a very high-quality dry chert forest and a chert savannah located northwest of the Weldon Spring quarry. These communities are not contiguous with property that has been identified as affected by site contamination. Although no unique or high-quality habitats have been identified at the Howell Island Wildlife Area, the area does provide habitat for bald eagles that overwinter along the Missouri River in the Weldon Spring site vicinity.

5.5.4 Threatened and Endangered Species

The Missouri Department of Conservation Natural Heritage database lists 13 state endangered and 15 rare state species for St. Charles County (Dickneite 1988, MDOC 1990, MDOC 1991). Four of these species are Federally listed. Eight species are listed as candidates for the Federal endangered species list. Ten species of special concern are listed for the county (Table 5.5-6).

5.5.4.1 Chemical Plant Area. Prior to construction activities, a biotic survey was performed south of the chemical plant area along the quarry haul road route (MKF and JEG 1992d). Vegetation and birds were surveyed, and incidental sighting of amphibians, reptiles, and mammals were recorded. No Federal or State endangered species were sighted during the surveys and no critical habitat has been designated in the area. The wood frog was seen at the southernmost portion of the haul road route. This species, a state-listed rare species, exists in locally abundant populations in St. Charles County (Hlohowskyj 1990). Electrofishing surveys of the on-site aquatic habitats have indicated that no Federal or State-listed fish species occur on site. Occasional sightings of the pied-billed grebe (*Podilymbus podiceps*) in the raffinate pits have been documented. The grebe is listed as rare in the state of Missouri. The frequency of occurrence for the grebe is not known.

5.5.4.2 Busch/Weldon Spring Area. Federal- and State-listed species that may occur on or near the August A. Busch Wildlife Area include the bald eagle, sicklefin chub, sturgeon chub, Cooper's hawk, wood frog, and arrow arum (Table 5.5-6). The Federally endangered pallid sturgeon, a State endangered starwort variety, and the Federally endangered peregrine falcon may occur in the area (Brabander 1990; U.S. Fish and Wildlife Service). Endangered bald eagles overwintering in the area roost at the Howell Island Wildlife Area (Gaines 1988).

The Federally endangered pallid sturgeon and the Federal candidate starwort occur in the Missouri River near the Weldon Spring site (Gaines 1988). The sturgeon and sicklefin chubs have been reported in the Missouri River at Daniel Boone Bridge on U.S. Route 40/61 (Gaines 1988). This location is approximately 5 km (3 mi) downstream of the confluence of the southeast drainage with the Missouri River. Both of these fish are Federal candidate species and rare according to the State. The chubs and the pallid sturgeon are restricted to the open channels of large turbid rivers and do not enter tributary streams (Pflieger 1975). Open channels of the Missouri River are found where it is contiguous with the Weldon Spring Wildlife Area and at the confluence of the river and the southeast drainage; the pallid sturgeon and chubs would not be expected to enter the southeast drainage proper. Electrofishing surveys conducted on the Missouri River and upstream of the site have not resulted in the collection of any listed, threatened, or endangered species (Lusk 1991).

The Cooper's hawk, a State-listed rare species, nests in pine plantations in the Weldon Spring Wildlife Area. The wood frog is classified rare by the State and is known to occur at the Weldon Spring Wildlife Area (Saladin 1989). In Missouri, the wood frog is generally associated with wooded hillsides; it breeds in small, fishless woodland ponds and pools. Arrow arum, a State rare species with two sightings in the state, may occur along Dardenne Creek north of Interstate 70 (MDOC 1990). No critical habitats for these species are designated in the chemical plant area. The Blanding's turtle, a State endangered species, was sighted in 1991 near the Busch Wildlife Area and Highway D in Weldon Spring, Missouri.

5.5.5 Biouptake Studies

Biouptake refers to the ingestion, inhalation, or adsorption of a contaminant by a plant or animal and the subsequent incorporation of that contaminant into the plant or animal tissue. Biouptake investigations initiated by the PMC in 1987 identify the possible exposure pathways of chemical and radiologic contamination from the Weldon spring site to humans through the ingestion of fish and game. In 1984, the MDOC collected samples and analyzed radionuclides found in game fish at the Busch Wildlife Area lakes. PMC studies were conducted to examine organisms at lower levels of the food chain that are consumed by game species. An examination of contaminants in the local ecosystem was investigated using the RETA sampling program (RETA 1978).

Twenty-five small mammals and five waterfowl were collected in 1987 and 1990, respectively, during the PMC biouptake studies. From 1987 to 1991, the PMC has collected over 90 fish and in 1991, 10 benthic invertebrate samples were taken from Frog Pond and the Busch lakes. Opportunistic samples collected include one common snapping turtle from the raffinate pit 4 area and one male white-tailed deer from the material storage area near Ash Pond. Table 5.5-7 lists vertebrate species sampled in both the RETA (1978) and PMC studies.

All biouptake studies initially included analysis for isotopic (or total) uranium, isotopic thorium, and radium-226. Uranium was frequently detected in water, sediments and biotic media, where as thorium and radium were seldom detected. Uranium is a relatively water soluble metal, in comparison to radium and thorium, and can be incorporated into soft tissue and bone.

The RETA sampling program was conducted to investigate the transport of site contaminants in the local ecosystem (RETA 1978). Major phenomena include uptake and accumulation of contaminants in organisms and transfer of those contaminants through the food web. One hundred eighteen terrestrial biological samples were collected at 31 sites; samples were taken from background sites, contaminated areas, and other areas.

Approximately 60 aquatic samples, including algae, rooted aquatic macrophytes, macroinvertebrates, fish, amphibians, and muskrats were collected at 22 sites. Water and sediment samples were collected in coordination with the aquatic biological samples to obtain correlative data on accumulation and uptake. Three types of radiological analyses were employed in the biological program: gamma spectroscopy, uranium testing by fluorometry, and isotopic thorium analysis. Table 5.5-8 lists the distribution of uranium, thorium, and radium-226 in the Frog Pond system reported in the RETA study.

5.5.5.1 Fish. In 1983 and 1984, the Missouri Department of Conservation (MDOC) collected samples of water, fish, and sediments from Busch Lakes 25, 34, 36, and the Femme Osage Slough. The edible portion of ten fish were composited per sample. Table 5.5-9 lists the results from the MDOC sampling. The background samples used in this study were collected from Little Dixie Lake which is located north of Jefferson City, Missouri approximately 100 miles west of the WSS. Natural uranium concentrations in fish sampled from the contaminated Busch Lakes 34 and 36, and the Slough ranged from 0.002 to 0.06 pCi/g. Background concentrations ranged from 0.002 to 0.02 pCi/g.

Fish samples were collected by the PMC during the period from 1987 to 1991. Uranium, thorium, and radium concentrations were determined by analysis in 1987. Isotopic uranium was analyzed in the 1988 to 1991 samples. These data are presented in Table 5.5-10. In general, one sample was collected each year for each species and sample type. In 1989 and 1990, duplicate samples were also taken. These average values are also presented in Table 5.5-10. The highest concentrations detected in samples obtained from 1987 to 1991 were found in whole catfish samples (1.863 pCi/g) and whole sunfish samples (0.529 pCi/g). These samples were obtained from Lake 36 in 1989 and 1990. Fillet samples from the Busch lakes ranged from not detected (0.002 pCi/g) to 0.072 pCi/g. Busch Lakes 33 and 37 were selected as background or control lakes and had uranium concentrations in fish samples ranging from non-detected (0.001 pCi/g) to 0.003 pCi/g. In the 1987 background samples, no uranium was detected using a detection limit of 0.02 pCi/g. No PCBs were detected in any of the four composite samples which were analyzed at detection limits of 0.04 to 0.06 μg/g (ppm) (Table 5.5-11). Table 5.5-12 presents the results of CLP metals analyses for the mixed species composites. Metals which were not detected at CLP detection limits include aluminum, selenium, beryllium, cadmium, copper, silver, vanadium, barium, cobalt, nickel, and magnesium. Metals such as calcium and potassium occur naturally in living tissue, and the levels found in fish from Busch Lakes 34, 35, and 36 are not measurably different from the results from background lakes. Iron concentrations were found to be higher in samples from

Busch Lakes 34, 35, and 36 than from Busch Lake 37, the background lake. Iron was detected in concentrations ranging from 11.7 to 50.7 μg/g (detection limit of ≤10 μg/g) as compared to not detected (5.0 μg/g) in Lake 37.

Chromium was detected at 2.98 μg/g or roughly three times the detection limit in one mixed species composite fish sample from Lake 34.

The metals arsenic, mercury, thallium, and zinc were found in Busch Lakes 34, 35, and 36 at concentrations above the detection limits of 1.0 μg/g, 0.1 μg/g, 1.0 μg/g, 2.0 μg/g, respectively. These values are equal to concentrations found in Lake 37 (the background lake).

Arsenic levels of approximately 14 times the detection limit (1.0 μg/g) were found in fish samples from Lakes 35 and 37. Lake 37, the background lake with no hydric influence from the Weldon Spring site, recorded the highest levels of arsenic in fish.

Bioaccumulation factors (BF) were also calculated from PMC uranium data results. Bioaccumulation factors are an expression of the potential concentration of radionuclides in non-human receptors caused by contaminated soil, sediment, or water. These factors are used in human dose calculations to characterize levels of radionuclides in biota when actual concentrations are not available. Bioaccumulation factors can also be used to determine whether actual concentrations or radionuclides in fish are comparable to residual guidelines reported by the National Council on Radiation Protection (NCRP) (1985). Gilbert (1985) reports the bioaccumulation factor for uranium for freshwater fish at 2.0. The NCRP (1985) considers feeding preferences and habitats in reporting their BF, noting that "innate characteristics and behavioral attributes of organisms markedly affect the degree to which they accumulate radionuclides" (Whicker and Schultz, 1982). The NCRP (1985) reports bioaccumulation factors for uranium of 0.5 to 0.7 for predators (bass, gar), 0.3 to 09.6 for planktivorous (shad) and 0.7 to 38 for omnivorous (sunfish, catfish, carp).

The bioaccumulation factors for uranium have been calculated for fish collected at the WSS and Busch Wildlife Area and are shown in Table 5.5-13. The majority of the fillet samples fall into the ranges published by the NCRP and Gilbert. The exception is bass fillet from Lake 35 which has a bioaccumulation factor of 1.13 which is within the values reported by Gilbert but above the NCRP guidelines. In comparing the bass fillet to the bass whole from the same lake, the bioaccumulation factor for the whole samples (0.728) is lower. This result is not consistent based upon the contribution of uranium to whole-body is greater than the contribution to muscle or fillet tissues (NCRP 1985). A 63:1 ratio for whole body to muscle tissue concentration for radium-226 and a 1.6:1 for whole body to bone concentration were reported (Anderson 1963). All other samples tested for at the Weldon Spring site are within the value reported. The NCRP points out that sampling protocols, varying standards, and wet versus ash weight data conversion have a significant influence on the bioaccumulation factors (NCRP 1985).

5.5.5.2 Small Mammals. A small mammal study was conducted at the Weldon Spring site in 1987 (Figure 5.5-4). Animals collected include eight rabbits and three squirrels from the Ash Pond area, three rabbits from the chemical plant building area two rabbits from the Imhoff tank drainage area and three squirrels from the Frog Pond area. Table 5.5-14 presents the results of the radiological analyses of these specimens. Radiological contaminants were not detected within the analytical detection limits of 0.01 to 1.0 pCi/g.

5.5.5.3 Waterfowl. Five waterfowl were collected from raffinate pit 4 in 1990. Samples included three wood ducks, one mallard, and one Canada goose. The residence time of these birds was not known. Table 5.5-15 shows the results of radiological analyses. Overall, low levels of specific radionuclides were found in the samples, primarily in the organ samples. Radium-226 concentrations ranging from 0.001 to 0.028 pCi/g were detected in all organ samples. Concentrations in tissue samples were recorded at or below the detection limit. Radium-228 was detected at low levels in three of the eight samples with concentrations ranging from below detection level to 0.030 pCi/g.

Thorium-227 was detected in all samples in concentrations ranging from 0.037 pCi/g in goose organ samples to 0.800 pCi/g in wood duck flesh samples. Thorium-228 was detected in two organ samples, the goose organ and mallard organs samples, with concentrations of 0.008 pCi/g and 0.022 pCi/g, respectively. Thorium-230 was found in concentrations of 0.170 pCi/g in the composite duck organ sample, 0.040 pCi/g in the mallard duck organ sample, 0.483 pCi/g in the goose organ sample, and at low levels in the tissue samples. Thorium-232 was detected in the goose organ sample at 0.008 pCi/g.

Uranium-232, uranium-234, and uranium-238 were detected in all samples; concentrations reported were 0.002 pCi/g in the wood duck flesh sample, 0.006 pCi/g in the mallard flesh sample and 0.334 pCi/g in the composite duck organ sample. Uranium-235 was not detected in tissue samples but was detected in two organ samples, 0.005 pCi/g in the mallard organs and 0.020 pCi/g in the composite duck organs.

Background samples for the waterfowl were not collected and background levels are not currently available. Thorium-230, thorium-232, and uranium-238 are the primary radiological concerns in the raffinate pit. Bioaccumulation factors calculated for raffinate pit 4 waterfowl are listed in Table 5.5-15. Factors range from 0.0015 in wood duck flesh to 0.2118 in composite duck organs. The data results indicate that a very low level of accumulation is occurring in waterfowl. The surface water concentration of uranium averages 1,581 pCi/l and extremely low concentrations of uranium are shown in waterfowl samples reflected by low bioaccumulation factors. It must also be noted that no data is available on use and duration of stay at the raffinate pits by waterfowl taken for analysis.

5.5.5.4 Reptiles. One snapping turtle was collected in 1990 from raffinate pit 4 as part of the opportunistic sampling program. Skin, muscle, bone, and organs were sampled; the results are shown in Table 5.5-15. Bone samples contained the greatest radionuclide concentrations: radium-226 (3.89 pCi/g), radium-228 (4.05 pCi/g), thorium-228 (7.170 pCi/g), and thorium-230 (1.130 pCi/g). Skin samples showed the highest concentration of uranium-238 at 0.068 pCi/g. Bioaccumulation factors for the turtle ranged from 0.23 for muscle tissue to 5,121 for thorium-228 in bone samples (Table 5.5-16). Bioaccumulation factors calculated for the turtle sample indicates a high BF for all radium and thorium radionuclides in bone samples. These factors range from 62.5 for thorium-232 to 5,121 for thorium-228 bone samples. BFs for turtle flesh samples were considerably lower, ranging from 1.414 for radium-226 to 14.493 for thorium-230. Radium is known to accumulate in the bone and contributes approximately 80% to the whole body concentration over muscle concentration, which is less than 1%. Bioaccumulation factors for radium in fish are listed as 42 to 137 for fish while other lower trophic organisms range from 200 to 2,800 (NCRP 1985).

5.5.5.5 Ryckman/Edgerley/Tomlinson & Associates Biouptake Study. The RETA study conducted in 1978 was designed as a screening process to determine whether or not uptake of radioactive material was taking place in select organisms at or around the WSS. The RETA study included sampling of uranium, thorium, and radium in algae, cattail roots, and arrowhead roots. Also sampled were terrestrial organisms including smartweed, goldenrod, and animal organs such as raccoon stomach, intestine contents, bone and kidneys. Table 5.5-8 lists the results of the RETA sampling. Detectable concentrations of natural uranium were found in invertebrates at 1.7 μg/g (1.15 pCi/g), the gastrointestinal tract of raccoon, 13.3 μg/g (9.04 pCi/g) and aerial portions of smartweed plant at 45 μg/g (30.6 pCi/g). Uranium-238 was found in cattail roots at 723 μg/g (491 pCi/g). No detectable U-238 was found in organs of raccoon or opossum. Thorium-230 and -232 was detected at very low levels ranging from 8.9×10^{-14} to 4.9×10^{-11} pCi/g. Radium-226 also was found at extremely low levels, 3.3×10^{-12} and 3.2×10^{-13} pCi/g.

The data results were used to develop a generalized food chain relationship of contaminants. RETA (1978) found that some organism are accumulating contaminants at levels equal to or greater than levels in their substrates. "No organism, directly consumed by man was shown to be highly contaminated" (RETA 1978).

5.6 Air Monitoring

A continuous air monitoring program was established at the site in 1981 to quantify radon emanations from on-site contamination. Monitoring for external gamma radiation levels was initiated in 1982, and air particulate and asbestos monitoring began in 1987. Radon, thermoluminescent dosimeter (TLD) (gamma), and air particulate detectors are deployed around the site perimeter fence to ensure adequate detection of any contaminants dissipating from the properties. Detectors have also been placed near the Busch Wildlife Area headquarters to determine background levels. The detectors at Francis Howell High School and the Army reserve training area are used to assess exposure to students, hunters, and Army reserve personnel (Figure 5.6-1). Air monitoring data for the most current year, 1989, are shown in Tables 5.6-1 through 4.

Background concentrations of radon vary quarterly and annually. This is because the amount of radon that actually enters the atmosphere varies, depending on the radium concentration, moisture content, porosity and density of the soil, and the emanating fraction. The guideline for radon (Rn-222) at the site is an annual average of 3 pCi/l above background. Table 5.6-1 summarizes the quarterly and annual average concentrations of radon (Rn-220 plus Rn-222) at the chemical plant, raffinate pits, quarry, and off-site locations for 1989. The highest concentration measured was 52% of the DOE guideline of 3 pCi/l.

To determine background levels of gamma radiation as measured with TLDs, the gamma exposure rates at the four background monitoring stations were averaged. This yielded 68 ± 8.0 mR/year at two standard deviations.

In addition to monitoring gamma radiation with TLDs, natural background gamma radiation exposure rates were measured one meter from the ground surface with a pressurized ionization chamber (PIC) from October through December 1988. Total gamma exposure was integrated with the PIC over time intervals ranging from one to three hours at each measurement location. Based on this information, the background for this measurement period can be determined by averaging the results, which yields an estimate of the natural background surrounding the site of 8.9 ± 0.9 μR/hr at two standard deviations. This translates to a yearly average gamma exposure of 78 ± 7.98 mR at two standard deviations (8.9 μR/hr times 8,760 hours per year).

The average exposure as measured by TLDs is significantly lower than the average exposure as measured by the PIC at the 95% confidence level. This is probably due to the fact that the PIC measurements were short-term measurements (i.e., hourly) while the TLDs integrate gamma exposure for 13 weeks. Thus the TLD results provide a better estimate of natural background exposure.

Yearly background gamma exposures have been measured previously by the PMC and other contractors for the DOE around the site. Results have ranged from 60 to 104 mR/year (BNI 1985a, 1985b, 1984b; and MKF and JEG 1989a). There continues to be agreement between previous monitoring results and current results. This is expected because nothing has significantly changed the configuration or location of the wastes at the site.

Air particulate monitors did not detect any activity which was statistically different from the background station (AP-4007) activity. The annual average alpha concentration at each monitoring station is shown in Table 5.6-3. In all cases, the detection limits were less than the derived concentration guideline (DCG) for each radionuclide.

A routine environmental monitoring program for airborne asbestos was initiated in 1988 and continued through calendar year 1989. Samples were collected on a weekly basis at two of five site perimeter monitoring stations and at the Francis Howell High School monitoring station. The site perimeter samples were selected on the basis of the prevalent wind direction at the beginning of the sampling period. Daily asbestos monitoring was performed at the high school monitoring station during periods when asbestos abatement operations were being conducted at the site. Three interim response actions involving asbestos abatement were completed during the period from November 1988 to September 1989, i.e., overhead piping removal, building 409 dismantling, and building 401 dismantling.

Samples were analyzed by phase contrast microscopy (PCM). This method provides a total airborne fiber concentration for fibers having a size and shape which are characteristic of asbestos fibers. The method does not distinguish asbestos fibers from other airborne fibers having similar characteristics. The results of the PCM samples collected at the site perimeter and high school monitoring stations during calendar years 1988 and 1989 are provided in Table 5.6-4.

Selected samples were analyzed by transmission electron microscopy (TEM) during 1988-1989. This analytical method is capable of positive asbestos fiber identification. Twelve such samples were collected at the high school. The TEM samples ranged from less than 0.0005 to 0.060 structures per cubic centimeter of air (s/cc) and averaged 0.006 s/cc. Two site perimeter TEM samples were collected, with results of less than 0.001 and 0.004 s/cc. With the exception of several anomalous sample results, the results of the environmental monitoring program for calendar years 1988 and 1989 indicate no significant findings or trends.

Although no ambient air criteria have been established for airborne asbestos fibers, the clearance air limits established by the EPA for reoccupancy of school buildings (i.e., 0.01 f/cc for PCM and 0.005 s/cc for TEM) may be used as a basis for evaluation of the asbestos monitoring data. A further discussion of the asbestos monitoring results may be found in the Weldon Spring Site Remedial Action Project Annual Environmental Monitoring Reports.

6 ENVIRONMENTAL FATE AND TRANSPORT OF CONTAMINANTS

Investigations and studies that have been completed to date are discussed in Sections 3, 4, and 5. The results of these activities indicate that chemical and radiological contaminants have migrated off site. The sources of contamination at the Weldon Spring site are described in Section 5.1. Evaluation of the water quality of the receptor locations indicates that the major contaminants which have migrated off site are uranium, nitrate, and nitroaromatics.

The primary sources of uranium are (1) seepage from the raffinate pits, (2) surface runoff from the Ash Pond and Frog Pond areas, (3) contaminated soils scattered throughout the site, and (4) surface runoff and sewer discharge to the southeast drainage.

Seepage from the raffinate pits and Ash Pond and surface runoff from the Ash Pond area are the predominant sources of nitrate. An apparent intermittent source of nitrate is the surface discharge into the southeast drainage.

Major sources of nitroaromatics are indicated by high concentrations in groundwater near Frog Pond, in the northeast portion of the site (near process buildings), and in the area west and south of raffinate pit 4. Surface runoff from the site may contribute trace concentrations of nitroaromatics. Sources of nitroaromatics also exist off site.

6.1 Potential Routes of Migration

Whenever sufficient quantities of a contaminant are present, some migration is possible. The three most common migration pathways are air, surface water, and subsurface water. The most probable routes of migration from the Weldon Spring site are via surface and subsurface water.

6.1.1 Air

The release mechanisms for air transport of contaminants include the generation of fugitive dust, disturbance of friable asbestos, and to a lesser extent, volatilization of contaminants. The abundant vegetation cover on and surrounding the site, the climatic conditions (e.g., sufficient annual rainfall to minimize dust generation), and the general low volatility of the site contaminants minimize the potential for air transport (MKF and JEG 1988x; Peterson et al). In addition, no materials are currently being processed at the site. Although air transport of contaminants may have been important historically, results of air monitoring presented in Section 5.6 indicate that air transport is currently not a significant exposure pathway. However, the potential for air transport of contaminants may be increased during remediation activities involving construction and soil removal.

6.1.2 Surface Water

As discussed in Section 5.3, surface water flow in significant drainage features could permit the migration of contaminants from the site. The site can be divided into three general drainage systems (in Section 4.4): Ash Pond and the raffinate pits, Frog Pond, and the southeast drainage. Surface flow paths from the site are depicted in Figure 6.1-1. Results of water quality studies, seepage run studies, and dye tracing studies demonstrate that surface water released from the site affects streams, lakes, and springs within drainages 6200 and 6300 to the north and drainage 5300 to the southeast of the site (see Figure 4.4-4 for drainage designations).

Contaminant transport occurs when storm runoff flows over contaminated surfaces on site. Contaminants, which may be dissolved or suspended, are carried by the runoff and are either deposited in Ash Pond or Frog Pond or are discharged off site. Water within the raffinate pits and precipitation falling directly onto the pits are contained within the dikes, although seepage through the subsurface may occur.

Surface water runoff from the Ash Pond basin flows off site via the National Pollutant Discharge Elimination System (NPDES) outfall (NP-0003) at the northwest corner of the site (see Figures 4.4-2 and 4.4-3). The raffinate pit drainage runoff flows through a separate, more southerly outfall (NP-0004). As shown on Figure 4.4-3, runoff from relatively small areas on site bypasses the NPDES locations. These tributaries are ephemeral. They flow only after periods of rainfall and as minor drainage basins, and do not receive discharge from major source areas on site.

As discussed in Section 4.4, seepage run studies performed by the U.S. Geological Survey (USGS) indicate that both of these tributaries lose water to the subsurface. Missouri Department of Natural Resources (MDNR) dye tracing studies determined that this lost water resurfaces at Burgermeister Spring south of Lake 34 in an unnamed tributary to Dardenne Creek. During heavier flow conditions, however, the entire flow is probably not lost to the subsurface. Water that remains within the stream channel flows to Lake 35. The natural drainage area (drainage 6300) above Burgermeister Spring is about 144 ha (356 ac). Runoff from 688 ha (1,700 ac) in the adjacent watershed (drainage 6200) also contributes to flow at Burgermeister Spring. Approximately 8% of the total contributing runoff area is within the site boundary.

Frog Pond receives runoff from the eastern portion of the site. Frog Pond outflow and runoff from the northern portion of the site flow into an unnamed tributary of Schote Creek, which in turn flows into Lake 36. USGS seepage run studies indicate that this tributary does not lose water to the subsurface (Kleeschulte and Emmett 1986). The total drainage area at Lake 36 is 100 ha (244 ac), of which 27% (27 ha or 65.8 ac) is within the site boundary. Between Lakes 35 and 36, flow is normally lost to groundwater and is assumed to resurge in the Burgermeister Spring watershed (MDNR 1988a). Streamflow that is not lost to the subsurface flows into Lake 35. Water from Lake 35 is lost to the subsurface and appears to resurface in Lake 34 and at Twin Island Lake Spring within drainage 6300 (MKF and JEG 1988t).

Surface water leaving the southeast portion of the site at NP-0005 flows through the southeast drainage to the Missouri River. This drainage pathway also receives outfall (NP-0001) from an Imhoff tank (formerly the chemical plant sanitary sewage system). Currently, flow from the Imhoff tank consists only of stormwater infiltrating into the sewer system and not sanitary wastes (MKF and JEG 1988t). Although seepage run studies by the USGS (Kleeschulte and Emmett 1986) and MDNR (Hoffman 1987) indicate the existence of both gaining and losing stream reaches along the southeast drainage, essentially all water remains within the drainage basin. All flow eventually reaches the Missouri River. The total area of the southeast drainage at the confluence with the Missouri River is 151 ha (373 ac). About 6% of this area is within the site boundary and is identified in this report as the southeast site area.

6.1.3 Subsurface Water

Infiltration from precipitation is dependent on the type of surface cover. On the western portion of the site, storm water infiltrates the heavily vegetated soils with evapotranspiration processes being of significance in the first few meters of soil. The western portion of the site may also receive infiltration from surface water bodies, such as Ash Pond and the raffinate pits. On the eastern portion of the site, the ground surface is extensively covered by roads, sidewalks, and buildings, and infiltration to the unsaturated zone occurs primarily along drainage ditches, leaking storm sewer lines, and small areas covered by vegetation. Leaking storm sewer lines may act as infiltration galleries for the eastern end of the site (Figure 4.5-2). Infiltration from Frog Pond in the northeast corner of the site is of particular significance because the overburden is generally thinner in that area.

6.1.3.1 Subsurface Pathways Above the Water Table. Details about unsaturated flow paths at the site have not yet been determined; however, some general comments can be made. Although vertical cracks in the overburden may provide discrete conduits, the low hydraulic conductivities in the silty clay and clay overburden materials generally retard unsaturated flow in the vadose zone. While unsaturated flow generally occurs vertically, less permeable materials in the unsaturated zone at the site may cause significant lateral flow and perched groundwater. In particular, lateral migration is expected to occur at the residuum/bedrock interface because of a significantly lower hydraulic conductivity in the underlying bedrock. Perched groundwater is known to occur in the vadose zone below raffinate pit 3 and adjacent to pits 1, 2, and 4 (BNI 1986b). Moisture was also noted in the bottom few inches of silt just above each clay layer during lysimeter installation in the raffinate pit vicinity. In general, perched groundwater is expected to occur in silts or fill materials above clay layers that are below or near surface water bodies on site. Perched groundwater zones allow for increased lateral migration within the saturated lens before resuming predominantly unsaturated vertical flow toward the water table. Flow in the vadose zone at the site is schematically represented in Figure 6.1-2.

6.1.3.2 Groundwater Pathways. Groundwater flow in unconfined carbonate aquifers varies between diffuse-flow and free-flow end members (Fetter 1980; White 1988). Diffuse flow carbonate aquifers are commonly homogenous and relatively free of larger channels which may develop in response to solution activity. Free-flow carbonate aquifers receive diffused recharge but have well-developed solution channels along which most flow occurs. The upper zone of the Burlington-Keokuk aquifer at the site seems to exhibit aspects of both types of flow.

In diffuse-flow aquifers, water movement is along joints and bedding planes that have been only modestly affected by solution. Discharge is likely to occur through a number of small springs and seeps. In a typical diffuse-flow aquifer, the horizontal flow of water is along bedding planes. Vertical recharge and flow occur through fractures. The water table in diffuse-flow aquifers is well defined and can rise to a substantial elevation above the regional base level (Fetter 1980).

Free-flow carbonate aquifers have substantial development of solution enlarged passages. Not only are many joints and bedding planes enlarged, but some have formed large conduits. While all of the openings are saturated, the vast majority of flow occurs in the large channels, which behave hydraulically like pipe flow. Velocities are similar to surface streams. Flow is turbulent, and the subsurface conduit may carry a sediment load both as suspended material and as bedload. Regional discharge may occur through a few large springs, which are highly responsive to precipitation events. Because of the rapid drainage, the water table is nearly flat, with only a slight elevation above the regional base level (Fetter 1980).

Fracture or lineament traces at the surface may be indicators of higher hydraulic conductivity areas in carbonate terrains. As they represent the surface expression of nearly vertical zones of fracture concentration, they are often areas with hydraulic conductivity 10 to 1,000 times that of adjacent rock. Fracture zones can be tens of feet wide and have surface expressions such as swales and sags; vegetation differences resulting from variations in soil moisture and depth to the water table; alignment of vegetation type; and straight stream and valley segments. Linear surface features can reveal fracture traces covered by as much as 95 m (300 ft) of residual or transported soils (Fetter 1980).

The shallow bedrock aquifer of the Burlington-Keokuk Limestone in the Weldon Spring area can conceptually be classified as a diffuse-flow carbonate aquifer with some free-flow characteristics. In general, groundwater flows along fractures that are nearly horizontal and solution features that are parallel to bedding planes in the limestones; vertical connections are established by regionally extensive, nearly vertical joints and fractures. Groundwater flow in the bedrock trends away from the regional divide at elevations up to 36.6 m (120 ft) above the regional grade established by the Mississippi and Missouri Rivers (Figures 4.6-1 and 4.6-4). Ephemeral springs and seeps predominate over springs with perennial discharges.

In addition to the primary diffuse-flow character of the aquifer, evidence of free flow also exists. Some springs in the region appear to be fed by subsurface conduit flow (Figure 4.4-10). Conduit flow in the area around the site could be characterized by very high velocities and by linear paths up to several thousand meters in length. Water from Burgermeister Spring, a perennial spring to the north of the site, becomes cloudy in response to precipitation, which indicates turbulent subsurface flow. Surface features in the site vicinity, such as straight stream segments, indicate strong structural control (Figure 4.4-4). Figure 6.1-3 is a generalized depiction of structural control in a carbonate rock aquifer.

On Site. Groundwater flow within the upper bedrock aquifer in the immediate vicinity of the site is predominantly characterized by a diffuse-flow system. In a general sense, groundwater will flow perpendicular to the potentiometric contours as shown on Figures 4.6-5 to 4.6-8. Groundwater is presently believed to flow along thin fractures that are parallel to nearly horizontal bedding planes and, to a lesser extent, along vertical fractures with a limited degree of solution features. The upper 6.1 m (20 ft) of weathered bedrock seems to have a higher hydraulic conductivity than bedrock deeper within the shallow upper zone. Fracturing and weathering in the upper 3 to 6.1 m (10 to 20 ft) of bedrock near the water table probably cause the potential groundwater flow paths to be more closely spaced and interconnected. Flow in the upper few feet of saturated thickness may approximate flow in a homogeneous medium. As the intensity of weathering and fracturing decreases with depth, the aquifer becomes less homogeneous, and the flow paths spread further apart. In the competent (unweathered) bedrock, where the deep monitoring wells are located, flow paths may be predominantly horizontal along bedding planes and the influence of the vertical fractures more limited. This premise is supported by the decreased mean hydraulic conductivity observed with depth and may account for the lower potentiometric surface at depth.

The degree of heterogeneity in the groundwater flow regime beneath the site is, in part, dependent on the spacing and aperture of the vertical fractures and horizontal bedding planes. Zones in which fracturing is more intense may act as vertical pathways for groundwater or horizontal conduits of higher flow rate than the surrounding bedrock. Possible locations of more highly fractured zones may be inferred by examining the linear depressions in the weathered bedrock topography (Figure 4.3-17). As suggested by Figure 4.3-22, these depressions may represent deeper weathering of bedrock below ancient drainages located along a local fracture trace or fracture zone. Some or all of these features may indicate locations of potential paths for groundwater flow. While the presence of groundwater conduit flow pathways beneath the site has not been verified, this type of flow may be responsible for contaminant concentration distributions in the groundwater or springs.

Near surface groundwater flow paths may be defined by the relationship between the water table elevation and the deeply weathered zone near the top of the bedrock (Figure 4.6-18). The top 3 to 6 m (10 to 20 ft) of weathered bedrock are believed to possess a higher hydraulic conductivity than the deeper, unweathered bedrock. In areas where the upper 3 m (10 ft) of weathered bedrock are saturated, a significant volume of groundwater may move in a preferred horizontal direction and at a greater velocity than groundwater moving through bedrock at depth. The location and extent of these flow paths may vary seasonally with fluctuations in the water table elevation.

Under the site, groundwater flux to deeper levels is slowed by the general tightness of vertical fractures and by thin shaley layers observed between limestone beds in the Burlington-Keokuk Limestone (BNI 1987). Continued migration to deep productive aquifers, such as the St. Peter Sandstone, is impeded by an approximately 106.6-m- (350-ft-) thick sequence of sedimentary rocks, classified by the USGS (Kleeschulte and Emmett 1986) as a leaky confining bed of low hydraulic conductivity. These rocks include the Maquoketa Shale, Kimmswick Limestone, shales in the Decorah Formation, and underlying Ordovician siltstone, limestones and dolomites (MKF and JEG 1988t). According to USGS simulation models, the time required for surface recharge to reach the deep aquifers is on the order of hundreds of years (Kleeschulte 1991).

Off Site. Potential pathways for contaminant migration off site include the diffuse-flow fracture system, as well as free-flow conduits. Both types of pathways occur to the north and south of the groundwater divide.

Diffuse-flow pathways for groundwater toward the north include nearly horizontal fractures and solution features and vertical fractures and fracture zones. Pathways made by fractures are expected to have a preferred orientation within the regional joint set orientation of N 30-60° W and N 30-70° E (Kleeschulte and Emmett 1987). Flow may occur along preferred pathways where joints intersect bedding. Potentiometric surface maps show a steep gradient in the vicinity of monitoring wells MW-2023 and MW-2024. Diffuse groundwater flow off site is to the northeast in the vicinity of wells MW-4009 and MW-4002 (Figure 4.6-5). Receptors of groundwater flow north of the divide include private wells, springs, and Dardenne Creek.

Figure 4.6-3 illustrates the potentiometric surface of the water table aquifer in the vicinity of the chemical plant. The prominent feature of the potentiometric surface is a linear depression which extends from the area west of the chemical plant northward toward Burgermeister Spring and Lake 34. Figure 4.6-5 is a potentiometric map of the water table aquifer in the chemical plant and raffinate pit areas. The steep potentiometric gradient near MW-4002 and the linear depression shown in Figure 4.6-3 are inferred to be a function of both surface relief and conduit flow. In the vicinity of the chemical plant and the raffinate pits areas, the axis of the linear depression parallels the surface drainage pattern. Toward Burgermeister Spring, however, the linear depression crosses a subdrainage divide. The MDNR conducted groundwater dye tracing tests which confirmed the presence of conduit flow within the area of the linear depression. Figure 6.1-1 illustrates the locations where the dye traces were initiated and the resurgence points (springs) for those traces. Conduit flow by its nature is orders of magnitude greater than the predominant Darcian-type diffuse flow.

The potentiometric surface suggests that to the southeast, diffuse flow is predominant. Discharge points for groundwater flow to the southeast are perennial springs within the surface drainages toward the Missouri River. Perennial springs SP-5501, SP-5402, SP-5303, and SP-5104 occur between elevations 167.4 m (550 ft) and 182.9 m (600 ft) mean sea level (NGVD). Perennial springs SP-5604, SP-5304 and SP-5105 occur at about elevation 152.4 m (500 ft) NGVD. Groundwater discharge may occur at these elevations due to changes in lithology or bedding planes in the Burlington-Keokuk Limestone. Vertical flow may be impeded by semi-confining beds causing groundwater to flow laterally toward the slope surface (Figure 6.1-4).

A generalized representation of potential subsurface pathways as discussed above is presented in Figure 6.1-5. The conceptual model will be modified as new information from both on-site and off-site investigations becomes available.

6.2 Contaminant Persistence and Attenuation

The geochemical mechanisms that affect the persistence and attenuation of the various contaminants in soil, surface water, and groundwater include oxidation, reduction, precipitation, and adsorption. These mechanisms depend upon the chemical character of the soil and water. The geochemical behavior, coupled with the previously described hydrologic flow patterns, controls the transport of contaminants. This subsection describes the geochemical relationship between the contaminants and the subsurface environment that affect contaminant transport in the limestone groundwater system.

In an undisturbed natural system, a steady state is established between the chemical composition of an aqueous phase and the mineralogy of a host geologic medium. When a waste solution or source is introduced, disequilibrium results. Chemical reactions between the geologic medium and aqueous phase will occur as the system moves to reestablish a state of equilibrium. These reactions may act to retard or facilitate migration of the contaminant.

The primary chemical mechanisms that retard contaminant migration within the vadose zone are oxidation-reduction, precipitation, and adsorption. If transport of contaminated water through the system is more rapid than the kinetics of the chemical reactions, equilibrium is unlikely to be achieved. However, in simple systems it may be possible to constrain the mechanisms controlling contaminant behavior. Conversely, in instances where contaminant water mixes with waters having different chemical compositions transport mechanics become less predictable.

The primary mechanisms that appear to limit contaminant concentrations within the weathered and competent zones of the bedrock aquifer are diffusion, dilution, and oxidation-reduction. In ground and surface waters, adsorption and dilution are the primary processes by which contaminant concentrations are reduced. Chemical reduction, which may lead to precipitation, does not occur in water in contact with the atmosphere, but reduction-induced precipitation does occur in sediments with low redox potential (Eh). Photolysis (decomposition by light) is an important process for degradation of some contaminants, especially nitroaromatics, in surface water.

The elements and compounds described in this section are those identified in Section 5 as potential contaminants: uranium, vanadium, molybdenum, nitrate, sulfate, nickel, chromium, aluminum, and nitroaromatics. The mechanisms of transport and retardation as described herein are based upon the observed chemical distribution across the site, an understanding of general chemical properties of the elements and compounds, and calculations performed using the geochemical computer code PHREEQE (described in Appendix C).

6.2.1 Uranium

The mobility of uranium in surface water and in groundwater within the vadose zone is enhanced by the formation or uranyl carbonate and phosphate complexes. Uranium migration is retarded by precipitation of uranium minerals, substitution of uranium for other cations in minerals such as apatite, and adsorption onto oxyhydroxides and organic matter in the soils (Schumacher and Stollenwerk 1991). The high concentration of uranium in the raffinate pits decreases significantly in the overburden (Table 5.4-1) and drops to nearly background levels in the weathered limestone aquifer immediately adjacent to the pits. The oxidizing conditions present in the raffinate pit waters coupled with the availability of vanadium and potassium favors the precipitation of the uranium vanadate minerals carnotite and tyuyamunite (Schumacher and Stollenwerk 1991). According to Schumacher and Stollenwerk (1991), uranium vanadates have been observed in the pit sludges; however, their abundance is not sufficient to account for the dramatic reduction in uranium concentrations in the groundwaters beneath the site. More likely, these reductions reflect attenuation by sorption reactions with oxyhydroxides present in the Ferrelview Formation and clay till beneath the pits. Alternatively, these decreases may result from dilution with uncontaminated groundwater. At present, it is difficult to determine if one or both of these processes are controlling uranium concentration.

If conditions become sufficiently reducing with depth beneath the site, uraninite, a relatively insoluble mineral, would become the stable uranium phase. Uraninite has not been identified in the soils and pit sludges from the Weldon Spring site. Groundwater modelling with PHREEQE (Table C-1, Appendix C) indicates that the sampled groundwaters are undersaturated with respect to uraninite; thus precipitation of uraninite is not expected to occur even under favorable Eh conditions. This undersaturation may result from dilution with uncontaminated groundwater or uranium attenuation by reactions with the shallow level soils.

6.2.2 Vanadium and Molybdenum

Vanadium and molybdenum are common constituents in uranium ores and, therefore, occur as impurities in yellowcake (Harshman 1974). Vanadium and molybdenum were separated from uranium during chemical processing and are thus significant components of the raffinate sludges and liquids. The association of these elements with uranium reflects their similar chemical properties. In general, uranium, vanadium, and molybdenum are soluble in oxidizing conditions and precipitate as oxides in reducing environments. All of these metals exist as anionic species in their oxidized forms. The most important mechanism for retardation of vanadium and molybdenum in oxidizing conditions is coprecipitation with ferric hydroxides (Evans and Garrels 1958; Kaback and Runnels 1980; Howard 1977).

Although vanadium and molybdenum are present in the liquids and sludges in the raffinate pits these elements are not detected at significant levels in the groundwater. This distribution pattern suggests that retardation occurs near the interface between the raffinate pits and the soil. Although surface water is a significant transport medium for uranium, vanadium and molybdenum are not present at detectable concentrations in the surface water. The apparent divergence in the geochemical behaviors of these elements is likely to be a function of the low levels of vanadium and molybdenum in the soils in comparison to those of uranium.

6.2.3 Chromium, Nickel, Copper, Zinc, and Lead

Concentrations of chromium, nickel, copper, zinc, and lead are above estimated background levels in the sludges of the raffinate pits and in a few of the monitoring wells on the site. In reducing environments, most of these metals precipitate as sulfide or hydroxide minerals. Except for chromium, the dissolved metals exist as cations or as complexes with anions such as bicarbonate/carbonate, sulfate, or chloride (Forstner and Wittmann 1983). In natural waters at near neutral pH values, chromium exists as a hydroxide complex.

Calculations using PHREEQE predict that chromium at the site should exist in the trivalent form (Cr^{+3}), with the aqueous species being $Cr(OH)_2^+$, which is relatively insoluble and precipitates as chromium hydroxide ($Cr(OH)_3$). At the pH values measured for site groundwater, calculations with PHREEQE indicate that the groundwater at the site is undersaturated with respect to chromium hydroxide (Appendix C); this suggests that the source of chromium is not within the aquifer or that there has not been sufficient time to establish equilibrium between the groundwater and aquifer minerals. The chromium source is presumed to lie in the overburden soils. Chromium leached from these soils is subsequently diluted as downward migrating fluids reach the water table.

Calculations with PHREEQE (Appendix C) for the other metals indicate that the dominant aqueous species at the site are divalent nickel (Ni^{2+}) and nickel bicarbonate ($NiHCO_3^+$), monovalent copper (Cu^+), and cupric carbonate ($CuCO_3$), divalent zinc (Zn^{2+}), and zinc bicarbonate ($ZnHCO_3^+$), and divalent lead (Pb^{2+}). Uncomplexed copper, nickel, lead, and zinc ions are likely to be adsorbed onto the charged surfaces of clay minerals in overburden soils, but metals complexed by anions are much less likely to participate in sorption reactions.

However, these metals are removed from groundwater by coprecipitation with iron hydroxides. The saturation indices of the nickel-, zinc-, and copper-bearing iron oxide minerals are listed on Table C-2 (Appendix C). Thermodynamic data for these mineral reactions are somewhat uncertain; therefore, a broader range of the saturation index (defined in Appendix C) should be used to estimate the formation and stability of these minerals. The fact that the saturation index for the zinc and copper minerals ranges from -1 to +1 suggests that groundwater concentrations of these elements are controlled by equilibrium with iron hydroxides in the host bedrock. This hypothesis is consistent with reports that zinc and copper are part of the natural mineralization of the bedrock (Conner and Ebens 1980).

The saturation index for the nickel-iron oxide mineral is in excess of 1. This indicates that precipitation should occur. The fact that nickel iron hydroxides have not been observed in the system may be due to slow kinetics for this reaction. No conclusion can be reached regarding the location of the nickel source.

6.2.4 Aluminum

Aluminum is predominantly complexed by hydroxide, but when fluoride is present, such as in the water adjacent to the raffinate pits (MW-3008), a significant proportion of the aluminum is present as aluminum-fluoride complex. Groundwater samples from areas that are likely to have been impacted by site activities (MW-3008, MW-2006, MW-2017) (Appendix C) are in equilibrium with aluminum hydroxide ($Al(OH)_3$) (saturation index - 0). Aluminum hydroxide saturation does not generally occur in natural groundwater systems. In undisturbed groundwater, the aluminum concentrations are commonly in equilibrium with alumino-silicate minerals. Equilibrium with respect to aluminum hydroxide may be evidence for a relatively recent discharge of an acidic or basic solution that created conditions favorable to leaching aluminum from alumino-silicate minerals in the soils. As the affected groundwater migrated further from the acid/base source, the buffering action of the limestone minerals returned pH conditions to their normal, near neutral, levels, and aluminum was removed from solution by precipitation as aluminum hydroxide.

6.2.5 Nitrate

A significant nitrate source exists in the raffinate pits. Nitrate has been detected at concentrations above background levels in off-site groundwater and in surface water originating from Ash Pond and in water in the southeast drainage. Nitrate is a highly soluble anion that is not readily adsorbed, thus it is mobile in ground and surface waters. Two potential mechanisms for removing nitrate from the groundwater are chemical reduction to nitrite and ammonia and biological uptake within the root zone.

Groundwater modelling, using PHREEQE (Appendix C), predicts that chemically reducing conditions, which may be present beneath the site, should promote the chemical reduction of nitrate to nitrite and ammonia. At the measured pH and estimated Eh values for the site groundwater, the predominant nitrogen species is predicted to be ammonia; however, the observed species is nitrate. Studies of interstitial waters from raffinate pit 3 sludges conducted by Schumacher and Stollenwerk (1991) found that concentrations of reduced nitrogen species did increase with depth below the sediment-water interface but only accounted for a small fraction of the available NO_3. The high nitrate and low nitrite and ammonia concentrations measured for the sludge and ground waters indicate that either Eh values are too high for nitrate reduction or the kinetics of this reaction are extremely slow. Although nitrate concentrations in raffinate pit waters are high, they decreased by one to two orders of magnitude between 1961-1987 (Table 5.1-13). This decrease is attributed to nutrient cycling in which nitrate is reduced by algae and other organisms.

6.2.6 Sulfate

The raffinate pits are also the expected source of elevated sulfate levels in the ground and surface water. This sulfate is derived from sulfuric acid and sodium sulfite, which were used in the ordnance works operations. Similar to nitrate, sulfate is a highly soluble anion and is not attenuated by adsorption. At low Eh values, sulfate is reduced to sulfide and commonly precipitates with iron as pyrite. Calculations using PHREEQE (Appendix C) indicate that under the oxidizing to moderately reducing conditions expected for site ground and surface water, the concentrations of sulfate are controlled by gypsum equilibria. The redox potential estimated for the groundwater does not appear to be sufficiently low to promote chemical reduction of sulfate to sulfide. Therefore, any decrease in sulfate concentrations along the groundwater flow path is probably due to gypsum precipitation, diffusion, or dilution. Water samples taken from areas removed from the raffinate pits have lower sulfate concentrations and are unsaturated with respect to gypsum. Thus a significant source of sulfate is not expected to be present in the bedrock.

6.2.7 Nitroaromatics

The production and handling of trinitrotoluene (TNT) and dinitrotoluene (DNT) at the ordnance works contributed solid nitroaromatic residues to the soils. Groundwater analyses indicate at least three source areas at the site; however, soil investigations have not detected nitroaromatic contamination in the quantities expected based on the extent of groundwater contamination. With distance from the apparent sources, concentrations of nitroaromatics in the groundwater decrease markedly to a range of low values (generally less than 2 μg/l). These values appear consistently in groundwater on and off the site (Appendix B).

Based upon groundwater analyses of nitroaromatic compounds, a conceptual model has been developed in which the primary source of these compounds is assumed to lie in the vadose zone. Groundwater infiltrating the vadose zone leaches nitroaromatic compounds from the contaminated soil and rock, with concentrations being governed by the solubility of these compounds in water. Migration of nitroaromatic compounds is limited by degradation and readsorption as the contaminated water migrates through uncontaminated portions of the vadose zone. When contaminated recharge from the vadose zone reaches the water table, contaminant concentrations are further decreased, in the direction of flow, by diffusion and by dilution.

The mobility of nitroaromatics in soils, surface water, and groundwater is controlled by solubility, adsorption, volatilization, and degradation. These reactions occur in a broad range of pH conditions; however, reaction rates are typically faster at low pH values. Based on their environmental impact, the nitroaromatics can be divided into two groups: nitrobenzenes and nitrotoluenes. Generally, nitrobenzenes are slightly more soluble and more toxic than the nitrotoluenes. The nitrotoluenes are of greater concern due to their carcinogenic characteristics, especially 2,6-DNT. Predictions for the persistence and attenuation of nitroaromatics in the environment are based on physical, chemical, and biological information from the literature. These properties of the nitroaromatic species are presented in Table 6.2-1.

6.2.7.1 2,4,6-Trinitrotoluene (TNT). The solubility of 2,4,6-TNT is about 150 mg/l at 25°C (Burrows et al. 1989). Upon exposure to sunlight or ultraviolet light, TNT in an aqueous solution undergoes photolytic decomposition. This process is accelerated both by the products of TNT photodecomposition and by photosensitizing solutes such as humic and fulvic acids, which are common in some natural waters. Decomposition is retarded by dissolved oxygen. Under favorable conditions in natural surface waters, the half-life of TNT due to photolytic degradation is estimated to be 3 hours or less (Spanggord et al. 1980).

In natural waters the end-product of photodegradation of 2,4,6-TNT is 1,3,5-trinitrobenzene; in distilled water the end-products are 2,4,6-trinitrobenzonitrile and 1,3,5-trinitrobenzaldehyde (Environmental Science and Engineering 1986). These photoproducts will readily volatilize from sediments and water (Callahan et al. 1979). However, based on the relatively low Henry's Law constant for 2,4,6-TNT (0.18 torr M^{-1}), volatilization is not an expected pathway for attenuation of 2,4,6-TNT (Spanggord et al. 1980).

The tendency for 2,4,6-TNT to adsorb to soils is primarily dependent upon the organic content of the soil (Environmental Science and Engineering 1985). Due to the extremely low organic content of the Ferrelview and clay till formations, adsorption is not expected to be a significant retardation factor in Weldon Spring site soils. Minimal adsorption is expected on carbonate minerals and chert concretions in the limestones, so dispersion and dilution are the most likely mechanisms for decreasing TNT concentrations in the bedrock aquifer.

The biotransformation of 2,4,6-TNT in natural waters is very slow, even in the presence of organic nutrients (Spanggord et al. 1980). The half-life for biotransformation of 2,4,6-TNT in surface waters is estimated to be 8 to 25 days, which is far longer than that for photolysis (Burlinson 1977). Hence, the degradation of TNT in surface water will primarily be controlled by photolysis.

The biotransformation process for 2,4,6-TNT involves reduction of the nitro groups through the nitroso and hydroxyl amino to either amines or azoxy dimers. Bacteria- and fungi-aided transformation of TNT in soil is known to occur under both aerobic and anaerobic conditions. Biotransformation products include 4-amino - 2,6-dinitrotoluene, 2-amino 4,6-dinitrotoluene, 2,6-diamino - 4-nitrotoluene, 2,4-diamino - 6-nitrotoluene, 4-hydroxylamino - 2,4-dinitrotoluene, 2,2',6,6'-tetranitro - 4,4'-azoxytoluene, and 4,4',6,6'-tetranitro - 2,2'-azoxytoluene (McCormick et al. 1978)

The environmental factors shown to affect the rate of TNT transformation include initial TNT concentration, soil moisture, the presence of microorganisms, temperature, and oxygen levels. Of these factors, the initial concentration of TNT has the greatest overall effect on the rates of biotransformation; the greatest biotransformation rates occur at low concentrations of TNT (0.1%), with progressively slower transformation rates occurring at 1% and 10% concentration of TNT (Kaplan et al. 1985). After TNT concentration, the presence or absence of microorganisms and temperature have the greatest effect. Moisture level is less important, and organic matter and oxygen levels have relatively insignificant affects on the rate of biotransformation; however, the presence or absence of oxygen does alter the biotransformation products. Under anaerobic conditions, production of triamine is increased, whereas aerobic conditions lead to the formation of diamine and monoamine.

6.2.7.2 1,3,5-Trinitrobenzene (TNB) and 1,3-Dinitrobenzene (DNB). TNB detected at the site is probably the product of photolytic oxidation of the TNT methyl group. TNB is a very stable compound; it is resistant to hydrolysis and is not photolytically or biochemically degraded or transformed as readily as TNT. TNB is essentially insoluble in water.

The volatility of TNB is nearly an order of magnitude greater than that of TNT (Table 6.2-1) (half-life is approximately 130 days); hence, volatilization is expected to have a significant effect on TNB concentrations in surface water. TNB has a sorption partition coefficient (K_{OC}) for organic carbon of 520 and is readily adsorbed onto sediments and soils having a sufficient organic fraction. Due to the very limited organic content of the site soils, however, adsorption is probably not a major factor in retarding migration of TNB. Volatilization is also not considered a significant factor affecting the persistence of TNB in soils.

1,3-DNB is sparingly soluble in water and is slightly less volatile than TNB (Table 6.2-1). Studies have shown that DNB is subject to photolysis, but the rate of volatilization is much higher than that of TNB; hence, volatilization is considered to be the more important process controlling TNB levels in surface waters. DNB is not expected to be as strongly adsorbed onto soils as TNB as indicated by its lower K_{OC} value of 64. Alexander and Lustigman (1966) reported that 1,3-DNB is resistant to attack by soil microorganisms but found that it is almost completely degraded in a two-stage model wastewater treatment system Bringman and Kuehn (1971). Laboratory studies performed by McCormick et al. (1978) using a bacterial enzyme preparation demonstrated that 1,3-DNB and 1,3,5-TNB were reduced by hydrogen.

6.2.7.3 2,4- and 2,6-Dinitrotoluene (2,4-DNT and 2,6-DNT). 2,4-DNT and 2,6-DNT are formed as impurities and intermediates during the production of TNT. They are only sparingly soluble in water. Based on calculated soil adsorption coefficients (Spanggord et al. 1980), both DNT compounds are expected to have only a slight tendency to adsorb onto soils, sediments, and suspended solids. Biotransformation may occur in both the aerobic and anaerobic soil zones. In natural water systems, large amounts of supplemental carbon are needed for biotransformation to occur. In surface water, photolysis is rapid and is probably the most important process for DNT removal. Volatilization may be a significant factor for 2,6-DNT in surface water but not for 2,4-DNT; neither compound is expected to volatilize from soils.

The biotransformation products of DNT are the aromatic amines and aminonitrotoluenes and include 2-nitroso - 4-nitrotoluene, 2-amino - 4-nitrotoluene, 4-amino - 2-nitrotoluene, 4-nitroso - 2-nitrotoluene, 2,2'-dinitro - 4,4'-azoxytoluene, 4,4'-dinitro - 2,2'-azoxytoluene, 4-acetamino - 2-nitrotoluene, 4-methyl - 3-nitroaniline, and 2-methyl - 5-nitroamine (McCormick et al. 1978). Many of the biotransformation products are toxic and act to inhibit the biotransformation process. With sufficient supplemental carbon, anaerobic biotransformation proceeds much faster than aerobic biotransformation and favors the production of the amine 2-methyl - 5-nitroamine.

Both isomers of DNT rapidly photolyze in ultraviolet light or sunlight. Photolysis of 2,4-TNT results in production of the following compounds: 2,4-dinitrobenzaldehyde, 2-amino - 4-nitrobenzaldehyde, 2,2'-carboxaldehyde - 5,5'-dinitroazoxybenzene, 2,4-dinitrobenzoic acid, 2-amino - 4-nitrobenzoic acid, and 2,2'-carboxy - 5,5'-dinitroazoxybenzene (Burlinson and Glover 1977).

The nitrobenzoic acids may be further broken down into other products such as 1,3-dinitrobenzene. Reaction products are carbon dioxide, water, and nitric acid. In sunlight, the photolytic half-life for 2,4-DNT is estimated to be from 2 to 10 hours, depending upon the amount of humic substances present and the concentration of activated transformation products. These factors can accelerate the rate of photolysis by 1.3 to 2.5 times (Simmons and Zepp 1986).

The photolytic half-life for 2,6-DNT is approximately 12 minutes by indirect photoreaction. In natural water, the rate is affected by the presence of humic materials, which can accelerate photodecomposition 11 to 17 times (Mill and Mabey 1985; Simmons and Zepp 1986).

In water the half-life for volatilization of 2,4-DNT is estimated to be 410 days (Spanggord et al. 1980); hence, this process is not considered a significant environmental pathway for 2,4-DNT. On the other hand, the volatilization half-life for 2,6-DNT is considerably shorter (140 days) (Spanggord et al. 1980) indicating that volatilization may be an important environmental fate process for 2,6-DNT.

6.2.7.4 Nitrobenzene (NB). Nitrobenzene is moderately soluble in water and has a moderate tendency to adsorb onto soils and sediments, especially those with high organic content. In soils, nitrobenzene is readily degraded by biologic agents under both aerobic and anaerobic conditions. Reduction of the nitro (NO_2) group of nitrobenzene is an important degradation process in groundwater under reducing conditions, such as may be present in the groundwater beneath the Weldon Spring site. Nitrobenzene in surface waters is degraded by sunlight. The photolytic half-life of nitrobenzene is estimated to be 133 days but may be accelerated by the presence of humic substances and nitrate ions (Simmons and Zepp 1986). The main photoproducts are azobenzene and aniline (Barltrop and Bunce 1968).

6.3 Contaminant Transport

This subsection describes the hydrologic and geochemical factors that are likely to control transport of the primary contaminants at the Weldon Spring site. Theoretical descriptions are presented for the three major contaminant transport systems: (1) the surface runoff and groundwater flow from Ash Pond and the raffinate pits toward the north, Lakes 34 and 35 and Burgermeister Spring, (2) the surface runoff and groundwater flow from the northeast corner of the site and Frog Pond toward Lakes 34, 35 and 36, and (3) the surface runoff and groundwater flow from the site in the southeast drainage toward the Missouri River. The basis for these descriptions includes (1) the qualitative surface and subsurface hydrology, (2) the characteristics of the sources of contaminants within the site, and (3) the observed water quality in the surface water and groundwater.

6.3.1 General Concepts of Contaminant Transport

Contaminant migration from the site into the surrounding environment is controlled by a combination of hydrologic and geochemical factors. Hydrologic factors include flow patterns and velocities for both surface water and groundwater. Geochemical factors include interactions between the contaminants and the chemical environment that lead to changes in the concentrations along flow paths.

Fundamental controls on the hydrologic flow patterns and velocities are the subsurface geology, surface features, and meteorology. Groundwater flow in the site vicinity is significantly influenced by recharge from surface flows and discharge to springs and seeps. The groundwater flow system is composed of diffuse flow, characteristic of a porous medium, and free flow, characterized by bedrock conduits and channels (Section 4.6.1).

As groundwater passes through geologic media, changes in contaminant concentrations occur by the physical processes of dispersion and dilution as contaminated water mixes with uncontaminated water, and by geochemical processes. Geochemical processes that significantly affect the transport of specific elements at the site include adsorption and precipitation of uranium and other metals, biological uptake and biochemical reduction of nitrate, and chemical degradation and adsorption of nitroaromatics.

6.3.2 Contaminant Transport from Ash Pond and the Raffinate Pits

Contaminant transport from the west-northwest portion of the site occurs through seepage from the raffinate pits, discharge of contaminated surface water from the raffinate pits area and Ash Pond, and flow of groundwater in a northerly direction. The groundwater discharging from Burgermeister Spring represents a mixture of contaminated seepage from the raffinate pits, surface water infiltration and recharge to the groundwater, contaminated recharge from losing streams north and northwest of the site, and groundwater from recharge areas to the west of the site. The groundwater from the west may contain elevated levels of nitroaromatic compounds from contaminated soils in the Weldon Spring Training Area to the west of the site (Campbell Design Group and Geotechnology, Inc. 1987 and Law Engineering, Inc. 1988).

Lysimeter and overburden monitoring well samples reveal chemical changes in water seeping from the raffinate pits and moving through the clayey soil profile (Table 5.4-1). Water collected in the lysimeters also reflects leaching of contaminated soils as rainfall percolates through the soil column. The chemical character of the aqueous phase that descends to the groundwater is determined by the interaction within the vadose zone of seepage from raffinate pits, leachate from contaminated soil, and infiltration from rainfall.

In general, the major differences between the chemical characteristics of the raffinate pit and soil solutions collected in the lysimeters are lower nitrate, uranium, and sodium concentrations and lower pH in the soil solutions (Table 5.4-1). The changes in uranium and nitrate levels indicate that uranium adsorption and/or precipitation, and nitrate uptake within the root zone are occurring in the soils, as previously described.

The decrease in pH and sodium concentrations between the raffinate pit water and the vadose zone water is thought to be caused by the cation exchange of sodium for hydrogen on the charged edges of clay minerals. In a natural state, clay minerals may have edges with hydrogen balancing the negative charge of the oxygen ion. As water with high pH and high sodium concentrations migrates through the clay-rich vadose zone, sodium exchanges with the hydrogen that is bonded to the clay minerals. Hydrogen ions added to solution combine with the carbonate anion to form bicarbonate ($CO_2^{-3} + H^+ = HCO_3^-$). The loss of carbonate to bicarbonate promotes the dissolution of calcite, an abundant mineral in the overburden. This may account for the decreased sodium concentration and increased calcium and magnesium concentrations in the deeper lysimeter samples.

Groundwater beneath the raffinate pits and Ash Pond generally flows toward the north. As groundwater flows beneath Ash Pond, the concentrations of certain contaminants decrease significantly (especially nitrate, sulfate, and aluminum; Figures 5.4-3, 5.4-5, and 5.4-9, respectively). This decrease in concentrations may be due to a lack of hydraulic communication across the upper reaches of the subsurface conduit which connects the stream downstream of Ash Pond with Burgermeister Spring.

Surface water discharged from the site and additional runoff from watershed 6200 are lost to the subsurface just west of the site. This surface recharge mixes with groundwater derived from the site and regional recharge. Water emerging at Burgermeister Spring represents this combination of sources. Compared to the surface water discharged from the site and to the groundwater beneath the site, water from Burgermeister Spring contains significantly less uranium and nitrate. Concentration levels are orders of magnitude less than the maximum level detected in site groundwater. The lower concentrations of these constituents are likely due to dilution and to chemical reactions within the subsurface.

As discussed in Section 5.3 and illustrated in Figure 6.3-1, nitrate concentrations at Burgermeister Spring are inversely proportional to discharge. The inverse relationship between concentration and discharge suggests that runoff lost to the subsurface mixes with the groundwater to dilute nitrate concentrations (Figure 5.3-9). In contrast, uranium flux is roughly directly proportional to discharge at Burgermeister Spring, indicating that surface runoff is the primary vehicle for uranium transport (Figure 6.3-2).

6.3.3 Contaminant Transport from Frog Pond and Process Area

Uranium is transported off site in surface discharge from Frog Pond and in runoff from the northeast portion of the chemical plant. Nitroaromatics are primarily transported off site in groundwater. The source of nitroaromatic compounds appears to lie within the vadose zone near the historic TNT processing line (near the present location of Frog Pond).

Surface water from Frog Pond discharges into a tributary to Lake 36 which, in turn, drains into Lake 35. Uranium transport to these lakes is indicated by elevated uranium concentrations in the inflow and outflow of Lake 36 and in the sediments of the lakes. Elevated sodium and chloride concentrations, characteristic of the surface water discharge from Frog Pond, are also measured in Lake 36. Significant dilution of sodium and chloride occurs between the outflow of Lake 36 and the inflow of Lake 35. The decrease in uranium between Lakes 36 and 35 is not comparable to that of sodium and chloride, suggesting that the drainage from Ash Pond which joins the drainage from Frog Pond downstream from Lake 36 contributes significant concentrations of uranium. During periods of high flow, not all of the discharge from Ash Pond and the raffinate pits area is lost to the subsurface.

Nitroaromatics appear to be transported from the sources within the vadose zone to the groundwater, which flows in a north-northwesterly direction. Because of degradation upon exposure to sunlight, surface water is not a significant transport medium for nitroaromatics. Low concentrations in the groundwater monitoring wells near the northern site boundary probably reflect dilution with infiltrating surface water. The low concentrations of nitroaromatics measured in these wells are comparable to the steady state concentrations of these compounds in groundwater from a large area within, and adjacent to, the site.

6.3.4 Contaminant Transport from Southeast Drainage

Contaminant transport down the southeast drainage to the Missouri River occurs through a combination of surface discharge and groundwater. The southeast drainage contains a series of four losing reaches with associated springs. All water lost to the subsurface in the first two losing reaches resurges at the associated downstream springs. Contaminant concentrations measured in the water from the perennial springs during periods of base flow are probably representative of the groundwater quality of the area.

Uranium concentrations above background were measured in several springs within the southeast drainage. Uranium is also present in the sediments in concentrations above background levels. Downstream decreases in uranium concentration may be due to dilution, precipitation, and adsorption reactions. A sample from one spring (SP-5203) south of Francis Howell High School revealed elevated uranium during the first sampling event. That spring has been monitored on a quarterly basis for eight quarters since that finding, and uranium concentrations have been within the background range. The initial positive result for uranium may have been erroneous. Sampling of that spring will continue.

Nitrate is intermittently discharged from the site in surface water. Nitrate is primarily transported off site to the southeast drainage via NP-0005 and may be transported by groundwater flowing from the southeast portion of the site.

Nitroaromatics were measured in samples from springs in several of the drainages south and southeast of the site. The concentrations, particularly of TNT, are greater than the concentrations in the groundwater flowing off the site. Higher concentrations in the springs than in the groundwater suggest an additional source of nitroaromatics within the southeast drainage. Solid nitroaromatic compounds have been observed on the ground surface in this area.

7 SUMMARY AND CONCLUSIONS

7.1 Introduction

In compliance with the guidelines and requirements of the remedial investigation/feasibility study (RI/FS) procedure of the National Contingency Plan, this remedial investigation report presents the background and history of the Weldon Spring site, describes the studies and investigations that were conducted during the site characterization, and presents the chemical and radiological data describing the sources and extent of contamination. The report draws on characterization data, descriptive geological and hydrological data, and geochemical concepts of contaminant mobility to assess the transport and fate of site contaminants. This report addresses only the Weldon Spring chemical plant and raffinate pit area.

The site characterization investigations performed in support of the RI/FS program by the Project Management Contractor (PMC) were based on information available from previous studies and were designed to meet the objectives of the RI/FS process. Site characterization activities will continue beyond completion of this RI report. Supplementary data are expected to add detail to the current understanding of the sources, distribution, transport, and fate of contaminants, but are not expected to alter the general understanding of the Weldon Spring site.

Potential threats to human health and the environment from the Weldon Spring site are evaluated in the baseline assessment (DOE 1992a). It provides the basis for determining whether or not remedial action is necessary and the justification for performing remedial actions. The screening and evaluation of technologies for site remediation are addressed in the feasibility study (DOE 1992b). Both the baseline assessment and feasibility study reports are being produced under separate covers.

7.2 Physical Characteristics of the Study Area

The hydrology and geology of the Weldon Spring site were characterized from measurements of aquifer properties and interpretation of geologic logs from groundwater monitoring wells and geotechnical drill holes. The geology strongly influences the hydrology of the area and, therefore, exerts significant influence on contaminant transport.

7.2.1 Geology

The geologic logs from 139 geotechnical and monitoring well borings and 32 trenches were used to map the stratigraphy of the overburden units, establish the elevations at the top of bedrock, and delineate the weathered and competent bedrock units. Selected samples underwent geotechnical laboratory tests for physical properties such as particle size distribution, Atterberg limits, density, shrinkage limits, and saturated hydraulic conductivity. Capillary moisture tests were conducted to calculate radon attenuation and unsaturated hydraulic conductivity. Various consolidation and compaction tests were conducted to evaluate the effective strength parameters of the soils.

The geology beneath the site is characterized by 5 to 18 m (15 to 60 ft) of clayey overburden overlying an argillaceous, cherty limestone bedrock. The overburden has been divided into six mappable units based on physical characteristics. These are, in descending order: topsoil/fill, loess, Ferrelview Formation, clay till, basal till, and residuum. The overburden is generally thickest where the bedrock is lowest. The Mississippian limestone bedrock has been divided into two units determined by the degree of fracturing and weathering exhibited in the rock. The upper, weathered unit ranges in thickness from 3 to more than 15 m (9 to more than 50 ft). The lower, competent unit extends approximately 40 m (130 ft) to another limestone unit.

The elevation of the bedrock surface is highest in the southeastern portion and lowest in the north/northwestern portion of the site. The upper unit is highly weathered at the top, exhibiting solution features ranging from pinpoint vugs to small cavities which are generally filled with clay. Linear depressions developed on the bedrock surface are interpreted to be preglacial drainages. The formation of these features appears to have been controlled by northeasterly and northwesterly joint sets.

7.2.2 Surface Water and Groundwater Hydrology

The hydrologic regime of the site consists of intermittent surface drainages incised into the vadose zone, six surface impoundments, a vadose zone containing perched water, unsaturated bedrock, and saturated bedrock. Much of the original drainage system across the site was destroyed by cut and fill operations during the construction of the uranium feed materials plant. The vadose zone generally extends through the overburden and the top few feet of the bedrock. In the saturated limestone, the potentiometric surface indicates a groundwater divide that trends east-northeast. This corresponds roughly to the regional surface divide. The groundwater divide passes within approximately 100 to 200 m (327 to 657 ft) of the southern border of the site. To the north of the divide, groundwater moves toward Dardenne Creek and the Mississippi River. South of the divide, groundwater moves toward the Missouri River. The groundwater wells that are deeper than 18 to 24 m (60 to 80 ft) into the bedrock show a potentiometric surface approximately 1.5 m (5 ft) lower than the wells completed in the upper 12 m (40 ft) of the aquifer. This hydraulic gradient between the shallow and deeper portions of the aquifer may be attributable to reduced hydraulic conductivity with depth.

North and northwest of the site, intermittent streams lose discharge to the subsurface. The lost discharge resurges at springs in an adjacent drainage. Other surface flow in the vicinity is the result of a series of springs which discharge shallow groundwater into drainages flowing to Dardenne Creek and the Mississippi River, and into drainages flowing to the Missouri River. The drainage area southeast of the site consists of a series of losing stream segments with associated springs. Several man-made lakes are present in the drainages that contribute flow to Dardenne Creek.

The site is divided into three general drainage systems: Ash Pond and the raffinate pits draining the western portion of the site; Frog Pond and related streams draining the northeast portion of the site; and the southeast drainage flowing from the site to the Missouri River. Surface runoff from Ash Pond and the raffinate pits flows off site via National Pollutant Discharge Elimination System (NPDES) outfalls into ephemeral tributaries of Schote Creek. Much of the water discharged to the tributaries is lost to the subsurface and resurfaces at Burgermeister Spring. Frog Pond receives runoff from the northeast portion of the site and discharges through an NPDES outfall into a tributary of Schote Creek and into Lake 36. Surface water from Lake 36 is lost to the subsurface. Surface water leaving the southeast portion of the site flows through the southeast drainage. Groundwater in this drainage may be in part due to infiltration of storm water collected by the sewer system.

Groundwater movement in the limestone aquifer below the site is believed to occur predominantly by diffuse flow along horizontal bedding planes and, to a lesser extent, through vertical fractures. In general, hydraulic conductivity decreases with depth from the top of the water table. As the intensity of bedrock weathering and fracturing decreases with depth, groundwater flow paths are more widely spaced, and the influence of vertical fractures is reduced. Groundwater flow off site may occur by diffuse-flow as well as through free-flow conduits on both sides of the groundwater divide. Discharge points for the conduits are perennial springs such as Burgermeister Spring and two unnamed springs in the southeast drainage.

7.3 Nature and Extent of Contamination

Wastes produced during operation of the ordnance works and uranium feed materials plant have contaminated soils, surface water, and groundwater on the site. This contamination has spread off site to surface water, sediments, and groundwater. The contaminated soils on site may require remediation either because of their inherent contamination or because they provide a source for contamination of infiltrating water or runoff.

7.3.1 Sources of Contamination

The Weldon Spring chemical plant and raffinate pits areas contain several media which are contaminated. The primary contaminant sources are sludge and water in the four raffinate pits; water and soil in Ash Pond and Frog Pond; and soil in the former coal storage area, the north dump, and around the processing and non-processing facilities. These source areas contain chemical and radioactive waste. Contaminants are transported by runoff to Ash Pond and Frog Pond and, during periods of high precipitation, discharged off site. Infiltration of water from the raffinate pits and precipitation falling on contaminated soils transports certain contaminants through the vadose zone to the groundwater.

Feed materials plant buildings and processing facilities are radiologically contaminated and contain asbestos and polychlorinated biphenyls (PCBs). Sewer lines connected to these buildings and facilities may provide a route for contaminant transport to surface water and groundwater. Numerous studies have been completed to characterize the contamination of the buildings, raffinate pits, Ash Pond, Frog Pond, and soils.

7.3.1.1 Buildings and Facilities. Buildings were sampled and surveyed to determine the levels of PCBs, asbestos-containing material, and radioactivity. At least half of the samples taken from the non-process buildings exceeded cleanup standards for PCBs. Asbestos-containing material was detected in the insulation on pipes, steam valves, heating ducts, and in corrugated siding. Radiological sampling of the interiors and exteriors of the buildings, and equipment within the buildings, showed that major process buildings are contaminated and do not meet the guidelines for release for unrestricted use. The radiological surveys of the non-process buildings showed that, although all buildings contain some contaminated material, more comprehensive surveys may allow many building components to be released without decontamination. Most air samples taken were below the occupational standards for radiological exposure. The results of this sampling work are presented in *Radiological Sampling and Measurement Results for the Non-Process Related Buildings Equipment* (MKF and JEG 1990a).

7.3.1.2 Raffinate Pits. The PMC sampled the water from the raffinate pits and conducted an extensive sampling of the sludges for radiological and chemical characterization. With a pH greater than 7, the water in the raffinate pits is alkaline. Alkaline waters generally contain low concentrations of the heavy metals in solution, and this tends to prevent migration of these elements through seepage from the pits. However, inorganic anions and metals such as uranium, vanadium, and molybdenum, which exist as anionic species, are quite soluble in the raffinate pit water and are available for seepage through the subsurface. No nitroaromatic compounds were detected in the raffinate pit waters.

Chemical characterization of the sludges from the four raffinate pits consisted of analysis of more than 100 samples for metals, nitroaromatic compounds, and inorganic anions. In addition, composite sludge samples were analyzed for PCBs, pesticides, organic compounds, total organic carbon and halogens, and oil and grease. These tests indicated that the sludges consist of more or less similar material in all the pits except pit 4. The sludges contain greater than background concentrations of all of the metals and anions included in the analyses. Nitroaromatic and semivolatile compounds were not detected in the raffinate sludges.

The radiological characterization consisted of analysis of 137 samples collected from 39 locations. The samples were analyzed for certain radionuclides from the natural uranium and thorium decay series. These tests indicated that the sludges contain concentrations of several hundred to several thousand pCi/g of uranium, radium, and thorium. The ranges of radionuclide concentrations in pits 1, 2, and 3 are similar to each other, indicating that the sludge came from similar process operations. Pit 4 contains the same type of neutralized raffinate solids as pits 1, 2, and 3 and, in addition, contains waste from thorium processing and drums and rubble that were placed in the pit when the feed materials plant was shut down.

7.3.1.3 Ash Pond and Frog Pond. Chemical analysis of surface water in Ash Pond and Frog Pond began with sampling of the Ash Pond discharge by Bechtel in 1985. In 1987, the U.S. Geological Survey performed an analysis of Ash Pond. Also in 1987, the PMC began sampling the on-site water including Ash Pond and Frog Pond, the NPDES outfalls, and the groundwater monitoring wells. Routine sampling will continue throughout the remediation process.

7.3.1.4 Soils. The chemical analysis program for soils was conducted in two phases, plus a third sampling campaign. In Phase I, 149 samples were taken from 37 locations throughout the site and analyzed for metals, anions, and nitroaromatic compounds. Phase II consisted of samples from 245 locations selected for (1) biased sampling to investigate specific areas impacted by uranium processing and nitroaromatic production operations, (2) unbiased sampling to investigate the random distribution of contaminants across the site, and (3) sampling of off-site soils to establish background concentrations of metals. In the third sampling campaign, 150 soil samples were collected from 30 locations in the areas proposed for interim remedial actions (IRAs) and for the construction of the project administration building. These samples were analyzed for metals on the U.S. Environmental Protection Agency (EPA) hazardous chemical list, organics, pesticides, PCBs, anions, and nitroaromatic compounds.

All of the metals and anions included in the analyses exist in concentrations greater than background. Metals and anions occurring with the greatest frequency are silver, arsenic, cadmium, fluoride, mercury, nickel, nitrate, lead, antimony, sulfate, and zinc. Low levels of nitroaromatic compounds were detected in a few samples, particularly in the area of Ash Pond. Only low contaminant levels of volatile organic compounds, PCBs, and pesticides were encountered in the soils analyzed. Low concentrations of semivolatile organic compounds are present in areas related to burn areas and coal storage.

Radiological characterization of the soils consisted of analyses for (1) radium-226, thorium-232, thorium-230, and potassium-40 on surface and subsurface soil samples; (2) downhole measurements of radium-226, thorium-232, and potassium-40; (3) estimates of radium-226 in surface soils by delta gamma measurements; (4) in situ low-energy gamma radiation; (5) direct gamma ray exposure rate measurements, and (6) surface spectrometer measurements for radium-226, thorium-232, and potassium-40.

The radiological sampling of soils across the site showed widespread surface contamination of uranium with a lesser extent of radium and thorium. Based on reference levels of 5 pCi/g (top 15 cm) and 15 pCi/g (subsurface) for radium plus thorium and a cleanup reference level for uranium of 15 pCi/g, approximately 63,700 m^3 (83,300 cy) of exposed soil over an area of 19.2 ha (47.4 ac) were identified for potential remediation. Various depths of soils with radionuclide concentrations in excess of reference levels are present in Ash Pond, Frog Pond, the south dump, and the north dump. Radionuclide concentrations above reference levels scattered throughout the soils in the other site areas are mostly within the top 30 cm (1 ft).

7.3.2 Surface Water, Sediment, and Groundwater Contamination

The distribution of contamination in the groundwater, surface water, and sediments was evaluated by comparing the concentrations of the analytes with background concentrations and water quality standards. Chemical compounds identified in the groundwater, surface water, and sediments which were consistently elevated above the comparison criteria are uranium, nitrate, sulfate, chromium, nickel, aluminum, and nitroaromatic compounds in the groundwater; uranium in the surface water; and uranium in sediments.

Groundwater contamination is generally confined to the weathered zone of the shallow bedrock aquifer in the weathered limestone, except for sulfate and nitroaromatic compounds, which were detected above background concentrations in the competent zone of the shallow bedrock aquifer. Uranium contamination occurs in localized areas in the groundwater near the raffinate pits and near the southeast boundary of the site. Uranium contamination also occurs in surface water, springs, and sediments on and off site. Groundwater flowing off site from the raffinate pits is contaminated with nitrate. Surface water discharged from the NPDES outfalls to the drainages to the north, west, and southwest transports nitrate off site. Sulfate is elevated in the groundwater in areas adjacent to the raffinate pits and in the east-southeast portion of the site along the former trinitrotoluene (TNT) processing lines. Chromium, nickel, and aluminum are present in elevated concentrations in the groundwater in localized areas. Elevated concentrations of nitroaromatic compounds were detected in groundwater samples from three locations: (1) west of the raffinate pits; (2) near Frog Pond, where TNT processing lines were located; and (3) north of Ash Pond in the burn area.

7.4 Transport and Fate of Contaminants

Contaminants are being transported off site through groundwater and surface water pathways. Transport in the groundwater is generally confined to the shallow portion of the aquifer. During operation of the ordnance works and uranium feed materials plant, airborne contamination was also a likely pathway for transport off site. Recent air monitoring for asbestos, organic vapors, and radioactivity indicates that levels of constituents are similar to background or decrease markedly with distance from the on-site source.

The conceptual model of the transport and fate of the contaminants was deduced from the characterization of the sources of contaminants; the distribution of the contaminants in the groundwater, surface water, and sediments; the nature of the local hydrologic system; and an understanding of the geochemical properties of contaminant retardation. Biouptake of contaminants in fish and mammals is not an important fate as determined by sampling of these species.

7.4.1 Uranium

Analysis of sludge and surface water in the raffinate pits indicates that they are a potential source of nitrate, fluoride, uranium, and other elements typically associated with uranium ore. Except for nitrate, the elements from all of the raffinate pits exhibit similar transport patterns. They are present in the groundwater very near the raffinate pits, but are not transported beyond the immediate vicinity of the pits because they are immobilized by precipitation and adsorption. Uranium is slightly more mobile than the other elements contained within the pits. Four wells within the chemical plant area and two wells in the vicinity of the southeast drainage contain mean uranium concentrations slightly in excess of background.

In general, the concentrations of uranium in the surface water flowing from the site are much greater than in the groundwater. A comprehensive source/transport model suggests that during storms, surface runoff picks up uranium from contaminated soils and flows through NPDES outfalls below Ash Pond and Frog Pond, and above the southeast drainage. Uranium is transported both in dissolved and suspended forms. In the drainages downstream from Ash Pond and the raffinate pits area, surface water is lost to the subsurface. Although a portion of the uranium is lost to the solid phase by sedimentation and precipitation, some uranium is transported through groundwater and resurfaces in springs.

Sediments sampled from the off-site drainages and lakes show that uranium is the only constituent that has accumulated to levels in excess of background. This may be due to the chemical precipitation of dissolved uranium and sedimentation of suspended uranium transported in surface water.

7.4.2 Nitrate

Seepage from the raffinate pits is the major source of nitrate in the groundwater. Because nitrate is not significantly retarded in soils, high concentrations of this contaminant are found in wells in the western portion of the site near the raffinate pits and Ash Pond. The diffuse flow model indicates that this groundwater flows off the site. Some of the groundwater likely reaches the conduits leading toward Burgermeister Spring. Surface water discharged off site contains lower concentrations of nitrate, but also likely contributes to the nitrate measured in the springs.

7.4.3 Nitroaromatic Compounds

Nitroaromatic compounds in the groundwater are believed to enter the saturated zone by leaching from contaminated soils as precipitation infiltrates through the vadose zone. Certain nitroaromatic compounds degrade upon exposure to sunlight and therefore are less likely to be transported in surface waters. The highest concentrations of nitroaromatic compounds are found in monitoring wells near the raffinate pits and Frog Pond where former TNT processing and wastewater lines were located. Due to dilution, concentrations in the groundwater decrease markedly with distance away from the source. Low level concentrations of nitroaromatic compounds are present in most groundwater wells within the site and in many springs in the drainages around the site. However, sources of the nitroaromatics related to the Weldon Spring Ordnance Works probably exist both on and off site.

7.4.4 Metals

Of the many metals contained in the raffinate pit sludges and soils, only nickel and chromium appear to be present above background concentrations in groundwater beneath the site. The data suggest that nickel, being the more mobile element, may be above background concentrations in wells immediately off site. Chromium is normally in the trivalent state in the geochemical conditions of the aquifer, and is probably retarded by precipitation and adsorption. The sources of nickel and chromium in the groundwater are most likely contaminated soils. In off-site surface water, the measured levels of most hazardous metals, are within the range of apparent background. Lead and barium are two metals which appear at levels slightly elevated above background at a few specific locations.

7.5 Data Gap Analysis

The information and data presented in this RI report have been evaluated for completeness for performing the feasibility study. The characterization data describe radiological and chemical contamination at the chemical plant and raffinate pit areas and present a picture of the nature and extent of contamination for the site as a whole. Although the data presented are considered sufficient to complete the feasibility study, additional data will be required to support engineering designs for site remediation activities. It is anticipated that such data will refine the understanding of the nature and extent of contamination as opposed to altering the basic concepts upon which the feasibility study is based.

The data refinement process is underway at this time. Through evaluation of the RI database, potential data gaps have been identified and will be addressed by collecting additional data in the following areas:

- Soil contamination: Extent of soil contamination under the buildings, raffinate pits, and Ash Pond and those areas for which the vertical extent of contamination was not fully defined. The following areas have been identified: Zone 9/Region 5, Zone 10/Region 5, Zone 6/Region 6, Zone 1/Region 8, and Zone 2/Region 8

(Plate 2).

- Overburden physical characteristics: Field tests to verify hydraulic conductivity values in the vadose zone.

- Contaminant transport and attenuation: Studies are being conducted by the U.S. Geological Survey/University of Missouri-Rolla to evaluate geochemical aspects of contaminant transport and attenuation.

- Ecological studies: Studies are being conducted to assess potential impacts to species using contaminated areas of the Weldon Spring site. Data from these studies will augment existing data from the Missouri Department of Conservation and site characterization programs.

- Additional representative background samples.

- Characterization data for site groundwater: Areal extent and nature of contamination.

- Characterization data for the southeast drainage: Define specific contamination areas which are above removal levels.

- Data developed during phased remedial action.

An additional data need is better definition of nitroaromatic sources in the vicinity of the Weldon Spring site. It is anticipated that this investigation effort will be coordinated with the Department of the Army.

Future data needs, which may be beyond the scope of data required for alternative selection, may also be identified for detailed design of the selected remediation alternative. These data needs will be identified as remedial design progresses.

8 REFERENCES CITED

Alexander, M. and B.D. Lustigman, 1966. *Effect of Chemical Structure on Microbial Degradation of Substituted Benzenes*. Journal of Agricultural Food Chemistry, Vol. 14, No. 4, pp. 410-13.

American Geological Institute, 1976. *Dictionary of Geological Terms*. Revised Edition. Anchor Press/Doubleday. Garden City, NY.

American Nuclear Standards Institute, 1989. *Quality Assurance Program Requirements for Nuclear Facilities*. ANSI NQA-1-1989.

Anderson, J.B., 1963. *Effects of Uranium Mill Wastes on Biological Fauna of the Animas River, Colorado–New Mexico*. Proceedings of the 1st National Symposium on Radioecology. Heinhold Publishing Corporation, New York. p. 373.

ANSI, see American Nuclear Standards Institute.

Barltrop, J.A. and N.J. Bunce, 1968. *Organic Photochemistry Part 8: Photochemical Reduction of Nitrocompounds*, Section C, Organic Chemistry, pp. 1467-74. Royal Society of Chemistry, formerly Journal of the Chemistry Society of London.

Bechtel National, Inc., 1983a. *Weldon Spring Site Environmental Monitoring Report, Calendar Year 1981*. Prepared under contract DE-AC05-81OR20722 for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. May.

Bechtel National, Inc., 1983b. *Weldon Spring Site Environmental Monitoring Report, Calendar Year 1982*. Prepared under contract DE-AC05-81OR20722 for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. May.

Bechtel National, Inc., 1983c. *Site Seismicity and Design Earthquake Considerations*. Final Report. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. July.

Bechtel National, Inc., 1983d. *Weldon Spring Storage Site, 1982-1983 Geologic Characterization*. Draft. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. July.

Bechtel National, Inc., 1984a. *Weldon Spring Site Environmental Monitoring Report, Calendar Year 1983*. DOE/OR/20722-16. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. June.

Bechtel National, Inc., 1984b. *Radiological Survey Report for the Weldon Spring Raffinate Pits Site*. DOE/OR/20722-7. Prepared for the U.S. Department of Energy,. Oak Ridge Operations. Oak Ridge, TN. August.

Bechtel National, Inc., 1984c. *Geologic Report, Weldon Spring Raffinate Pits Site, Weldon Spring, Missouri*. DOE/OR/20722-6, 130 p. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. November.

Bechtel National, Inc., 1985a. *Weldon Spring Site Environmental Monitoring Report, Calendar Year 1984*. DOE/OR/20722-58. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. July.

Bechtel National, Inc., 1985b. *Radiological Survey Report for the Weldon Spring Quarry*. DOE/OR/20722-70. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. September.

Bechtel National, Inc., 1985c. *Report on Ground Water Monitoring Well Rehabilitation and Radiological Characterization Drilling, Weldon Spring Quarry*. DOE/OR/20722-63. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. December.

Bechtel National, Inc., 1986a. *Report on Water Balance Studies from 1983 to 1985, Weldon Spring Raffinate Pits Site*. DOE/OR/20722-94. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. March.

Bechtel National, Inc., 1986b. *Results of Additional Testing of the Raffinate Pits at Weldon Spring Site*. File No. 201. Prepared under Contract No. DE-AC05-81OR20722 for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. July 25.

Bechtel National, Inc., 1986c. *Weldon Spring Site Annual Site Environmental Monitoring Report, Calendar Year 1985*. DOE/OR/20722-101. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. September.

Bechtel National, Inc., 1986d. *Radiological and Chemical Characterization Report for the Weldon Spring Chemical Plant*. DOE/OR/20722-136. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. November.

Bechtel National, Inc., 1987. *Hydrogeological Characterization Report for Weldon Spring Chemical Plant*. DOE/OR/20722-137. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. July.

Bent, A.C., 1937. *Life Histories of North American Birds of Prey*, Part 1. Smithsonian Institution, U.S. National Museum Bulletin 167.

Berger, J.D., 1986. *Verification of Remedial Action Along Highway 94, Weldon Spring, Missouri*. Oak Ridge Associated Universities. Oak Ridge, TN.

Berkeley Geosciences Associates, 1984. *Characterization and Assessment for the Weldon Spring Quarry Low-Level Radioactive Waste Storage Site*. DOE/OR-853 (DE85005424). Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. September.

BGA, see Berkeley Geosciences Associates.

Black, J.A., et al., 1973. *The Significance of Physio-chemical Variables in Aquatic Bioassays of Heavy Metals*. Bioassay Techniques and Environmental Chemistry. G.E. Glass, ed. Ann Arbor Science Publishers. Ann Arbor, MI.

BNI, see Bechtel National, Inc.

Bouwer, H. and R.C. Rice, 1976. *A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells*. Water Resources Research. Vol. 12, No. 3. June.

Brabander, J., 1990. Personal communication to I. Hlohowskyj, Argonne National Laboratory, Argonne, IL. Subject: Endangered Species. U.S. Fish and Wildlife Service, Ecology Services Office, Hanford, MO. May 9.

Bringman, G. and R. Kuehn, 1971. *Biological Decomposition of Nitrotoluenes and Nitrobenzenes by Azotobacter agilis*. Gesundh.-lng. Vol. 92, No. 9, pp. 273-6. (Ger.).

Burlinson, N.E. and D.J. Glover, 1977. *Photochemistry of TNT and Related Nitrobodies*. Quarterly Progress Report No. 12, for 1 April to 30 June 1977. Explosive Chemistry Branch, Naval Surface Weapons Center. Silver Spring, MD.

Burlinson, N.E. et al., 1973. *Photochemistry of TNT. Pink Water Problem*. U.S. NTIS, Ad Rep., AD-769670.

Burrows, E.P., D.H. Rosenblatt, W.R. Mitchell and D.L. Parmer, 1989. *Organic Explosives and Related Compounds: Environmental and Health Considerations*, USABRDL Technical Report 8901. U.S. Army Biomedical Research & Development Laboratory. Fort Detrick, Frederick, MD.

Cahn, L., 1987. Inter-office memorandum to Sam Marutzky, UNC Geotech. Subject: Location of Lysimeters 3608, 3609, and 3610 in an Unsaturated Area Near a Perched Water Table. July 15.

Callahan, M.A. et al., 1979. *Water-Related Environmental Fate of 129 Priority Pollutants*. U.S. Environmental Protection Agency. EPA 440/4-79-029. Washington DC.

Campbell Design Group and Geotechnology, Inc., 1987. *Volume II, Geotechnical Report, Field Investigation of Hazardous Wastes at Weldon Spring Training Area, St. Charles County, Missouri*. Prepared under Contract No. DACA-41-85-D-0090 for Fort Leonard Wood, MO, and Kansas City District U.S. Army Corps of Engineers, Kansas City, MO.

Cassin, G., 1990. Personal communication to Y.S. Chang, Argonne National Laboratory. Subject: Criteria air pollutants. Missouri Department of Natural Resources. Jefferson City, MO. May 14.

COE, see U.S. Army Corps of Engineers.

Connor, J.J. and R.J. Ebens, 1980. *Geochemistry of Bedrock Units in Missouri and Parts of Adjacent States*. Geochemical Survey of Missouri. U.S. Geological Survey Professional Paper 954-F.

Cooper, Jr., H.H. and C.E. Jacob, 1946. *A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Wellfield History*. Transactions, American Geophysical Union. Volume 27, No. 4, pp. 526-534.

Cooperrider, A.Y., R.J. Boyd, and H.R. Stuart, eds, 1986. *Inventory and Monitoring of Wildlife Habitats*. U.S. Department of the Interior, Bureau of Land Management, Service Center. Denver, CO. 858 pp.

Coxon, G.D., 1985. Letter to G.A. Newtown, Jr. U.S. Department of Energy. Subject: Sampling of Ash Pond Outfall at the Weldon Spring Chemical Plant. Bechtel National, Inc. Pasadena, CA. May 22.

Crigler, D., 1992. Personal Communication to G. Valett, MK-Ferguson Company, St. Charles, MO. Subject: Visitor Statistics for Busch Wildlife Area and Weldon Spring Wildlife Area. August A. Busch Wildlife Area, St. Charles, MO. May 21.

DA, see U.S. Department of the Army.

Dale, J.M., B. Freedman, and J. Kerekes, 1985. *Acidity and Associated Chemistry of Amphibian Habitats in Nova Scotia*. Canadian Journal of Zoology, 63:97-105.

Daubel, K., 1992. Personal communication to M. Sizemore, MK-Ferguson Company, St. Charles, MO. Subject: Use of Army Training Grounds. U.S. Department of the Army. March 17. (This communication is documented in a memorandum from M. Sizemore to M. MacDonell, Agonne National Laboratory, March 17.

Dean, T.J., 1983a. *Summary of Water Tracing Experiments at Weldon Spring Complex*. Missouri Department of Natural Resources. Jefferson City, MO. November.

Dean, T.J., 1983b. *Water Tracing Experiment #2 Weldon Spring Area*. Missouri Department of Natural Resources. Jefferson City, MO. December.

Dean, T.J., 1983c. *Groundwater Tracing Project, Weldon Spring Area*. Missouri Department of Natural Resources. Jefferson City, MO. December.

Dean, T.J., 1984a. *Groundwater Tracing Project, Weldon Spring Area, Interim Report, Part One*. Missouri Department of Natural Resources. Jefferson city, MO. April.

Dean, T.J., 1984b. *Groundwater Tracing Project, Weldon Spring Area, Interim Report, Part Two*. Missouri Department of Natural Resources. Jefferson City, MO. November.

Dean, T.J., 1985. *Groundwater Tracing Project, Weldon Spring Area, Interim Report, Part Three*. Missouri Department of Natural Resources. Jefferson City, MO. April.

deRoos, C., 1984. Letter with attachments to G. Turi, U.S. Department of Energy. Subject: Heavy Metals in Fish Flesh. Missouri Department of Conservation. Jefferson City, MO. April 20.

Detection Science, Inc. 1987. *Seismic Refraction Survey - Weldon Spring Chemical Plant, Weldon Spring, Missouri* and Appendix E - *Electromagnetic Terrain Conductivity Survey of the Weldon Spring Chemical Plant Grounds*. Prepared for Bechtel National, Inc.

Dickneite, D.F., 1988. Letter to Dr. Ihor Hlohowskyj, Argonne National Laboratory. Subject: Area Wildlife. Missouri Department of Conservation. Jefferson City, MO.

Dickneite, D.F., 1990. Letter to Stephen McCracken, U.S. Department of Energy. Subject: Evaluation of Fish Flesh Data. Missouri Department of Conservation. Jefferson City, MO. August 3.

DOE, see U.S. Department of Energy.

Eardley, A.J., 1951. Structural Geology of North America. Second Edition. Harper and Row. New York.

EG&G, 1977. *Weldon Spring Chemical Plant Ground Survey Summary*. EGG/NRN-7712. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Project FUSRAP/14501. December.

Eisenbud, M., 1987. *Environmental Radioactivity*. Harcourt Brace Jovanovich. New York.

Emery, R.M., D.C. Klopfer, D.A. Baker, and J.K. Soldat, 1981. *Potential Radiation Dose from Eating Fish Exposed to Actinide Contamination*. Health Physics 40, No. 4, pp. 493-510.

Environmental Science and Engineering, 1985. *West Virginia Ordnance Works Remedial Investigation: Final Report*. Prepared for: U.S. Army, Contract No. DAAK11-83-D-0007. September.

Environmental Science and Engineering, 1986. *West Virginia Ordnance Works: Endangerment Assessment for Sewer Lines, the TNT Manufacturing Area, and the Burning Grounds: Final Report*. Prepared under Contract No. DAAK11-83-D-0007 for the U.S. Army. Aberdeen Proving Ground, MD. June.

EPA, see U.S. Environmental Protection Agency.

Evans, H.T., Jr. and R.M. Garrels, 1958. *Thermodynamic Equilibria of Vanadium in Aqueous Systems as Applied to the Interpretation of the Colorado Plateau Ore Deposits*. Geochimica et Cosmochimica Acta.

Everett, L.G., L.G. Wilson, and W.E. Hoylman, 1984. *Vadose Zone Monitoring for Hazardous Waste Sites*. Noyes Data Corporation, Park Ridge, NJ, 360 p.

Fetter, C.W., Jr., 1988. *Applied Hydrology.* 2nd Edition. Merrill Publishing Company. Columbus, OH.

Ficker, C.F., 1981. *Environmental Monitoring Program for DOE Weldon Spring, Missouri, Site.* NLCO-009EV (Special). National Lead Company of Ohio. Cincinnati, OH. August.

Fishel, V.C. and C.C. Williams, 1944. *The Contamination of Ground and Surface Waters by Liquid Wastes from the Weldon Spring Ordnance Works, MO.* U.S. Geological Survey. Lawrence, KS.

Forstner, U. and G.T.W. Wittman, 1983. *Metal Pollution in the Aquatic Environment.* Second Edition. Springer-Verlag.

Freeze, R.A. and J.A. Cherry, 1979. *Groundwater.* Prentice-Hall Inc. Englewood Cliffs, NJ, 604 p.

Gaines, E.P., 1988. Letter with enclosures to Dr. Ihor Hlohowskyj, Argonne National Laboratory. Subject: High-Quality Natural Communities in the Weldon Spring Area. Missouri Department of Conservation. Jefferson City, MO.

Garten, C.T., Jr., E.A. Bondietti, and R.L. Walker, 1981. *Comparative Uptake of Uranium, Thorium and Plutonium by Biota Inhabiting a Contaminated Tennessee Floodplain.* Journal of Environmental Quality. 10:207-211.

Gascon, C. and D. Planes, 1986. *Spring Pond Water Chemistry and the Reproduction of the Wood Frog,* Rana sylvatica. Canadian Journal of Zoology, 64:543-550.

Geotechnology Services, Inc., 1988b. *Final Report, Volumes I and II, Geophysical Investigation, Specification 3589-SC-WP028, Weldon Spring Chemical Plant.* Prepared for MK-Ferguson Company, Weldon Spring Site Remedial Action Project Office. St. Charles, MO. December 9.

Gilbert, T.L. et al., 1986. *Derivation of Site-Specific Soil Guidelines for Weldon Spring Vicinity Properties.* Draft. U.S. Army Reserve Property. Prepared for the U.S. Department of Energy, Division of Facility and Site Decommissioning, by Argonne National Laboratory, Environmental Research Division. Argonne, IL. January.

Gilbert, T.L. et al., 1989. *Supplement to U.S. Department of Energy Guidelines for Residual Radioactivity at FUSRAP and SFMP Sites.* A Manual for Implementing Residual Radioactivity Guidelines. Prepared by Argonne National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest Laboratory for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. June.

Green, R.E., L.R. Ahuja, and S.K. Chong, 1986. *Hydraulic Conductivity, Diffusivity, and Sorptivity of Unsaturated Soils: Field Methods, in Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods*, 2nd ed., A. Klute ed. American Society of Agronomy, Inc., Soil Science Society of America, Inc. Madison, WI, 1188 p.

GSI, see Geotechnology Services, Inc.

Hanson, W.C. and F.R. Miera, 1987. *Long-term Ecological Effects of Exposure to Uranium.* Rep. La-6269, 33 p. Los Alamos Scientific Laboratory. Los Alamos, NM.

Hantush, M.S. and R.G. Thomas, 1966. *A Method for Analyzing a Drawdown Test in Anisotropic Aquifers.* Water Resources Research. Volume 2, pp. 281-285.

Harshman, E.R. 1974. *Distribution of Elements in Some Roll-Type Uranium Deposits,* Proceedings of a Symposium on Formation of Uranium Ore Deposits. Athens, GA.

Hartwig, C., 1992. Personal communication to M. Sizemore, MK-Ferguson Company, St. Charles, MO. Subject: Student/Staff Enrollment. Francis Howell High School, St. Charles, MO. March 17. (This communication is documented in a memorandum from M. Sizemore to M. MacDonell, Agonne National Laboratory, March 17.)

Haseltine, S.D. and L. Sileo, 1983. *Response of American Black Ducks to Dietary Uranium: A Proposed Substitute for Lead Shot.* Journal Wildlife Management, 47(4), pp. 1124-1128.

Henry M. Reitz Consulting Engineers, 1964. *Design Memorandum for Twelve Million Cubic Foot Raffinate Pit, Atomic Energy Commission Plant, Weldon Spring, MO.* January.

Herron, J., 1991a. Record of Telephone Conversation with I. Hlohowskyj, Argonne National Laboratory. Subject: Sighting of adult geese roosting on chemical plant buildings. MK-Ferguson Company, Weldon Spring Site Remedial Action Project. St. Charles, MO. October 15.

Herron, J., 1991b. Inter-office correspondence to L. Gonzales. Subject: List of observed reptile, amphibian, and mammal fauna for the Weldon Spring Wildlife Area prepared by the Missouri Department of Conservation (J. Miller). MK-Ferguson Company, Weldon Spring Site Remedial Action Project. St. Charles, MO. November 7.

Hoffman, D., 1987. Letter to Rod Nelson, U.S. Department of Energy. Subject: Dye trace and water trace studies. Missouri Department of Natural Resources. Jefferson City, MO. November 23.

HOK Associates, 1976. *Environmental Impact Assessment for the Weldon Spring Site*. Prepared for the University of Missouri, Columbia, MO. September.

Hlohowskyj, I., 1990. Record of Telephone Conversation with Tom R. Johnson, Missouri Department of Conservation, Jefferson City, MO. Subject: State concerns and requirements for the wood frog and the Weldon Spring quarry pond. Argonne National Laboratory. Argonne, IL. January 18.

Hoffman, D.E., 1988. Inter-office correspondence to N.E. Hopson. Subject: *Asbestos Containing Materials - Building 409*. Jacobs Engineering Group, Inc., Weldon Spring Site Remedial Action Project. St. Charles, MO. February 8.

Hopkins, L., 1991. Interoffice Correspondence to R. Ferguson. Subject: ACDR Revisions to Estimates of Effective Porosity. Jacobs Engineering Group, Weldon Spring Site Remedial Action Project. St. Charles, MO. September 23.

Hopper, M.G., et al., 1983. *Estimation of Earthquake Effects Associated with a Great Earthquake in the New Madrid Seismic Zone*. Open-File Report 83-179. Prepared by the U.S. Geological Survey in cooperation with the Central United States Earthquake Consortium. Memphis, TN.

Howard, J.H., III, 1977. *Geochemistry of Selenium: Formation of Ferroselite and Selenium Behavior in the Vicinity of Oxidizing Sulfide and Uranium Deposits*. Geochimica at Cosmochimica Acta.

Huey, E.A., 1978. *Report on Preliminary Geological, Hydrological and Radiological Survey at the Weldon Spring Quarry During 1976 and 1977*. National Lead Company of Ohio. Fernald, OH. December 14.

Hvorslev, M.J., 1951. *Time Lag and Soil Permeability in Groundwater Observations*. U.S. Army Corps of Engineers. Waterway Experimental Station Bulletin 36. Vicksburg, MS.

Jacobs Engineering Group Inc., 1987. *Determination of Maximum Earthquake for Weldon Spring Disposal Facility*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO.

JEG, see Jacobs Engineering Group, Inc.

Johnson, T.R., 1987. *The Amphibians and Reptiles of Missouri*. Missouri Department of Conservation. Jefferson City, MO.

Johnston, A.C., 1982. *A Major Earthquake Zone on the Mississippi*. Scientific American, Volume 246, pp. 60-68.

Kaback, D.S. and D.D. Runnells, 1979. *Geochemistry of Molybdenum in Some Stream Sediments and Waters*. Geochimica et Cosmochimica Acta. Vol. 44, pp. 447-456.

Kaplan, D.L., et al., 1985. *Effects of Environmental Factors on the Transformation of 2,4,6-Trinitrotoluene in Soils*. Technical Report Natrick/TR-85/052. U.S. Army Natrick Research and Development Center. January.

Kleeschulte, M.J., 1989. Letter to Ann Connell, MK-Ferguson Company. Subject: Stream Gauges Installed Near Weldon Spring Site. U.S. Geological Survey, Rolla, MO. January 17.

Kleeschulte, M.J., 1991. "Geohydrology of Bedrock Aquifers and Public Supply and Domestic Water Use, 1962-85, in St. Charles County Missouri." *Proceedings of the Geosciences Workshop*. DOE/OR/21548-197. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office by MK-Ferguson and Jacobs ENgineering Group. February 21.

Kleeschulte, M.J. and J.L. Imes, 1991. *Assessment of the Geohydrology and Water Quality and Ground-Water Simulation at the Weldon Spring Chemical Plant Site and Vicinity Property, St. Charles County, Missouri—1987-1990* (Provisional Draft). Prepared in cooperation with the U.S. Department of Energy by the U.S. Geological Survey. Rolla, MO.

Kleeschulte, M.J. and L.F. Emmett, 1986. *Compilation and Preliminary Interpretation of Hydrologic Data for the Weldon Spring Radioactive Waste Disposal Sites—A Progress Report*. Water Resources Investigations Report 85-4272. U.S. Geological Survey. Rolla, MO.

Kleeschulte, M.J. and L.F. Emmett, 1987. *Hydrology and Water Quality at the Weldon Spring Radioactive Waste-Disposal Sites, St. Charles County, MO.* Water Resources Investigations Report 87-4169. U.S. Geological Survey. Rolla, MO.

Kleeschulte, M.J., et al., 1986. *Hydrologic Data for the Weldon Spring Radioactive Waste-Disposal Sites, St. Charles, MO--1984-1986.* Open File Report 86-488. U.S. Geological Survey. Rolla, MO.

Krummel, W.J., 1956. *The Geology of a Portion of the Weldon Spring Quadrangle.* Master's Thesis. Washington University. St. Louis, MO. June.

Law Engineering, Inc., 1988. *Surface Investigation Final Report for Weldon Spring Training Area, Weldon Spring, MO.* Prepared for Kansas City District U.S. Army Corps of Engineers, Kansas City, MO. Contract No. DACW41-86-D-0115.

Lawrence Berkeley Laboratory, 1980a. *Radiological, Hydrogeological, Geochemical and Geophysical Assessment of the Weldon Spring Quarry Disposal Site*, Preliminary Draft. Prepared under Contract No. W-7405-ENG-48 for the U.S. Department of Energy. University of California. Berkeley, CA. January.

Lawrence Berkeley Laboratory, 1980b. *Preliminary Characterization and Assessment of the Weldon Spring Low-Level Radioactive Waste Disposal Site, Weldon Spring, MO.* Prepared under Contract No. W-7405-ENG-48 for the U.S. Department of Energy. University of California. Berkeley, CA. September.

Layne Western Company, Inc., 1985a. *Groundwater Hydrology Investigation, Weldon Spring, MO.* Volumes I, II, and III. January 8.

Layne Western Company, Inc., 1985b. *Groundwater Study, Weldon Spring Site, MO.* September 9.

Lindsay, W.L., 1979. *Chemical Equilibria in Soils.* John Wiley and Sons. New York.

MacDonell, M.M., et al., 1990. *Engineering Evaluation/Cost Analysis for the Proposed Management of Contaminated Surface Water Impounded at the Weldon Spring Chemical Plant Area.* DOE/OR/21548-106. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, by Argonne National Laboratory, Environmental Assessment and Information Sciences Division, Argonne, IL. July.

McCormick, N.G., J.H. Cornell, and A.M. Kaplan, 1978. *Identification of Biotransformation Products from 2,4-Dinitrotoluene*. Applied Environmental Microbiology. Vol. 35, No. 5, pp. 945-8.

MDNR, see Missouri Department of Natural Resources.

MDOC, see Missouri Department of Conservation.

Meyer, K., 1989. Inter-Office correspondence to distribution. Subject: Discussion with former Mallinkrodt employee—Jacobs Engineering Group, Inc., Weldon Spring Site Remedial Action Project. St. Charles, MO. May 12.

Miera, F.R., Jr., 1980. *Measurements of Uranium in Soils and Small Mammals*. Rep. La-8624-T, 43pp. Los Alamos Scientific Laboratory. Los Alamos, NM.

Miera, F.R., Jr., W.C. Hanson, E.S. Galney, and P. Jose, 1978. *Mobility of Elevated Levels of Uranium in the Environment*. Pages 681-699 in Natural Radiation Environment III, Vol. 1. T.F. Gesell and W.M. Lowder, eds. U.S. Department of Energy Symposium Series 51. Oak Ridge, TN.

Mill, T. and W. Mabey, 1985. *Environmental Toxicology Chemistry*, Vol. 1, pp.175-216.

Missouri Botanical Garden, 1975. *An Introduction to the Biological Systems of the St. Louis Area*. Prepared for the East-West Gateway Coordinating Council under contract to the St. Louis District, Corps of Engineers, Metro Study, Vol. 1.

Missouri Department of Conservation, 1976. *August A. Busch Memorial Wildlife Area*. M892-09. Jefferson City, MO.

Missouri Department of Conservation, 1981. *A Checklist of Birds of the August A. Busch Memorial Wildlife Area, Weldon Spring, MO*. FD/2/81. Jefferson City, MO.

Missouri Department of Conservation, 1989. *Area Management Plan for August A. Busch Complex*. Jefferson City, MO.

Missouri Department of Conservation, 1990. Data from Missouri National Heritage Program Database provided to D. Reinhardt, Argonne National Laboratory, Argonne, IL.

Missouri Department of Conservation, 1991. *The Checklist of Rare and Endangered Species of Missouri*. Jefferson City, MO. 44 pp.

Missouri Department of Natural Resources, 1984. *Climatic Atlas for Design of Land Application Systems*. WP 84-1G. Jefferson City, MO.

Missouri Department of Natural Resources, 1988a. *Status Report, Shallow Groundwater Investigations at Weldon Spring*. Jefferson City, MO.

Missouri Department of Natural Resources, 1988b. *Update on Status of MDNR Studies at Weldon Spring*. Jefferson City, MO.

Missouri Department of Natural Resources, 1989a. *First Annual Report on Shallow Groundwater Investigations at Weldon Spring, MO*. Jefferson City, MO.

Missouri Department of Natural Resources, 1989b. *Shallow Groundwater Investigation Phase I Report*. Jefferson City, MO.

Missouri Department of Natural Resources, *Missouri Air Pollution Control Program Report for 1983*. Jefferson City, MO.

Missouri Department of Natural Resources, *Missouri Air Pollution Control Program Report for 1984*, Jefferson City, MO.

Missouri State Census Data Center, 1990. *Report 901: Population and Housing Unit Trends for Missouri Governmental Units: 1980-1990.* Part 3: Municipality Level Data. St. Louis, MO.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1986. *Asbestos Bulk Sampling and Air Sampling Results, Weldon Spring Chemical Plant*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987a. *Results of Radiological Analysis of PCB Transformer Oil*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. March 20.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987b. *Plan for Determination of Biological Uptake of Radionuclides and Nitroaromatics in Species in the Food Pathways at the WSS*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. June 22.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987c. *WSSRAP Report on Radiological Findings and Recommendations Regarding Army Reserve Property, Vicinity Property No. 7.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. July 15.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987d. *Environmental Monitoring Program Plan*, Rev. 1. DOE/OR/21548-054. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. August 20.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987e. *Radiological Survey Report for the Weldon Spring Chemical Plant Steam Production Facility*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. September 17.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987f. *Characterization Report IRA #13, Army Reserve Property Vicinity Property No. 2.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. September 18.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987g. *Characterization Report Army Reserve Vicinity Property No. 3, IRA #13.* DOE/OR/21548-025. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. September 22.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987h. *Radiological Survey Report for the Transformers Located at the Weldon Spring Site.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. September 28.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987i. *Radiological Survey Report for the Weldon Spring Chemical Plant Administrative Building*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. September 30.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987j. *Report on Radiological Findings and Recommendations Regarding Army Reserve Property Vicinity Property No. 1.* DOE/OR/21548-023. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. Oak Ridge, TN. October 8.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987k. *Radiological Characterization Report for the Planned Material Staging Area*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. November 4.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987l. *Plan for the Sampling and Analysis of Lake and Stream Sediments Influenced by the Weldon Spring Chemical Plant Drainage*. DOE/OR/21548-006. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. November.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987m. *Results of Asbestos Samples Analyzed for Radioactivity*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. December 1.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987n. *Report on Weldon Spring Site Chemical Contaminant Findings Regarding Army Reserve Property Vicinity Properties No. 1, 2, 3, and 7*, Rev. 0. DOE/OR/21548-026. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. December 2.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987o. *WSSRAP, Water Quality Phase I Assessment*. DOE/OR/21548-003. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. December.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987p. *PCB Survey Report - Building 401, Weldon Spring Chemical Plant, Weldon Spring Site Remedial Action Project*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. December.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987q. *Annual Environmental Monitoring Report, Weldon Spring, Missouri, Calendar Year 1986*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987s. *Asbestos Content of Pipe Insulation in Outdoor Overhead Utilities at the Weldon Spring Chemical Plant.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. February 3.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987u. *Technical Memorandum on Contract No. DE-AC05-860R21548, Falling-Head Permeability Tests.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. June 26.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988a. *Radiologic Sampling Results and Need for the Southeast Diversion Dike Interim Response Action.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. January 5.

MK-Ferguson Company and Jacobs Engineering Group, 1988b. *Weldon Spring Site Remedial Action Project, Soil Investigation Work Plan.* DOE/OR/21548-013. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. February.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988c. *PCB Survey Report, Building 409.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. February.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988d. *Radiological Survey Report for the Planned Construction Staging Area Interim Response Action.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. March.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988e. *Radiological Survey and Release Plan for Building 401.* DOE/OR/21548-018. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. April 8.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988f. *Radiological Survey and Release Plan for Building 409.* DOE/OR/21548-019. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. April 8.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988g. *Radiological Survey and Release Plan for the Overhead Piping/Supports and Asbestos.* DOE/OR/21548-017. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. April 8.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988h. *Army Vicinity Property 7 Certification Report.* Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. May 24.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988i. *Waste Assessment, Raffinate Pit Sampling Plan, Weldon Spring Site*, Rev. 1. DOE/OR/21548-010. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. May.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988j. *Weldon Spring Site Remedial Action Project, Chemical Soil Investigation Sampling Plan for the Weldon Spring Chemical Plant/Raffinate Pits*, Rev. 1. DOE/OR/21548-013. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. May.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988k. *Weldon Spring Site Remedial Action Project, Characterization Report for the August A. Busch and Weldon Spring Wildlife Area Vicinity Properties 3, 4, 5, and 8*, Rev. 0. DOE/OR/21548-022. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. May.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988l. *Phase I Chemical Soil Investigation Data Report for the Weldon Spring Chemical Plant/Raffinate Pits.* DOE/OR/21548-016. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. January.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988m. *Radiological Survey Results for Building 401.* Prepared for the U.S. Department of Energy, Weldon Spring Site Remedial Action Project. St. Charles, MO. July 25.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988n. *Weldon Spring Site Remedial Action Project, Geophysical/Geotechnical Investigation Sampling Plan*, Rev. 1. DOE/OR/21548-014. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. July.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988o. *Buildings Characterization Sampling Plan*, Rev. 0. DOE/OR/21548-021. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. August.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988p. *Lysimeter Data*. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office. Oak Ridge, TN. September 17.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988q. *Radiological Soil Characterization Report for the Weldon Spring Chemical Plant and Raffinate Pits Sites*, Rev. A. DOE/OR/21548-042. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. November.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988r. *Phase I Spring and Seep Report*, Rev. 0. DOE/OR/21548-045. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. November.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988s. *Annual Environmental Monitoring Report, Weldon Spring, Missouri, Calendar Year 1987*. DOE/OR/21548-015. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. April.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988t. *Hydrogeologic Investigations Sampling Plan*, Rev. 0. DOE/OR/21548-020. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. November.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988x. *Toxicological Profiles for the Weldon Spring Project*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988y. *Weldon Spring Site Remedial Action Project, Baseline Risk Assessment Protocol Document*, Rev. 0. DOE/OR/21548-047. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. October.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988z. *WSSRAP-Administration Building, Raffinate Pit, Disposal Cell Geotechnical Investigation*. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. September.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989a. *Chemical Soil Investigation Report for the Weldon Spring Chemical Plant/Raffinate Pits Phase II*, Rev. 0. DOE/OR/21548-061. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. August.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989b. *Weldon Spring Site Remedial Action Project, Chemical Soil Data Report to Support Interim Response Actions, Construction Staging Area and Administration Building*, Rev. 0. DOE/OR/21548-051. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. February.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989c. *Waste Assessment Chemical Characterization of the Weldon Spring Site Raffinate Pits*, Rev. 0. DOE/OR/21548-092. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. August.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989e. *Waste Assessment Radiological Characterization of the Weldon Spring Site Raffinate Pits*, Rev. 0. DOE/OR/21548-062. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. August.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989f. *1987 and 1988 Rainfall at the Weldon Spring Chemical Plant* (unpublished data).

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989h. *Characterization of Chemical and Radiological Contamination in Lake and Stream Sediments on Properties Surrounding the Weldon Spring Site*, Rev. 0. DOE/OR/21548-060. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project, St. Charles, MO. August.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989i. *Specifications for Overburden Hydrogeological Characterization*, Rev. 0. February.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989l. *Radiological and Chemical Uptake by Edible Portions of Selected Biota at the Weldon Spring Site*, Rev. 0. DOE/OR/21548-044. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. August.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989m. *Phase II Groundwater Quality Assessment for the Weldon Spring Site, Chemical Plant, Raffinate Pits and Surrounding Vicinity Properties*, Rev. 0. DOE/OR/21548-078. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. August.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989n. *Radiological and Chemical Characterization Report for the Planned Quarry Construction Staging Area and Water Treatment Plant*, Rev. 1. DOE/OR/21548-046. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. March.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989o. *Overburden Hydrogeological Investigation*, Rev. 1. WP-138, 74 p.

MK-Ferguson Company and Jacobs Engineering Group, 1989p. *Annual Environmental Monitoring Report, 1988*, Rev. 0. DOE/OR/21548-079. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. June.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1990a. *Radiological Sampling and Measurement Results for the Non-Process Related Buildings and Equipment, Weldon Spring Site*, Rev. D. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. February.

MK-Ferguson Company and Jacobs Engineering Group, 1990b. *Annual Site Environmental Monitoring Report, 1989*, Rev. 1. DOE/OR/21548-129. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. November.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1990c. *Asbestos and Chemical Characterization Report for Non-Process Related Buildings and Equipment*, Rev. E. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. April.

MK-Ferguson Company and Jacobs Engineering Group, 1991a. *WSSRAP Buildings Characterization—Chemical Characterization Report*, Rev. 0. DOE/OR/21548-236. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. October.

MK-Ferguson Company and Jacobs Engineering Group, 1991b. *Work Plan for Aquatic Biological Screening Investigation*, Rev. 0. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. April.

MK-Ferguson Company and Jacobs Engineering Group, 1991c. *Annual Site Environmental Monitoring Report, Calendar Year 1990*, Rev. 1. DOE/OR/21548-193. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. September.

MK-Ferguson Company and Jacobs Engineering Group, 1992a. *Environmental Data Administration Plan*, Rev. 1. DOE/OR/21548-119. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. February.

MK-Ferguson Company and Jacobs Engineering Group, 1992b. *Chemical Plant Site Remedial Investigation/Feasibility Study Data Validation Report*, Rev. 0. DOE/OR/21548-256. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. February.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1992c. *Aquifer Characteristics Data Report for the Weldon Spring Site Chemical Plant/Raffinate Pits and Vicinity Properties*, Rev. 0. DOE/OR/21548-122. Prepared for the U.S. Department of Energy, Oak Ridge Operations, Weldon Spring Site Remedial Action Project. St. Charles, MO. November.

MK-Ferguson Company and Jacobs Engineering Group, 1992d. *Quarry Haul Road Ecological Survey*, Rev. 1A. DOE/OR/21548-228. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. September.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1992e. *Environmental Quality Assurance Project Plan*, Rev. A. DOE/OR/21548-352. Prepared for the U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. October.

MK-Ferguson Company and Jacobs Engineering Group, 1992f. *Project Management Contractor Quality Assurance Program*, Rev. 0. DOE/OR/21548-333. Prepared for the U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. September.

MKF and JEG, see MK-Ferguson Company and Jacobs Engineering Group Inc.

Moylan, J.E. and L.G. Elser, 1967. *Geologic Appraisal of Settlement Pits, Weldon Spring Ordnance Works*. PMC Library Location File No. GE-10. October 19.

National Council on Radiation Protection and Measurements, 1985. *Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment*. NCRP Report No. 76.

National Lead Company of Ohio, 1977. *Study of Radioactive Waste Storage Areas at ERDA-Weldon Spring Site*. Report NCLO-1144 (Special). Prepared for the U.S. Energy Research and Development Administration under Contract EY-76-C-05-1156. Cincinnati, OH. April 25.

National Oceanic and Atmospheric Administration, 1981-1986. *Annual Climatological Summaries*. National Climatic Data Center. Asheville, NC.

National Oceanic and Atmospheric Administration, 1984. *Climatography of the United States, No. 20, St. Charles, MO*. National Climatic Data Center. Asheville, NC.

NCRP, see National Council on Radiation Protection and Measurements.

Nelson, R.R., 1986. Letter to Mr. Dennis Bigley, Missouri Highway and Transportation Department. Subject: BNI remedial action at DOC Location 1. U.S. Department of Energy, WSSRAP Project Manager, St. Charles, MO. September 19.

NOAA, see National Oceanic and Atmospheric Administration.

O'Kelley, J.C., 1986. *The Potential Biological Effects of Depleted Uranium on Range C-74 upon the Algal Flora of Rock Creek on Eglin Air Force Base*. Air Force Armament Laboratory, Rep. AFATL-TR-76-98. Eglin Air Force Base, FL. 48pp.

Oak Ridge Associated Universities, 1986a. *Radiological Survey ot the U.S. Army Reserve Property, Weldon Spring Site, St. Charles County, Missouri*. Prepared for the U.S. Department of Energy, Division of Remedial Action Projects. Oak Ridge, TN. January.

Oak Ridge Associated Universities, 1986b. *Radiological Survey of the August A. Busch and Weldon Spring Wildlife Areas, Weldon Spring Site, St. Charles County, Missouri.* Prepared for the U.S. Department of Energy, Division of Remedial Action Projects. Oak Ridge, TN. April.

Oak Ridge National Laboratory, 1979. *Chemical Analysis of Ponds 3 and 4 at Weldon Spring, MO.* P.O. No. W-31282. Oak Ridge, TN. December 10.

ORAU, see Oak Ridge Associated Universities.

ORNL, see Oak Ridge National Laboratory.

Parkhurst, B.R., et al., 1984. *An Environmental Hazard Evaluation of Uranium in a Rocky Mountain Stream.* Environmental Toxicology and Chemistry, Vol. 3, pp. 113-124.

Pennak, A.F., 1976. *Process Description and Resultant Radiological Contamination from Operations of the U.S. Atomic Energy Commission, 1956-1966, Weldon Spring Chemical Plant, Weldon Spring, MO.* National Lead Company of Ohio. Cincinnati, OH. October 27.

Peterson, J.M., et al., 1988. *Work Plan for the Remedial Investigation/Feasibility Study-Environmental Impact Statement for the Weldon Spring Site, Weldon Spring, MO*, Rev. 0. DOE/OR/21548-033. Prepared for the U.S. Department of Energy by Oak Ridge National Laboratory. Oak Ridge, TN. August.

Pflieger, W.L., 1975. *The Fishes of Missouri.* Missouri Department of Conservation, Jefferson City, MO.

Poston, T.M., 1982. *Observations on the Bioaccumulation Potential of Thorium and Uranium in Rainbow Trout (Salmo gairdneri).* Bulletin of Environmental Contamination Toxicology. Vol. 28. pp. 682-690.

Poston, T.M., R.W. Hahn, Jr., and M.A. Simmons, 1982. *Toxicity of Uranium to Daphnia magna.* Water Air Soil Pollution, Vol. 22, No. 3, pp. 289-298.

RETA, see Ryckman, Edgerly, Tomlinson & Associates.

Reynolds, W.D. and D.E. Elrick, 1986. *A Method for Simultaneous In Situ Measurement in the Vadose Zone of Field-Saturated Hydraulic Conductivity, Sorptivity and the Conductivity-Pressure Head Relationship.* Ground Water Monitoring Review, Vol. 6, No. 1, pp. 84.95.

Roberts, C.M., 1951. *Preliminary Investigation of Ground-Water Occurrences in the Weldon Spring Area, St. Charles County, MO.* U.S. Geological Survey, Indianapolis, IN. December.

Rudloff, W., 1981. *World Climates with Tables of Climatic Data and Practical Suggestions.* Wissenschaftliche Verlagsgelsellschaft, mbH. Stuttgart.

Ruffner, J.A., 1978. *Climate of the States.* Gale Research Company. Detroit, MI.

Ryckman, Edgerly, Tomlinson & Associates, 1977. *Phase II Technical Report, Narrative Section.* Prepared for the U.S. Department of the Army, Aberdeen Proving Ground, MD, under Contract No. DAAK11-77-C-0026. St. Louis, MO. December.

Ryckman, Edgerly, Tomlinson & Associates, 1978. *Weldon Spring Chemical Plant Survey and Assessment.* Prepared for the U.S. Department of the Army. June.

Saladin, T., 1989. Personal communication to I. Hlohowskyj, Argonne National Laboratory. Weldon Spring Wildlife Area, St. Charles County, MO. January 12.

Sax, E., 1984. *Dangerous Properties of Industrial Materials*, Sixth Ed. Van Nostrand Reinhold Company. New York.

Schumacher, J.G., 1990. *Geochemical Data for the Weldon Spring Chemical Plant Site and Vicinity Property, St. Charles County, MO—1989-1990.* U.S. Geological Survey Open-File Report 90-351, 64 p. Prepared in cooperation with the U.S. Department of Energy, Rolla, MO.

Schumacher, J.G. and K.G. Stollenwerk, 1991. "Geochemical Controls on Migration of Molybdenum, Uranium, and Other Constituents at the Weldon Spring Chemical Plant Site." *Proceedings of the Geosciences Workshop.* DOE/OR/21548-197. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office by MK-Ferguson and Jacobs Engineering Group. February 21.

Science Applications, Inc., 1979. *Preliminary Risk Assessment of the Weldon Spring Rock Quarry.* SAI-OR-79-135-01 (Draft). Oak Ridge, TN. September.

Shell Engineering and Associates, 1985a. *Water Balance Reports for the Weldon Spring Raffinate Pits*. Prepared for Bechtel National, Inc., Oak Ridge, TN, under Contract No. DOE-AC05-81OR20722. Columbia, MO. October 4.

Shell Engineering and Associates, 1985b. *Precipitation Gauge Calibration Report*. November 15.

Shell Engineering and Associates, 1985c. *1985 Water Balance Report for the Weldon Spring Raffinate Pits*. Prepared for Bechtel National, Inc., Oak Ridge, TN, under Contract No. DOE-AC05-81OR20722. Columbia, MO. December 13.

Shissler, J., 1990. Personal communication to Y.S. Chang, Argonne National Laboratory. Missouri Department of Natural Resources. Jefferson City, MO. May 10.

Simmons, M.S. and R.G. Zepp, 1986. *Water Resources*, Vol. 20, pp. 899-904.

Sizemore, M., 1991. Memorandum to M. MacDonell, Argonne National Laboratory. Subject: State Highway Department. MK-Ferguson Company. St. Charles, MO. November 18.

Soil Consultants, Inc., 1988. *Ground Water Monitoring Program, St. Charles County Weldon Spring Well Field*. Prepared for the Missouri Department of Natural Resources. SCI No. 87-061. St. Peters, MO. March.

Spanggord, R.J., et al., 1980. *Environmental Fate Studies on Certain Munition Wastewater Constituents--Literature Review*. U.S. Army Medical Research and Development Command, Contract DAMD17-78-C-8081. March.

Stephens, D.B., M. Unruh, J. Havlena, R.G. Knowlton, Jr., E. Mattson, and W. Cox, 1986. *Vadose Zone Characterization of Low-Permeability Sediments Using Field Permeameters*. Ground Water Monitoring Review, Vol. 8, No. 2, pp. 59-66.

Surdex Corporation, 1987. *Topographic Maps for Weldon Spring Raffinate Site*. Prepared for MK-Ferguson Company by Surdex Corporation, Chesterfield, MO. Date of photography - April 4.

Thom, R.H. and J.H. Wilson, 1980. *The Natural Division of Missouri*. Transactions of the Missouri Academy of Science, Vol. 14, No. 9. pp 9-23.

Todd, D.K., 1980. *Groundwater Hydrology*. John Wiley & Sons. New York.

Tom, E., 1988. Inter-office correspondence to Joe Jordan/Dennis Reppond. Subject: Water in boreholes GT38 & GT41. Morrison-Knudsen Engineers, San Francisco, CA. September 16.

Trautwein, S.J., 1988. *Field Measurement of Infiltration Rates Using a Sealed Double-ring Infintrometer in Clay Liners and Covers for Waste Disposal Facilities.* College of Engineering, University of Texas at Austin.

Tsai, S.Y., et al., 1984. *Analysis of Potential Groundwater Contamination in the Vicinity of the Weldon Spring Raffinate Pits Site.* ANL/ER-84-4. Argonne National Laboratory, Argonne, IL. August.

Turi, G., 1988. Inter-office memorandum. Subject: Discussions with U.S. Department of Energy, Division of Environmental Safety and Health on Radiation ARARs for the Weldon Spring Site Remedial Action Project. FUSRAP/SFMP Special Projects Manager. U.S. DOE, Office of Nuclear Energy (NE-23). January 12.

Union Electric, 1988. *Operational Radiological Monitoring Program — Callaway Plant-St. Louis, MO, 1988 Summary Report.* Prepared by Controls for Environmental Population, Inc. Santa Fe, NM. 46 pp.

Union Electric, 1989. *Radiological Environmental Monitoring Program — Callaway Plant-St. Louis, MO, Annual Report.* pp. 85-92.

Union Electric, 1990. *Radiological Environmental Program — Callaway Plant-St. Louis, MO Annual Report.* 36 pp.

U.S. Army Corps of Engineers, 1954. *Report of Foundation Investigation, United States Atomic Energy Commission, Weldon Spring, MO.* Office of the District Engineer, St. Louis District, St. Louis, MO. February.

U.S. Army Corps of Engineers, 1987. *Wetlands Delineation Manual.* 100 pp. plus appendices. Technical Report 4-87-1. January.

USDA, see U.S. Department of Agriculture.

U.S. Department of Agriculture, 1982. *Soil Survey of St. Charles County, Missouri.* Soil Conservation Service in cooperation with the Missouri Experimental Station. May.

U.S. Department of Energy, 1986. *Historical Nuclear Materials Balance Report for the Former AEC-Owned Weldon Spring Chemical Plant, Weldon Spring, MO.* DOE/OR-872. Oak Ridge Operations Office. Oak Ridge, TN. July.

U.S. Department of Energy, 1987. *Draft Environmental Impact Statement, Remedial Action at the Weldon Spring Site.* DOE/EIS-0117D. Office of Remedial Action and Waste Technology. Washington, DC. February.

U.S. Department of Energy, 1989. *Remedial Investigations for Quarry Bulk Wastes.* DOE/OR/21548-066. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project. St. Charles, MO. January.

U.S. Department of Energy, 1992a. *Baseline Assessment for the Chemical Plant Area of the Weldon Spring Site*, Rev. 0. DOE/OR/21548-091. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, by Environmental Assessment and Information Sciences Division, Argonne National Laboratory. November.

U.S. Department of Energy, 1992b. *Feasibility Study for Remedial Action at the Chemical Plant Area of the Weldon Spring Site*, Rev. 0. DOE/OR/21548-148. Prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, by Environmental Assessment and Information Sciences Division, Argonne National Laboratory. November.

U.S. Department of Energy, 1992d. *Proposed Plan for Remedial Action at the Chemical Plant Area of the Weldon Spring Site*, Rev. 0. DOE/OR/21548-160. Prepared for the U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, by Environmental Assessement and Information Sciences Division, Argonne National Laboratory, under Contract W-31-109-Eng-38. November.

U.S. Department of Housing and Urban Development, 1978. *Flood Insurance Rate Map, St. Charles County, Missouri, Unincorporated Areas Community Panel Number 290315 0250 A*. Page 250 of 350. Prepared Federal Insurance Adminsitration. Effective September 15.

U.S. Department of the Army, 1969. *Radiological Survey of the Weldon Spring Chemical Plant*. Edgewood Arsenal, MD. October 7.

U.S. Department of the Army, 1976. *Assessment of Weldon Spring Chemical Plant in St. Charles County, MO.* Office of the Project Manager for Chemical Demilitarization and Installation Restoration. Aberdeen Proving Ground, MD. March.

U.S. Environmental Protection Agency, 1979. *Water-Related Environmental Fate of 129 Priority Pollutants.*

U.S. Environmental Protection Agency, 1983. *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*. QAMS-005/80. Office of Research and Development. Washington, DC.

U.S. Environmental Protection Agency, 1984. *Eastern Environmental Radiation Facility Radiochemistry Procedures Manual*. Robert Lieberman. EPA 520/5-84-006. USEPA Office of Radiation Programs EPA. Montgomery, AL.

U.S. Environmental Protection Agency, 1986a. *RCRA Groundwater Monitoring Technical Enforcement Guidance Document*. OSWER 9950.1. U.S. Government Printing Office. Washington DC. September.

U.S. Environmental Protection Agency, 1986b. *Quality Criteria for Water*.

U.S. Environmental Protection Agency, 1986c. *Quality Assurance Program Plan for Region VII*. R7QA0-86-001. Kansas City, KS. May.

U.S. Environmental Protection Agency, 1986d. *Users' Guide to the Contract Laboratory Program*. Office of Emergency and Remedial Response. Washington, D.C. December.

U.S. Environmental Protection Agency, 1987. *Data Quality Objectives for Remedial Response Activities*. EPA 540/G-87/003. OSWER Directive 9355.0-7B. Washington, DC. March.

U.S. Environmental Protection Agency, 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*. OSWER Directive 9335.3-01. Washington, DC. October.

U.S. Fish and Wildlife Service, 1990. *National Wetlands Inventory Wetlands Map, Weldon Spring, MO, 1:58,000*. U.S. Department of the Interior, Fish and Wildlife Service, National Wetlands Inventory. St. Petersburg, FL.

U.S. Geological Survey, 1972. *7.5 Minute Topographic Map, Defiance Quadrangle, MO*.

U.S. Geological Survey, 1982. *7.5 Minute Topographic Map, Weldon Spring Quadrangle, MO*.

U.S. Geological Survey, 1987a. *Water Resources Data for Missouri, Water Year 1986*. USGS/WRD/HD-87/251. Water Resources Division. Rolla, MO. July 24.

U.S. Geological Survey, 1987b. *Water Resources Data, Illinois, Water Year 1986, Volume 1, Illinois except Illinois River Basin*. USGS/WRD/HD-87/248. Water Resources Division. Urbana, IL. July.

U.S. Geological Survey, 1990. *Geochemical Data for the Weldon Spring Chemical Plant Site and Vicinity Property, St. Charles County, Missouri—1989-1990.* Open-File Report 90-351. Prepared in cooperation with the U.S. Department of Energy. Rolla, MO.

U.S. Geological Survey, 1991. *Water Resources Data, Missouri, Water Year 1991.* Report No. MO-91-1. Prepared in cooperation with the Missouri Department of Natural Resources, Division of Geology and Land Survey and Division of Environmental Quality; Missouri State Highway and Transportation Commission; and other State and Federal agencies.

UNC Geotech, 1988. *Radiologic Characterization of the Weldon Spring Remedial Action Site.* DOE/ID/12584-22. Prepared for the U.S. Department of Energy, Oak Ridge Operations. Oak Ridge, TN. February.

University of Missouri-St. Louis, 1990. *RPT901: Population and Housing Unit Trends for Missouri Governmental Units, 1980-1990; Part 3: Municipality Level Data, PRC=E-W Gateway Coordinating Council County=St. Charles*, Missouri State Census Data Center, Urban Information.

Uppot, J. and C.L. Rauser, 1989. *New Way to Measure Landfill Clay Liner Conductivity.* Pollution Engineering. December.

USGS, see U.S. Geological Survey.

Ville, Claude A., 1977. *Biology*, 7th Ed. W.B. Saunders Company, Philadelphis, PA. 870 pp.

Weston Geophysical, 1983. *Geophysical Measurements/DOE Raffinate Pit Site, Weldon Spring, MO.* Prepared for Bechtel National, Inc., Pasadena, CA. March.

White, W.B., 1988. *Geomorphology and Hydrology of Karst Terrains.* Oxford University Press. NY.

Whitfield, J.W., K.G. Brill, Jr., and W.J. Krummel, 1989. *Geologic Map of the Weldon Spring 7.5 Minute Quadrangle, St. Charles County, MO.* OFM-89-252-GI. Missouri Department of Natural Resources, Division of Geology and Land Survey. Rolla, MO.

Wixson, B.G. and N.L. Gale, 1982. *Lead Studies of Fish in the Big River and Tailings Impoundment of Southeast Missouri.* University of Missouri–Rolla. Rolla, MO.

Zoback, M.D. and M.L. Zoback, 1981. *State of Stress and Intraplate Earthquakes in the United States.* Science, Volume 213, pp. 96-104.

9 GLOSSARY

ABSORBED DOSE	The amount of energy absorbed in any material from incident radiation. Measured in rads, where one rad equals 100 ergs of energy absorbed in one gram of matter.
ACTIVITY	A measure of the rate at which radioactive material is undergoing radioactive decay; usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time. The special unit of activity is the curie (Ci).
ADVECTION	Lateral movement of a gas or liquid.
ALLUVIUM	All material deposited permanently or in transit by streams.
ALPHA PARTICLE	A particle emitted from the nucleus during the radioactive decay of certain nuclides. It consists of two protons and two neutrons bound together. It is identical to the nucleus of a helium (HE^{+4}) atom.
AQUIFER	A water-bearing layer of permeable rock or soil that will yield water in usable quantities to wells. Confined aquifers are bounded on top and bottom by less permeable materials. Unconfined aquifers are bounded on top by a water table.
ARGILLACEOUS	Applied to all rocks or substances composed of clay minerals or having a notable proportion of clay in their composition, as shale, slate, etc.
ATTERBERG LIMITS	Based on the Atterberg scale which is a proposed scale for the classification of sediments based on a decimal system beginning with 2mm. The limits of the subclass are found by taking the square root of the product of the larger grade limits. The subdivision thus made follows the logarithmic rule. This is the accepted European method for classification of particle size.

BACKGROUND LEVELS	Naturally occurring chemical, metal, and radioactive concentrations in the soil and surface and groundwater within a specific geographic region.
BACKGROUND RADIATION	Background radiation includes both the natural and man-made (e.g., fallout) radiation in the human environment. It includes cosmic rays and radiation from the naturally radioactive elements that occur both outside and inside the bodies of humans and animals. For persons living in the United States, the individual dose from background radiation ranges from about 80 to 200 millirems per year.
BEDROCK	A solid rock formation usually underlying one or more unconsolidated units.
BETA PARTICLE	A particle emitted from the nucleus during radioactive decay. Beta particles are easily stopped by a thin sheet of metal or plastic. Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body.
BIOLOGICAL DEGRADATION	The process whereby a pollutant is consumed or altered by biological processes.
CHEMICAL DISSOLUTION	The process of putting a solid constituent into a solution by chemical reaction.
CHEMICAL PRECIPITATION	The process of separating dissolved constituents from a solution by chemical reaction.
CHERT	A compact siliceous rock of varying color composed of microorganisms or precipitated silica grains. Occurs as nodules, lenses, or layers in limestone and shales.
COMPLEXATION AGENT	Chemicals that react with other chemicals to form complex molecules. Complexation agents are used to remove certain chemical pollutants from solution.
CUMULATIVE RADIATION DOSE	The total dose resulting from repeated radiation exposure of the same organ or the whole body over a period of time.

CURIE	A measure of the rate of radioactive decay. One curie is equal to 37 billion disintegrations per second (3.7×10^{10} dis/s) which is approximately equal to the decay of one gram of radium.
DEMOGRAPHY	Study of human population - size, density, distribution, and vital statistics, e.g., age, sex, and ethnicity.
DISCHARGE	In groundwater hydrology, the volume of water that issues naturally or is withdrawn from an aquifer within a given period of time. In surface water hydrology, the volume of water that passes a given point within a given period of time.
DISPERSAL	Act or result of scattering a material in the environment.
DISPERSION	The continuous variation in the concentration of a pollutant or tracer as it moves through a medium. Refers to the rate of mixing and transport of the pollutant in the medium, e.g. atmosphere, groundwater, etc.
DOSE	Total radiation delivered to a specific part of the body or to the body as a whole.
DOSE COMMITMENT	The dose that an organ or tissue would receive during a specified period of time, e.g. 50 or 100 years, as a result of intake, as by ingestion or inhalation, of one or more radionuclides from one year of release.
DOSE EQUIVALENT	A term used to express the amount of effective radiation when modifying factors have been considered. It is the product of adsorbed dose (rads) multiplied by a quality factor and any other modifying factors. It is measured in rems (Roentgen Equivalent Man).
DOSE RATE	Radiation per unit time, (i.e., rem per minute, rem per hour) as it is being delivered to the body.
EFFLUENT	Liquid, gaseous, or solid discharges into the environment generated by a process or procedure.

EP TOXICITY TEST	The Extraction Procedure Toxicity Test is the procedure used to determine whether or not a material is classified as hazardous as defined by RCRA (40 CFR 261, Appendix II). On September 25, 1990, this procedure was superseded by the Toxicity Characteristic Leaching Procedure (TCLP) as defined in 40 CFR 268, Appendix I.
EPHEMERAL STREAMS	Streams that flow only in direct response to precipitation.
EPICENTER	The point on the surface of the earth above the focus of an earthquake.
EXPOSURE, RADIATION	The amount of ionization produced in air by X-rays or gamma rays which will incur a dose equivalent of about one rem.
FAULT	A geologic fracture or fracture zone along which there has been displacement of the sides relative to one another, parallel to the fracture.
FLOODPLAIN	The portion of a river or stream valley that is periodically inundated. The 100 year floodplain is the area that is likely to be inundated once in 100 years.
FRACTURE	Breaks in rock formations due to structural stresses. Fractures may occur as faults, shears, joints, or planes of cleavage.
GAINING STREAMS	A stream, or reach of a stream, in which the flow is increased by inflow of groundwater. Also known as an effluent stream.
GAMMA RADIATION	Penetrating high energy, short wave length electromagnetic radiation (similar to X-rays) emitted during radioactive decay. Gamma rays are very penetrating and require dense materials such as lead or uranium for shielding or to be stopped.

GENETIC EFFECTS OF RADIATION	Effects of radiation on subsequent generations as a result of damage to the genetic material of the exposed individual. These effects may not necessarily be observed in consecutive generations but observed in later generations (i.e., may skip one or more generations before being observed).
GROUNDWATER	Water within the zone of saturation below the ground surface.
GROUT	A mortar combined with water and bentonite to provide a matrix for sealing the annular space of a monitoring well.
HALF-LIFE	The time it takes for half the atoms of a quantity of a particular radioactive element to decay into another form. Half-lives of different isotopes vary from millionths of a second to billions of years.
HEALTH EFFECTS	Effects of radiation on exposed individuals (see also GENETIC EFFECTS OF RADIATION and SOMATIC EFFECTS OF RADIATION) that may affect the physical or psychological well being of the individual.
HORIZONTAL GROUND ACCELERATION	A measure of earthquake intensity measured as surface movement in terms of acceleration due.
HYDRAULIC CONDUCTIVITY	The volume of water that will move in a unit time under a unit hydraulic gradient through a unit area at right angles to the direction of groundwater flow.
HYDRAULIC GRADIENT	The rate of change in total head per unit distance of flow in a given direction.
HYDRAULIC HEAD (HEAD, TOTAL)	The sum of the elevation head, the pressure head, and the velocity at a given point in an aquifer.
HYDROGEOLOGY	The study of the character, source, and mode of occurrence of underground water.

HYDROLOGY	The study of the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.
INDIVIDUAL DOSE	The radiation dose received by an individual.
INFILTRATION RATE, SOIL	The rate at which water enters the surface layer of soil.
INTERMITTENT STREAM	A stream that flows only part of the time or during part of the year.
INTRUSION	Persons, plants, or animals breaking through the barriers that contain wastes in a disposal cell.
ION EXCHANGE	Replacement of ions adsorbed on a solid (such as a clay particle) or exposed at the surface of a solid by ions from solution, usually in water. The phenomenon is known to occur when water moves through clays, zeolitic rocks, and other materials of the earth's crust.
ISOTOPE	Radionuclides having the same atomic number, but different mass numbers.
KARST TOPOGRAPHY	An area where the surface is undulating and was developed as a result of dissolving limestones and dolomites. It is characterized by springs, sinkholes, natural arches, and disappearing streams. (Used interchangeably with Karst Terrain.)
LEACH	To remove or separate soluble components from a solid by contact with water or other liquids.
LOSING STREAM	A stream, or reach of a stream, that is losing water by seepage into the ground. Also known as an influent stream.
OLD-FIELD SUCCESSION	The progressive changes in vegetation and animal species structure and community processes that follow the abandonment of cropland or pasture.
ORGAN DOSE	The radiation dose to a specific organ.

ORGANIC CHEMICAL	Carbon compounds, especially those in which hydrogen is attached to carbon, whether derived from living organisms or not.
OVERBURDEN	All material, loose soil, sand, gravel, etc., that lies above bedrock.
OXIDATION-REDUCTION REACTIONS	Chemical reactions that involve the loss or gain of electrons such as happens during the discharge of a lead/acid battery.
PERENNIAL STREAMS	Streams that flow continuously.
PERMEABILITY	The relative ease with which a porous medium can transmit a liquid under a hydraulic gradient. In hydrology, the capacity of rock, soil, or sediment for allowing the passage of water.
PERSON-REM	The average dose per person multiplied by the number of persons exposed. For example, a thousand people each exposed to one millirem (1/1000 rem) would have a collective dose of one person rem.
PHOTOCHEMICAL REACTIONS	Chemical reactions that are triggered or driven by light such as happens when light strikes photographic film.
POTENTIOMETRIC SURFACE	The surface defined by the levels to which groundwater will rise by hydrostatic pressure.
PIEZOMETER	A nonpumping well, generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short wellscreen through which water can enter.
PLANT COMMUNITY	Any assemblage of plant populations living in a prescribed area or physical habitat. An organized unit having characteristics additional to its individual and population components.
POPULATION DOSE	Summation of the doses received by all individuals in a specific population.

POROSITY	That property of a rock or soil that enables the rock or soil to contain water in voids or interstices. Usually expressed in percentage or as a decimal fraction of void or interstice volume as compared to total volume.
PRIORITY POLLUTANT	Any one of the toxic pollutants defined for priority regulation by the EPA under the Clean Water Act.
RAD	Unit of absorbed dose. Acronym for Radiation Absorbed Dose (see ABSORBED DOSE).
RADIATION	A very general term that covers many forms of particles and energy from sunlight and radio waves to the energy that is released from inside an atom. Radiation can be in the form of electromagnetic waves (gamma rays, X-rays) or particles (alpha particles, beta particles, protons, neutrons).
RADIOISOTOPE	An unstable isotope of an element that spontaneously loses particles and energy through radioactive decay.
RADIONUCLIDE	An unstable nuclide that undergoes radioactive decay.
RAFFINATE	A waste product from a refining process.
RECHARGE	The process in which water is absorbed and is added to the zone of saturation, either directly into a formation or indirectly by way of another formation.
REFERENCE LEVEL	A particular concentration for a given radionuclide used by the PMC for discussion purposes in order to provide benchmarks from which soil characterization data can be interpreted. The reference level is not to be construed as a "cleanup" criterion for soil. These criteria will be determined in the feasibility study.
REGULATION	A law promulgated by an administrative agency or regulatory commission. Federal agencies and commissions obtain their power to promulgate laws from the U.S. Congress. State agencies and commissions obtain such power from their respective state legislatures.

REM (ROENTGEN EQUIVALENT MAN)	A quantity used in radiation protection to express the effective dose equivalent for all forms of ionizing radiation. It is the product of the absorbed dose in rads and factors related to relative biological effectiveness.
RISK	Assuming the factors can be quantified, risk equals the consequences per event multiplied by the probability of the event's occurrence.
ROENTGEN (R)	Unit of exposure. One roentgen is the amount of gamma rays required to produce one electrostatic unit (esu) of charge of one sign (either positive or negative) in one cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, a German scientist who discovered X-rays in 1895.
RUNOFF	All rainfall and snowmelt that does not soak into the ground, does not evaporate immediately, or is not used by vegetation, and hence flows over the land surface.
SECULAR EQUILIBRIM	In a radioactive decay series, the physical, chemical or nuclear condition in which a balance between reactants and products is established.
SEEPAGE	Any water or liquid effluent that migrates through a semi-permable medium, e.g., water lost through the bottom of a containment area.
SEISMIC	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
SHIELDING	A material interposed between a source of radiation and people for protection against the danger of radiation. Commonly used shielding materials are concrete, water, and lead.
SINKHOLE	A funnel shaped depression in the land surface generally in a limestone region communicating with a subterranean passage developed by solution.
SOLUBILITY	The ability or tendency of one substance to blend uniformly with another.

SOLUTION CAVITIES/ CHANNELS	Openings or passages formed in carbonate rocks such as limestone, dolomite, and marble, caused by the chemical solutioning of the rock along fractures, joints, etc.
SOMATIC EFFECTS OF RADIATION	Effects of radiation that are limited to the exposed individual as distinguished from genetic effects that may also affect subsequent unexposed generations.
SORBENTS	Materials that attach a gas, a liquid, or a solid onto or into themselves.
SORPTION	The process of placing the molecules of a gas, liquid, or solid onto or into another material.
SOURCE TERMS	The quantity of radioactive material or other pollutant released to the environment at its point of release (source).
SPECIFIC ACTIVITY	The activity per unit volume or mass of a pure substance (see ACTIVITY).
STORAGE COEFFICIENT	The volume of water an aquifer releases from, or takes into, storage per unit surface area of the aquifer per unit change in head.
STORATIVITY	See STORAGE COEFFICIENT.
STRATUM	Bed or layer, regardless of thickness, of homogeneous or gradational rock material.
SWALLOW HOLE	A vertical shaft in a karst terrain leading from a surface stream into a subsurface flow.
TECTONIC	Of or pertaining to, designating the process causing, and the rock structures resulting from deformation of the earth's crust.
TILL	Unstratified glacial deposits consisting of clay, sand, gravel, and boulders intermingled.

TRACE CONTAMINANT	Chemical compounds or elements that may occur in minute (trace) concentrations and may not be inherent to the medium in which they are found.
TRACE ELEMENTS	Chemical elements that normally occur in minute (trace) quantities. Includes metals such as chromium, zinc, cadmium, copper; nonmetals; and arsenic.
TRANSMISSIVITY	Volume of water flowing through a unit width of aquifer of given thickness under a unit hydraulic gradient (1 m vertically for each 1 m laterally) and at the viscosity prevailing in the field. Mathematically, it is the product of hydraulic conductivity and aquifer thickness.
URANIUM (NATURAL)	A naturally occurring radioactive element that consists of 99.2830% by weight uranium-238, 0.7110% uranium-235, and 0.0054% uranium-234. The activity ratio of uranium-238:uranium-234:uranium-235 in natural uranium is 1:1:0.046.
WATERSHED	An area of land that drains into a water body. Watersheds are separated by divides.
WATER TABLE	The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric.
WELL YIELD	The rate at which a well produces water.
WHOLE-BODY DOSE	The radiation dose to the entire body.

10 ACRONYMS & ABBREVIATIONS

** A **

ACM	Asbestos-Containing Material
AEC	U.S. Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
ANSI	American Nuclear Standards Institute
ARAR	Applicable or Relevant and Appropriate Requirement
ASME	American Society of Mechanical Engineers

** B **

BA	Baseline Assessment
BNI	Bechtel National Incorporated

** C **

CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
COE	U.S. Army Corps of Engineers

** D **

DA	U.S. Department of the Army
DACDIR	U.S. Army Chemical Demilitarization and Installation Restoration
DGLS	Division of Geology and Land Survey (MDNR)
DNB	Dinitrobenzene
DNT	Dinitrotoluene
DOE	U.S. Department of Energy
DQO	Data Quality Objectives

** E **

EA	Environmental Assessment

EIS	Environmental Impact Statement
EM	Electromagnetic
EPA	U.S. Environmental Protection Agency
EQAPjP	Environmental Quality Assurance Project Plan

** F **

FS	Feasibility Study
FIDLER	Field Instrument for the Detection of Low Energy Radiation
FUSRAP	Formerly Utilized Sites Remedial Action Program

** G **

GSI	Geotechnology Services Inc.

** H **

HSL	Hazardous Substance List

** I **

IRA	Interim Response Action

** J **

JEG	Jacobs Engineering Group

** M **

MDNR	Missouri Department of Natural Resources
MDOC	Missouri Department of Conservation
MEQ	Milliequivalent
MKE	Morrison-Knudsen Engineers
MKF	MK-Ferguson Company
MKT	Missouri-Kansas-Texas Railroad
MSL	Mean Sea Level

** N **

NB	Nitrobenzene
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection & Measurements
NEPA	National Environmental Policy Act
NLO	National Lead Company of Ohio
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NVGD	National Vertical Geodetic Datum

** O **

OD	Outside Diameter
ORAU	Oak Ridge Associated Universities
ORB	Ordnance Review Board
ORNL	Oak Ridge National Laboratory
OSHA	U.S. Occupational Safety and Health Administration

** P **

PCB	Polychlorinated Biphenyl
PCM	Phase Contrast Microscopy
PIC	Pressurized Ionization Chamber
PMC	Project Management Contractor

** Q **

QA	Quality Assurance
QAP	Project Management Contractor Quality Assurance Program
QC	Quality Control

**** R ****

RADCON	U.S. Army Radiation Control
RCRA	Resource Conservation and Recovery Act
RETA	Ryckman, Edgerly, Tomlinson and Associates
RI	Remedial Investigation
ROD	Record of Decision
RQD	Rock Quality Designation

**** S ****

SARA	Superfund Amendments and Reauthorization Act
SCCAHW	St. Charles Countians Against Hazardous Waste
SEM	Standard Error of the Mean
SI	International System of Units
SMSA	Standard Metropolitan Statistical Area
SOC	Semivolatile Organic Compound
SOP	Standard Operating Procedure
SP	Spontaneous Potential
SPT	Standard Penetration Test

**** T ****

TBP	Tributyl Phosphate
TDS	Total Dissolved Solids
TEM	Transmission Electron Microscopy
TNB	Trinitrobenzene
TNT	Trinitrotoluene
TOB	Top of Bedrock
TOC	Total Organic Carbon

**** U ****

UNC	UNC Geotech
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USGS	U.S. Geological Survey

** V **

VLF	Very Low Frequency

** W **

WGC	Weston Geophysical Corporation
WSCP	Weldon Spring Chemical Plant
WSOW	Weldon Spring Ordnance Works
WSRP	Weldon Spring Raffinate Pits
WSS	Weldon Spring Site
WSSRAP	Weldon Spring Site Remedial Action Project
WSTA	Weldon Spring Training Area
WSUFMP	Weldon Spring Uranium Feed Materials Plant

11 SYMBOLS AND UNITS OF MEASURE

ac	Acre
ac-ft	Acre-feet
Ag	Silver
Al	Aluminum
As	Arsenic
Ba	Barium
Be	Beryllium
Ca	Calcium
Cd	Cadmium
Ci	Curies
cm	Centimeters
cm/sec	Centimeters per second
cm^2	Square centimeters
cm^2/sec	Square centimeters per second
Co	Cobalt
Cr	Chromium
Cu	Copper
dpm	Disintegrations per minute
Eh	Redox potential
El	Elevation
Fe	Iron
ft	Foot/feet
ft^2	Square foot (feet)
ft^3	Cubic foot (feet)
ft/day	Feet per day
ft/min	Feet per minute
ft^3/min	Cubic feet per minute
ft/sec	Feet per second
ft^2/sec	Square feet per second
ft^3/sec	Cubic feet per second
g	Gram
g/cm^3	Grams per cubic centimeter
gpd	Gallons per day
gpm	Gallons per minute
h	Hour
ha	Hectare
Hg	Mercury
I	Iodine
in	Inches

K	Potassium (also Hydraulic Conductivity)
kg	Kilogram
km	Kilometer
km^2	Square kilometers
km/h	Kilometers per hour
lb	Pound
lb/ft^3	Pounds per cubic foot
l/m	Liters per minute
Li	Lithium
m	Meters
m^3	Cubic meters
Mg	Magnesium
mg	Milligram
mg/cm^2	Milligrams per square centimeter
mg/kg	Milligrams per kilogram
mg/l	Milligrams per liter
mi	Mile(s)
mi^2	Square miles
m/sec	Meters per second
m^3/min	Cubic meters per minute
m^2/sec	Square meters per second
ml/g	Milliliters per gram
min	Minute
mm	Millimeters
mm/day	Millimeters per day
Mn	Manganese
Mo	Molybdenum
mph	Miles per hour
mR/h	Milliroentgens per hour
mrem/yr	Milliroentgen equivalent man per year
n	Nano ($1/10^9$)
N	Nitrogen
Na	Sodium
NaI	Sodium iodine
Ni	Nickel
ohm/m	Ohm/meters
Pb	Lead
pCi	Picocurie
pCi/g	Picocuries per gram
pCi/l	Picocuries per liter
pH	Common logarithm of the reciprocal of the hydrogen ion concentration

Po	Polonium
Ra	Radium
rad	Radiation absorbed dose
rem	Roentgen equivalent man
Rn	Radon
Sb	Antimony
s/cc	Structures per cubic centimeters
Se	Selenium
sec	Second
Th	Thorium
Tl	Thallium
U	Uranium
μ	Micro ($1/10^6$)
μg	Micrograms
μg/g	Micrograms per gram
μg/kg	Micrograms per kilogram
μg/l	Micrograms per liter
μR/h	Microroentgen per hour
μrad/h	Microrads per hour
V	Vanadium
yd	Yards
yd^2	Square yards
yd^3	Cubic yards
yr	Year
Zn	Zinc
°C	Degrees Celsius
°F	Degrees Fahrenheit

12 SI CONVERSION FACTORS

This section contains the conversion factors applied to physical parameters relating to area, volume, mass, velocity, length, and temperature.

Acres = 4.05×10^{-1} hectares
Acres = 4.05×10^{3} square meters
Centimeters = 3.28×10^{-2} feet
Centimeters = 3.94×10^{-1} inches
Centimeters/second = 2834.6 feet/day
Centimeters/second = 1.97 feet/minute
Centimeters/second = 3.28×10^{-2} feet/second
Cubic centimeters = 3.53×10^{-5} cubic feet
Cubic centimeters = 6.10×10^{-2} cubic inches
Cubic centimeters = 2.64×10^{-4} gallons
Cubic feet = 2.83 x 104 cubic centimeters
Cubic feet = 2.83×10^{-2} cubic meters
Cubic feet = 2.83×10^{1} liters
Cubic feet/minute = 4.72×10^{2} cubic centimeters/second
Cubic feet/minute = 4.72×10^{-1} liters/second
Cubic inches = 1.64×10^{1} cubic centimeters
Cubic inches = 1.64×10^{-5} cubic meters
Cubic inches = 1.64×10^{-2} liters
Cubic meters = 3.53×10^{1} cubic feet
Cubic meters = 6.10×10^{4} cubic inches
Cubic meters = 1.38 cubic yards
Cubic meters/second = 35.3 cubic feet/second
Cubic meters = 2.64×10^{2} gallons
Cubic yards = 7.65×10^{5} cubic centimeters
Cubic yards = 7.65×10^{-1} cubic meters
Cubic yards = 7.65×10^{2} liters
Cubic yards/minute = 1.27×10^{1} liters/second
Degrees celsius = $(°C \times \frac{9}{5}) + 32$ degrees fahrenheit
Degrees fahrenheit = $(°F - 32) \times \frac{5}{9}$ degrees celsius
Feet = 3.05×10^{1} centimeters
Feet = 3.05×10^{-4} kilometers
Feet = 3.05×10^{-1} meters
Feet/minute = 5.08×10^{-1} centimeters/second
Feet/minute = 1.83×10^{-2} kilometers/hour
Feet/minute = 3.05×10^{-1} meters/minute
Feet/second = 3.05×10^{1} centimeters/second
Feet/second = 1.83×10^{1} meters/minute

Gallons = 3.79 x 10^3 cubic centimeters
Gallons = 3.79 x 10^{-3} cubic meters
Gallons = 3.79 x 10^1 liters
Gallons/minute = 2.23 x 10^{-3} cubic feet/second
Gallons/minute = 6.31 x 10^{-2} liters/second
Gallons/minute = 3.79 x 10^1 liters/minute
Grams = 3.53 x 10^{-2} ounces
Grams = 2.21 x 10^{-3} pounds
Grams/centimeters = 5.6 x 10^{-3} pounds/inch
Grams/cubic centimeters = 6.24 x 10^1 pounds/cubic foot
Grams/cubic centimeters = 3.61 x 10^{-2} pounds/cubic inch
Grams/liter = 6.24 x 10^{-2} pounds/cubic foot
Grams/square centimeters = 2.05 x 10 pounds/square foot
Hectares = 2.47 acres
Hectares = 1.08 x 10^5 square feet
Inches = 2.54 centimeters
Inches = 2.54 x 10^{-2} meters
Inches = 2.54 x 10^1 millimeters
Kilograms = 2.21 pounds
Kilograms = 1.10 x 10^{-3} tons
Kilograms/cubic meter = 6.24 x 10^{-2} pounds/cubic foot
Kilograms/cubic meter = 3.61 x 10^{-5} pounds/square inch
Kilograms/meter = 6.72 x 10^{-1} pounds/foot
Kilograms/square centimeter = 2.05 x 10^3 pounds/square foot
Kilograms/square centimeter = 1.42 x 10^1 pounds/square inch
Kilograms/square meter = 2.05 x 10^{-1} pounds/square foot
Kilograms/square meter = 1.42 x 10^{-3} pounds/square inch
Kilometers = 3.28 x 10^3 feet
Kilometers = 6.21 x 10^{-1} miles
Kilometers = 1.093 x 10^3 yards
Kilometers/hour = 5.47 x 10^1 feet/minute
Kilometers/hour = 9.11 x 10^{-1} feet/second
Kilometers/hour = 6.21 x 10^{-1} miles/hour
Liters = 3.53 x 10^{-2} cubic feet
Liters = 6.10 x 10^1 cubic inches
Liters = 1.31 x 10^{-3} cubic yards
Liters = 2.64 x 10^{-1} gallons
Liters/minute = 5.89 x 10^{-4} cubic feet.second
Liters/minute = 4.40 x 10^{-3} gallons/second
Meters = 3.28 feet
Meters = 3.94 x 10^1 inches
Meters = 6.21 x 10^{-4} miles

Meters = 1.09 yards
Meters/minute = 3.28 feet/minute
Meters/minute = 5.47 x 10^{-2} feet/second
Meters/minute = 3728 x 10^{-2} miles/hour
Meters/second = 1.97 x 10^{2} feet/minute
Meters/second = 3.28 feet/second
Metric tons = 1.10 tons (short)
Metric tons = 2.21 x 10^{3} pounds
Miles = 1.61 kilometers
Miles = 1.61 x 10^{3} meters
Miles/hour = 1.61 kilometers/hour
Miles/hour = 2.68 x 10^{-2} kilometers/minute
Miles/hour = 2.68 x 10^{1} meters/minute
Miles/hour = 1.68 x 10^{-2} miles/minute
Millimeters = 3.94 x 10^{-2} inches
Ounces = 2.84 x 10^{1} grams
Pounds = 4.54 x 10^{2} grams
Pounds = 4.54 x 10^{-1} kilograms
Pounds-feet = 1.38 x 10^{4} centimeter-grams
Pounds-feet = 1.38 x 10^{-1} meter-kilograms
Pounds/cubic feet = 1.60 x 10^{-2} grams/cubic centimeter
Pounds/cubic feet = 1.60 x 10^{1} kilograms/cubic meter
Pounds/cubic inch = 2.77 x 10^{1} grams/cubic centimeter
Pounds/cubic inch = 2.77 x 10^{4} kilograms/cubic meter
Pounds/foot = 1.49 kilograms/meter
Pounds/inch = 1.79 x 10^{2} grams/centimeter
Pounds/square foot = 4.88 kilograms/square meter
Pounds/square inch = 7.03 x 10^{2} kilograms/square meter
Pounds/square inch = 7.03 x 10^{2} kilograms/square centimeter
Square feet = 9.29 x 10^{2} square centimeters
Square feet = 9.29 x 10^{-2} square meters
Square inches = 6.45 square centimeters
Square inches = 6.45 x 10^{2} square millimeters
Square kilometers = 2.47 x 10^{2} acres
Square kilometers = 1.08 x 10^{7} square feet
Square kilometers = 3.86 x 10^{-1} square miles
Square kilometers = 1.20 x 10^{6} square yards
Square meters = 2.47 x 10^{-4} acres
Square meters = 1.08 x 10^{1} square feet
Square meters = 1.55 x 10^{3} square inches
Square meters = 3.86 x 10^{-7} square miles
Square meters = 1.20 square yards

Square miles = 2.59 square kilometers

Square miles = 2.59 x 10^6 square meters

Square yards = 8.36 x 10^3 square centimeters

Square yards = 8.36 x 10^{-1} square meters

Tons (short) = 9.07 x 10^2 kilograms

Tons (short) = 9.078 x 10^{-1} metric tons

Tons (short)/square foot = 9.77 x 10^3 kilograms/square meter

Yards = 9.14 X 10^1 centimeters

Yards = 9.14 X 10^{-4} kilometers

Yards = 9.14 X 10^{-1} meters

13 LIST OF CONTRIBUTORS

This remedial investigation study has been prepared by the U.S. Department of Energy (DOE) with contractual assistance from MK-Ferguson Company and Jacobs Engineering Group (MKF and JEG). The following MKF and JEG members contributed to the preparation of this report. Additional input was provided by individuals from Argonne National Laboratory.

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APPENDIX A

BACKGROUND SOIL COMPOSITION DETERMINATION

APPENDIX A

BACKGROUND SOIL COMPOSITION DETERMINATIONS

This appendix discusses the methods and procedures used to determine average background soil compositions in the site area. Background levels are defined as naturally occurring chemical and radioactive concentrations in the soil within a specific geographic region. These background ranges are an important consideration when interpreting the concentration levels in site soil samples. This appendix is divided into two separate discussions of the background level determinations. The first addresses the determination of background soil radioactivity levels, while the second discussion addresses how background ranges for inorganic anions and metals were established.

A.1 Radiological Background Determinations

To determine the conditions that are normally present in the site area, radiological measurements and soil samples were collected at varying distances from the site to establish normal background radiation levels. The characteristics of the soil and the environment at these locations were determined to be unaffected by site operations and other industrial activities which could have biased the results. Each of the DOE contractors--Bechtel National, Inc. (BNI), UNC Geotech (UNC), and the Project Management Contractor (PMC)--have developed data pertinent to the conditions that existed at the time of characterization activities.

BNI referenced background measurements collected by Oak Ridge National Laboratory (ORNL) in the state of Missouri (BNI 1984). Ten locations were sampled for average external gamma exposure rates and radionuclide concentrations in surface soils. Gamma exposure rates ranged from 4.6 to 10 μR/h with an average of 6.8 μR/h. Radionuclide concentrations in surface soils ranged from 0.31 to 1.4 pCi/g (radium-226), 0.32 to 1.3 pCi/g (thorium-232), and 0.33 to 1.7 pCi/g (uranium-238). The data and sample locations are presented in Table A-1.

UNC Geotech sampled four locations within an 8-km (5-mi) radius of the site (UNC 1988). Gamma exposure rates were measured with gamma scintillation detectors that were correlated to exposure rate measurements obtained by a pressurized ion chamber (PIC). The measured exposure rates ranged from 9.2 to 11.0 μR/h with an average of 10.2 μR/h. Radionuclide concentrations in surface soils ranged from 0.8 to 1.5 pCi/g (radium-226), 0.9 to 1.5 pCi/g (thorium-232), and 0.7 to 1.7 pCi/g (uranium-238). Additional FIDLER (field instrument for the detection of low energy radiation) measurement data and sample locations are presented with these results in Table A-2 and Figure A-1.

TABLE A-1 Background Radiation Levels and Nuclide Concentrations in Surface Soil Samples in the State of Missouri

Sample Designation	Description of Sample Location	Average External Gamma Exposure Rate (μR/h)[a]	Nuclide Concentration in Surface Soil (pCi/g)[b]		
			Radium-226	Thorium-232	Uranium-238
MO-1	Approx. 45 km E of Kansas City, Missouri, in pasture field on S side of I-70	6.0	1.4 ± 0.04	1.3 ± 0.10	1.7
MO-2	Approx. 140 km E of Kansas City, Missouri, at intersection of I-70 and exit J, SE corner	10.0	1.3 ± 0.06	1.2 ± 0.10	1.3
MO-3	Rest stop on S side of I-70, ~16 km E of Williamsburg, Missouri	6.7	1.1 ± 0.06	1.0 ± 0.08	1.2
MO-4	SE corner of intersection of Hwy 175 and I-70 in O'Fallon, Missouri	7.5	1.3 ± 0.08	1.1 ± 0.12	1.1
MO-5	Approx. 34 km N of Missouri-Arkansas border, on E side of I-55, mile marker 21	8.1	1.2 ± 0.04	1.2 ± 0.06	1.3
MO-6	E side of I-55, ~14 km N of intersection with Hwy Alt. 61, at mile marker 76	5.4	0.31 ± 0.04	0.32 ± 0.04	0.33
MO-7	E side of I-55, ~1.6 km S of Appleton exit E of Friedheim, Missouri	7.6	1.1 ± 0.06	1.1 ± 0.06	1.1
MO-8	Exit O off I-55, near Bloomsdale, Missouri	6.8	0.83 ± 0.04	0.76 ± 0.06	0.81
MO-9	E side of I-55, ~0.4 km S of Hwy 141 intersection, Maxville, Missouri	5.1	1.1 ± 0.06	1.1 ± 0.06	1.1
MO-10	W side of Hwy 367, ~0.3 km S of intersection with Hwy 67, N of St. Louis, Missouri	4.6	1.0 ± 0.10	0.95 ± 0.14	0.76

[a] Exposure rate determined from 3 to 4 measurements at each location using a "Phil" tube.

[b] Standard deviation of radium-226 and thorium-232 measurements are given as the 2 σ value. Error in the uranium-238 measurements is $\leq 5\%$ (2σ).

Source: BNI 1984

TABLE A-2 UNC Background Measurements

Location	Exposure Rate (μR/hr)	FIDLER A1006 (CPM)	FIDLER B1006 (CPM)	Surface Soil Radionuclide Concentrations (pci/g)[b][c] Ra-226	Th-232	K-40	U-238
1	10.0	5669	6117	0.8	0.9	9.3	1.0
2	10.3	5874	6314	1.1	1.5	12.2	0.7
3	9.2	5484	5823	1.2	1.3	10.3	0.7
4	9.2	5498	5986	1.1	1.1	9.6	0.7
5	11.0	6434	5935	1.3	1.1	14.5	1.3
6	10.5	5870	6294	1.3	1.0	13.2	1.0
7	10.7	5882	6276	1.2	1.4	8.4	1.7
8	10.5	5912	6481	1.3	1.1	11.1	1.7
AVERAGE	10.2	5828	6153	1.2	1.2	11.1	1.1

(a) Measured at one meter above ground surface

(b) Samples represent 0 to 6 inches

Source: UNC Geotech 1988

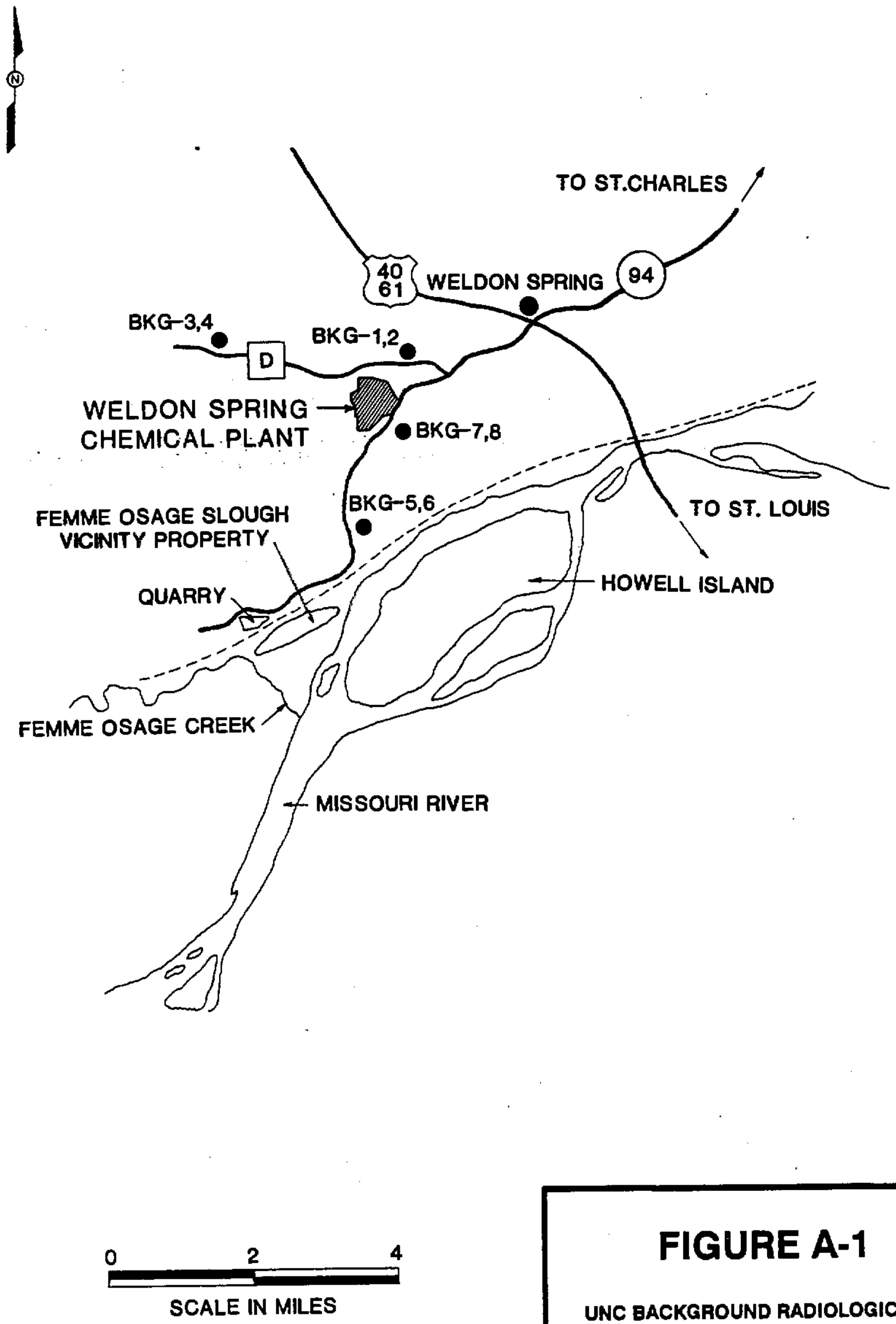

FIGURE A-1

UNC BACKGROUND RADIOLOGICAL SAMPLING LOCATIONS

SOURCE : MKF AND JEG, 1988

The PMC (MKF and JEG 1988) sampled six locations, also within an 8-km (5-mi) radius of the site. Radionuclide concentrations in surface and subsurface soils ranged from 0.5 to 1.3 pCi/g (radium-226), 0.4 to 1.2 pCi/g (thorium-232), and less than 2.0 pCi/g (uranium-238). The data and sample locations are presented in Table A-3 and Figure A-2.

The UNC and PMC data are more representative of the soil and vegetation cover native to the site than data from the BNI investigation and, therefore, have been used to interpret radiological concentration levels in site soils. Additionally, neither the BNI nor the ORNL investigation included soil analyses for potassium concentrations. The natural abundance of potassium can cause direct exposure rate measurements to vary by as much as 10%. Samples from the UNC and PMC investigations indicate concentrations of radionuclides that are normal for this geographic area.

A.2 Inorganic Anion and Metal Background Determinations

During the Phase II chemical soil investigation (MKF and JEG 1989) soil samples collected from areas unaffected by ordnance works and feed materials plant processes were analyzed for inorganic anion and metal concentrations. These off-site data were used to establish the statistical background determinations.

Table 5.2-1 indicates the upper limits for background concentrations which were used to evaluate the analytical data in this remedial investigation report.

TABLE A-3 PMC Background Measurements

Location	Exposure[a] Rate (μR/hr)	Surface Soil Radionuclide Concentrations (pCi/g)[b][c] Ra-226	Th-232	U-238	K-40
1	9.3	0.8	0.8	<1.9	3.8
2	9.0	1.1	0.9	<1.9	7.9
3	8.9	1.3	0.6	<1.8	<3.4
4	9.5	0.8	0.8	<1.9	8.3
5	9.2	0.9	1.0	<2.0	<3.2
6	9.5	1.1	1.0	<1.9	12.5
AVERAGE	9.2	1.0	0.9	<2.0	6.5

[a] Measured at one meter above ground surface

[b] "<" indicates less than lower limit of detection

[c] Samples represent 0 to 6 inches

Location	Subsurface Soil Radionuclide Concentrations (pCi/g)[a][b] Ra-26	U-238	Th-232	K-40
A	0.9	<1.9	0.7	8.7
B	0.5	<1.9	1.2	13.5
C	1.2	<1.8	0.4	12.1
AVERAGE	0.9	<1.9	0.8	11.4

[a] "<" indicates less than lower limit of detection

[b] Samples represent a composite of 0 to 3 feet

Source: MKF and JEG 1988

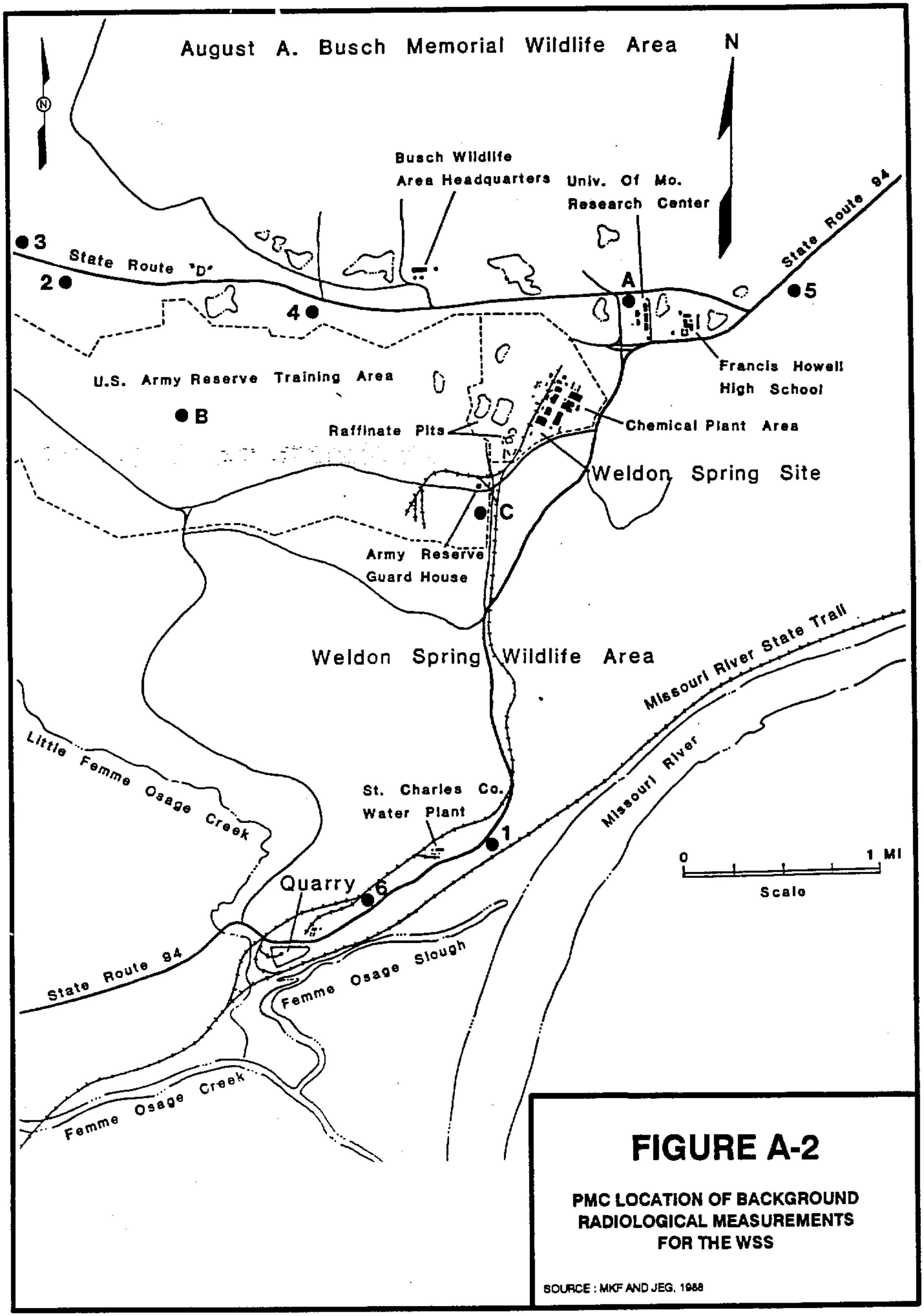

FIGURE A-2

PMC LOCATION OF BACKGROUND RADIOLOGICAL MEASUREMENTS FOR THE WSS

SOURCE : MKF AND JEG, 1988

References Cited

Bechtel National, Inc., 1984. Radiological Survey Report for the Weldon Spring Raffinate Pits Site. DOE/OR/20722 (DE84015853). August.

BNI, see Bechtel National, Inc.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988. Radiological Soil Characterization Report for the Weldon Spring Chemical Plant and Raffinate Pits Sites, Rev. A. DOE/OR/21548-42. November.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1989. Chemical Soil Investigation Report for the Weldon Spring Chemical Plant/Raffinate Pits Phase II, Rev. A. DOE/OR/21548-061. January.

MKF and JEG, see MK-Ferguson Company and Jacobs Engineering Group Inc.

UNC Geotech, 1988. Radiologic Characterization of the Weldon Spring, Missouri, Remedial Action Site. February.

UNC, see UNC Geotech.

APPENDIX B

DETERMINATION OF BACKGROUND CONCENTRATIONS FOR SPECIFIED ELEMENTS IN GROUNDWATER

APPENDIX B

DETERMINATION OF BACKGROUND CONCENTRATIONS FOR SPECIFIED ELEMENTS IN GROUNDWATER

Background concentrations in groundwater were estimated for elements that were determined to be potential contaminants by analysis of the source and groundwater data. Since representative site background data were not available, the background concentrations were estimated by 1) establishing the general geochemical distribution of specified elements in the Burlington-Keokuk and overburden units and 2) applying statistical analyses of the groundwater data to identify the noncontaminated populations.

The mineralogy of and trace element content in the soil and rock have a direct bearing on the background concentrations in groundwater. The groundwater quality in the limestone aquifer is the result of the infiltration of surface water through the overburden and through the limestone. Trace metals present in the overburden and limestone are generally also present in surface and ground water. To quantify the impacts of the soils and rocks on the groundwater, the U.S. Geological Survey conducted a geochemical survey of the rock units, overburden deposits, and water throughout Missouri and adjacent states. The results of a chemical sampling are described in Connor and Ebens (1980), Ebens and Connor (1980), and Feder (1979).

The Burlington-Keokuk Limestone at the site is part of Kaskaskia sequence of Mississippian Age. The results of chemical analyses of these rocks (Connor and Ebens 1980) are given in Table B-1. Table B-1 also includes the results of chemical analyses of the carbonate residuum and loess characteristic of the overburden at the site (Ebens and Connor 1980).

In general, the trace elements are present in significantly greater concentrations in this residuum and loess than in the limestone. Trace elements are elements that normally occur in minute (trace) quantities and include metals such as chromium, zinc, cadmium, copper, selenium, boron, and arsenic. Infiltration of rainfall through the residuum and loess may be the source of the trace metal concentrations in the groundwater in the limestone aquifer.

In addition, the potential exists for high concentrations of trace metals in the Mississippian limestones. The mineralized zone of the Joplin Mining Area is in the Mississippian limestones. Heavy metals, lead, cadmium, zinc, and nickel, are associated with sulfide minerals. Groundwater from this area shows very high concentrations of iron, sulfate, and heavy metals (Feder 1979).

Similar to the heavy metals, naturally occurring radionuclides may exist in the groundwater because of the presence of radionuclides in the soil and rocks. Limestones typically have low uranium concentrations. The overburden materials, however, have been found to contain higher levels of uranium (Nuelle 1988). The overburden deposits (surface sediments,

TABLE B-1 Trace Element Summary of Limestone of the Kaskakia Sequence, Limestone Residuum, and Loess in Missouri

	Limestone[a]		Residuum[b]		Loess[b]	
	Geometric Mean	Geometric Deviation	Geometric Mean	Geometric Deviation	Geometric Mean	Geometric Deviation
As, mg/kg	0.57	3.04	19	1.63	8.3	1.33
Ba, mg/kg	4	5.72	170	1.41	840	1.26
Cd, mg/kg	<1	--	1.5	1.75	<1	--
Co, mg/kg	<3	--	5.8	2.44	9.8	1.28
Cr, mg/kg	9.4	3.27	69	1.54	70	1.16
Cu, mg/kg	0.85	2.04	23	1.72	18	1.3
F, mg/kg	38	6.01	790	1.74	290	1.42
Fe, mg/kg	1,500	37,100	4,550	1,460	2,380	1,100
Hg, mg/kg	0.03	2.37	0.057	2.90	35	1.62
Li, mg/kg	0.78	3.87	39	1.5	23	1.2
Mn, mg/kg	160	2.05	110	2.43	510	1.54
Mo, mg/kg	<3	--	0.78	2.73	<3	--
Ni, mg/kg	2.3	2.43	22	1.71	22	1.29
Pb, mg/kg	<10	--	24	1.78	15	1.27
Se, mg/kg	0.19	2.28	0.39	2.04	0.18	2
Sr, mg/kg	270	3.62	46	1.77	220	1.26
V, mg/kg	7.5	2.11	100	1.46	93	1.21
Zn, mg/kg	19	1.68	80	1.83	61	1.25

[a] Connor and Ebens 1980
[b] Ebens and Connor 1980

glacial drift, loess, and residuum) are the result of the mechanical erosion of pre-existing rocks which may have originated some distance from the site. The Pennsylvanian shales, which are quite uraniferous and are located across northwestern Missouri, likely contributed to the glacial deposits across the site.

The range of background concentrations was estimated by plotting cumulative frequency distributions. This statistical method is widely used in both geochemical exploration to distinguish a mineralized population from background concentrations and in sedimentology to examine the particle size distribution (Sinclar 1976). The method involves plotting the concentrations (y-axis) against a cumulative percentage scale on the x-axis. The cumulative percentage scale is a mathematical transformation of a cumulative normal density distribution which will plot a bell-shaped curve as a straight line. Therefore, a normal statistical population of data will plot as a straight line. A statistically mixed population containing more than one normal population will plot as a series of straight lines.

Plots of site groundwater data for nitrate, sulfate, chromium, nickel, copper, zinc, aluminum, and uranium are shown in Figures B-1 through B-4. The very high concentration values were deleted from the data set before plotting to provide greater resolution of the lower concentrations. Straight lines were drawn to show the subjective determination of single normal populations. For each element, the population comprised of the lower concentrations is considered to be background. The population comprised of the greater concentrations is thought to represent contaminated groundwater samples. The intersection of the lines is an estimation of the upper bound of the background population. The statistics, arithmetic mean, and standard deviation describing the designated background populations are presented in Table B-2.

Two checks were performed to validate the use of cumulative frequency distributions to define a single population.

- The "mean plus two standard deviations" was compared with the maximum value.
- The standard deviation was compared with the mean value.

A "mean plus two standard deviations" near the maximum value and a standard deviation less than the mean value substantiate the normalcy of the population. The populations used to define the background ranges for the various elements easily passed the tests for normal populations (Table B-2).

A potential disadvantage to the use of this method may be the high detection limits relative to the mean value for several elements. Less-than-detectable values were not used in the statistical analysis. The omission of those values below the detection limit may skew the population and create a mean value higher than actually exists for the groundwater.

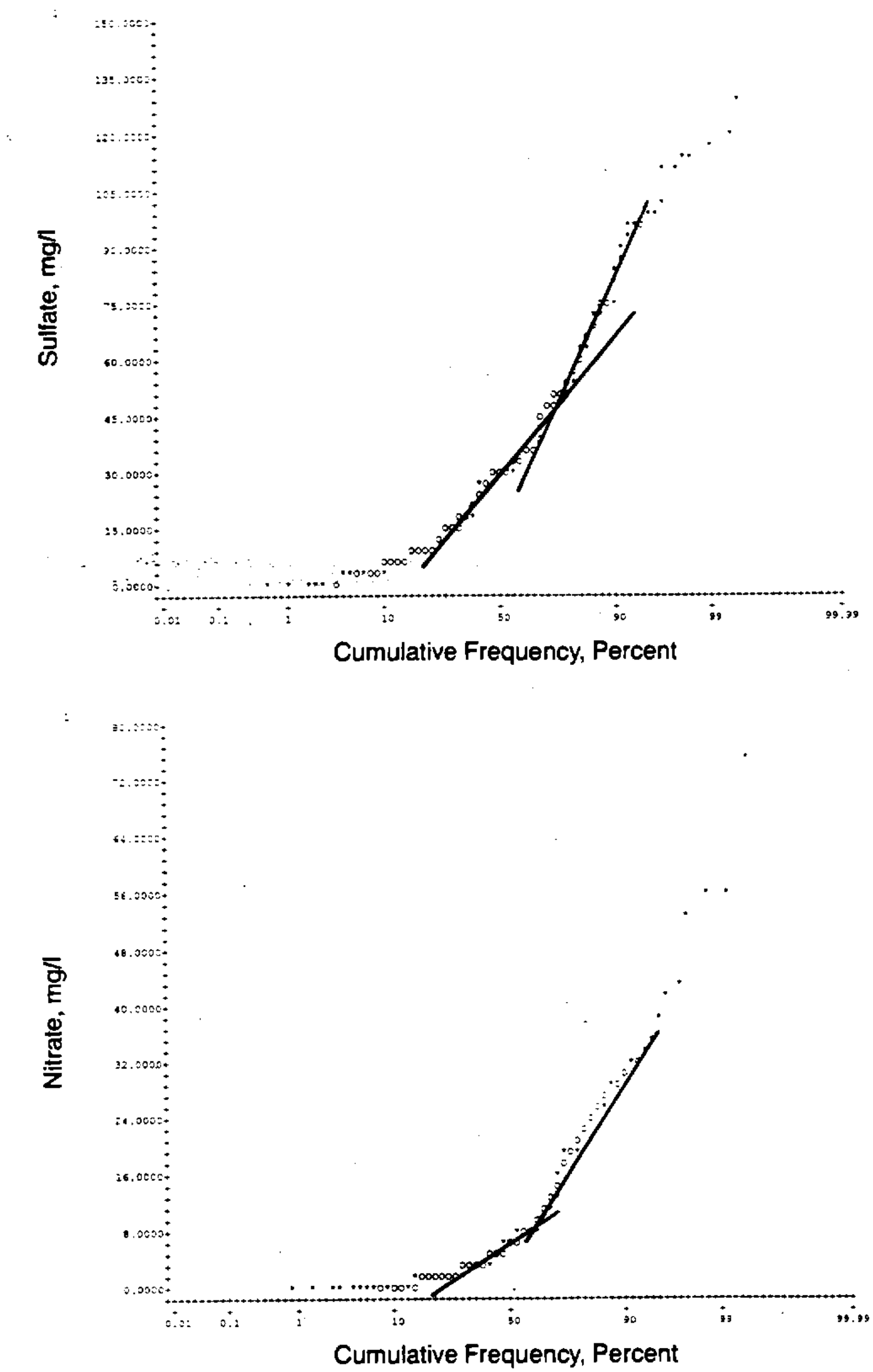

FIGURE B - 1

Cumulative Frequency Distributions

Nitrate and Sulfate

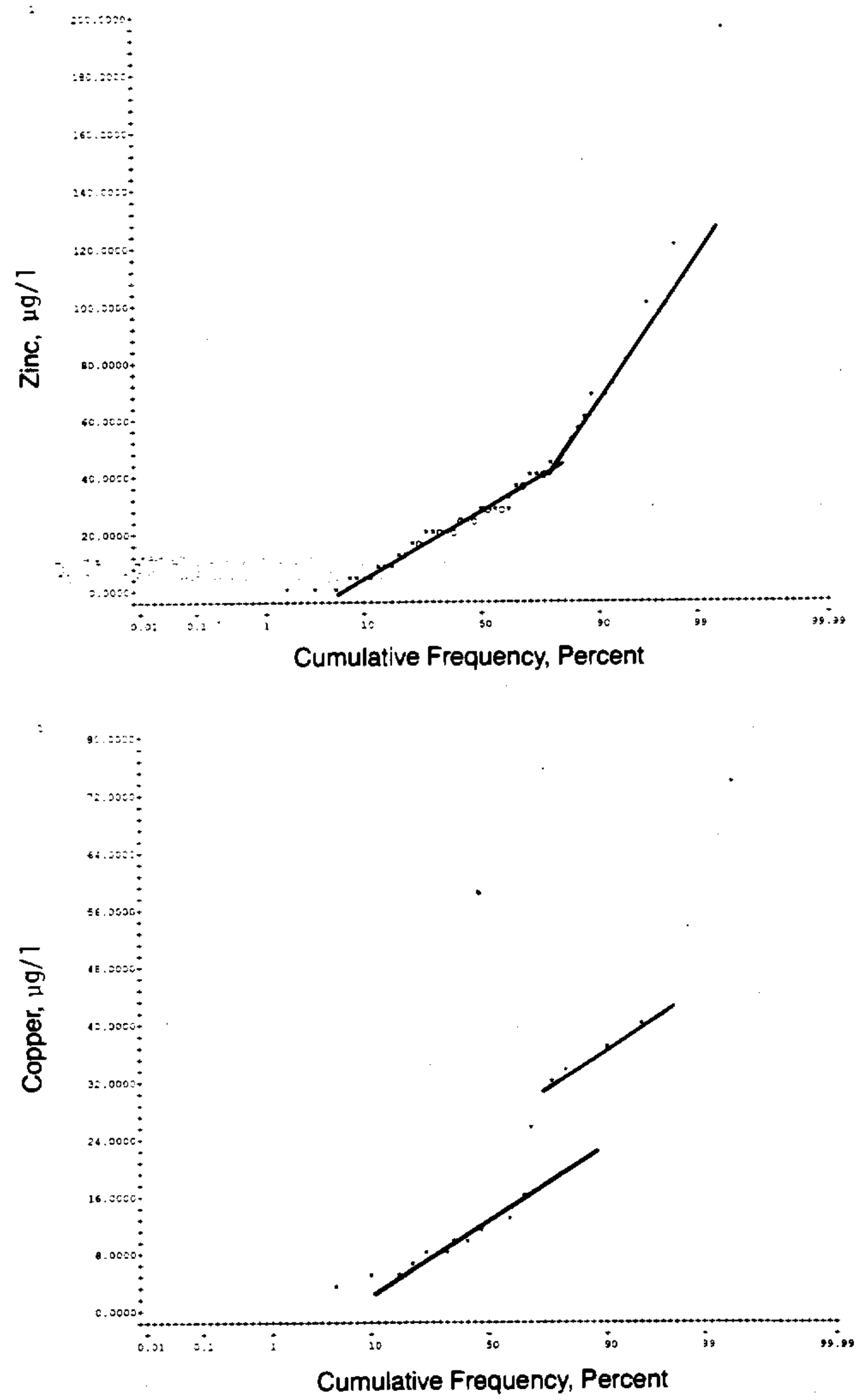

FIGURE B - 2

Cumulative Frequency Distributions

Copper and Zinc

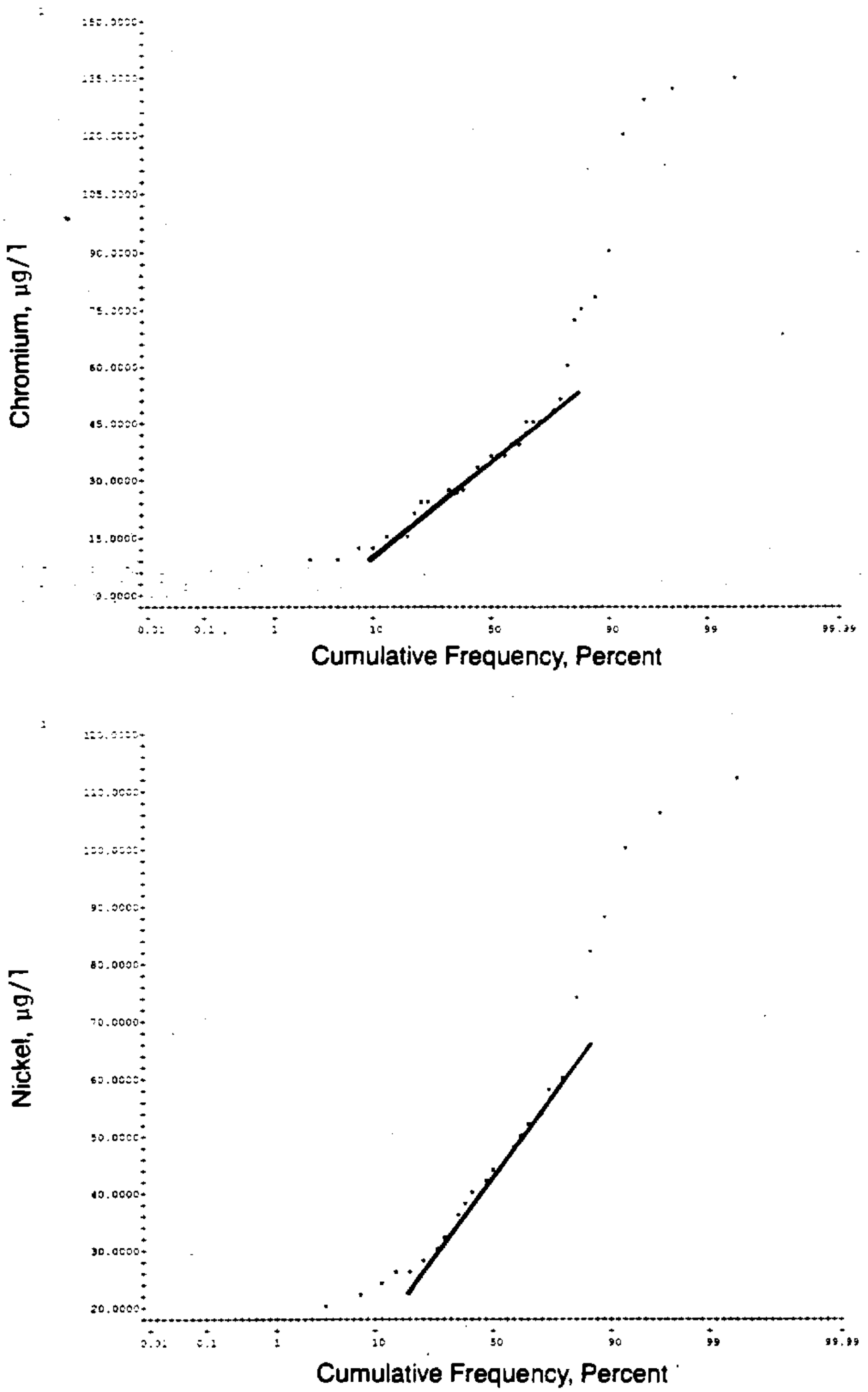

FIGURE B - 3

Cumulative Frequency Distributions

Nickel and Chromium

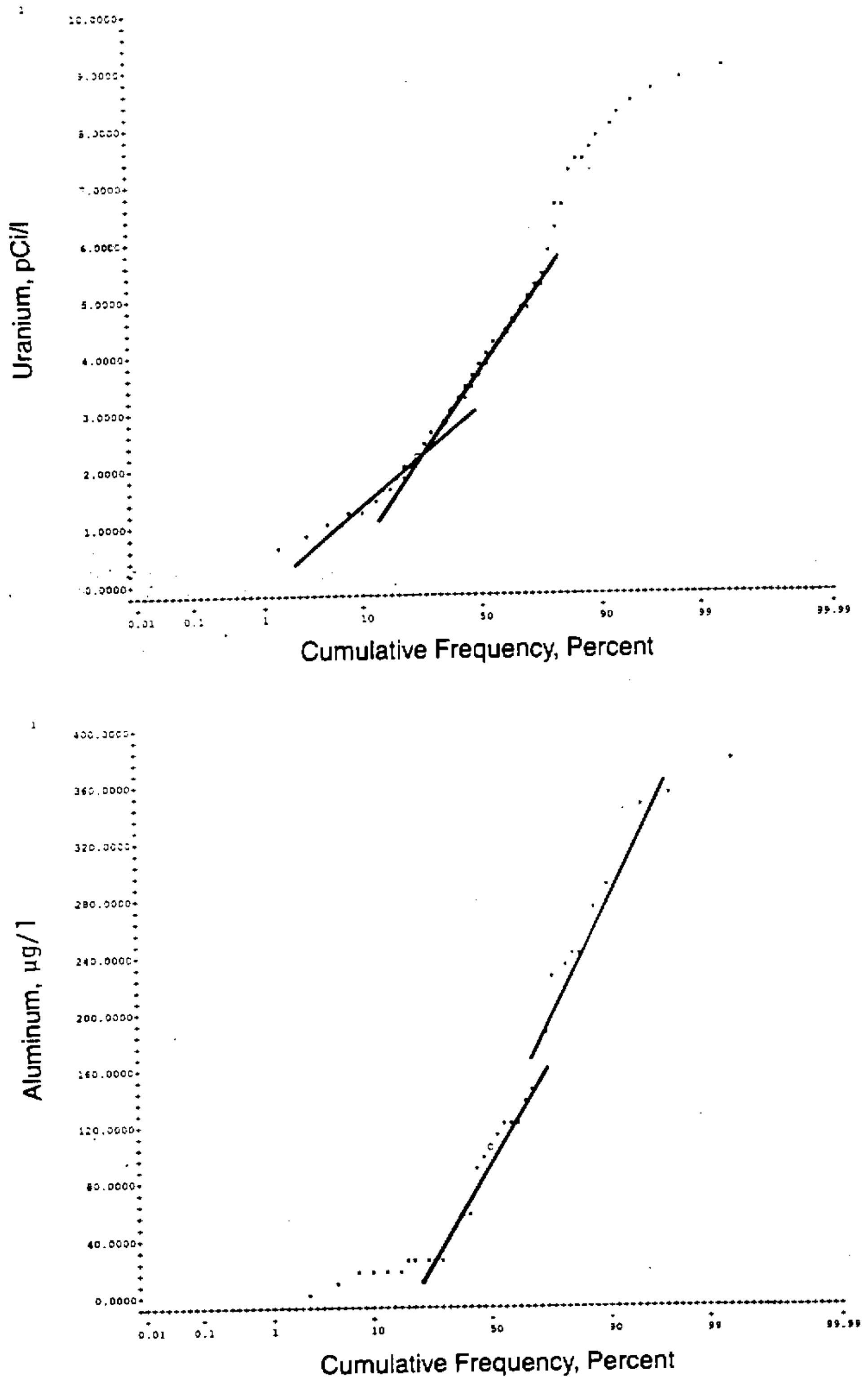

FIGURE B - 4

Cumulative Frequency Distributions

Aluminum and Uranium

TABLE B-2 Statistically Determined Background Concentrations for Groundwater at the Weldon Spring Site

Element	Number of Data	Arithmetic Mean (X)	Standard Deviation (S)	X + 2S	On-Site Background Range High	On-Site Background Range Low
Al (µg/l)	24	67	47	161	149	0.3
Cr (µg/l)	28	30	12	53	52	10.2
Cu (µg/l)	12	10	4	17	16	4
Ni (µg/l)	19	40	12	64	60	23
NO_3 (mg/l)	69	4	3	9	8.8	0.1
SO_4 (mg/l)	126	24	15	54	53.9	1.9
U-tot (pCi/l)	44	3	1	6	5.3	0.7
Zn (µg/l)	41	22	12	46	43.0	0.02

Even though the background for nitroaromatics is considered as zero because nitroaromatics do not occur in nature, cumulative frequency distributions were used for the nitroaromatics to distinguish between the concentrations measured near the sources and the lower concentrations that appear to be present in the groundwater over a large area. The plots for the nitroaromatic compounds are shown as Figures B-5 through B-7. The upper bound of the concentrations present in the groundwater away from the sources were determined from Figures B-5 through B-7 as follows: 2,4,6-TNT <2.4 μg/l; 1,3,5-TNB <1.2 μg/l; 2,6-DNT <1.2 μg/l; 2,4–DNT <0.7 μg/l; 1,3-DNB <1.8μg/l, and NB <1.8 μg/l.

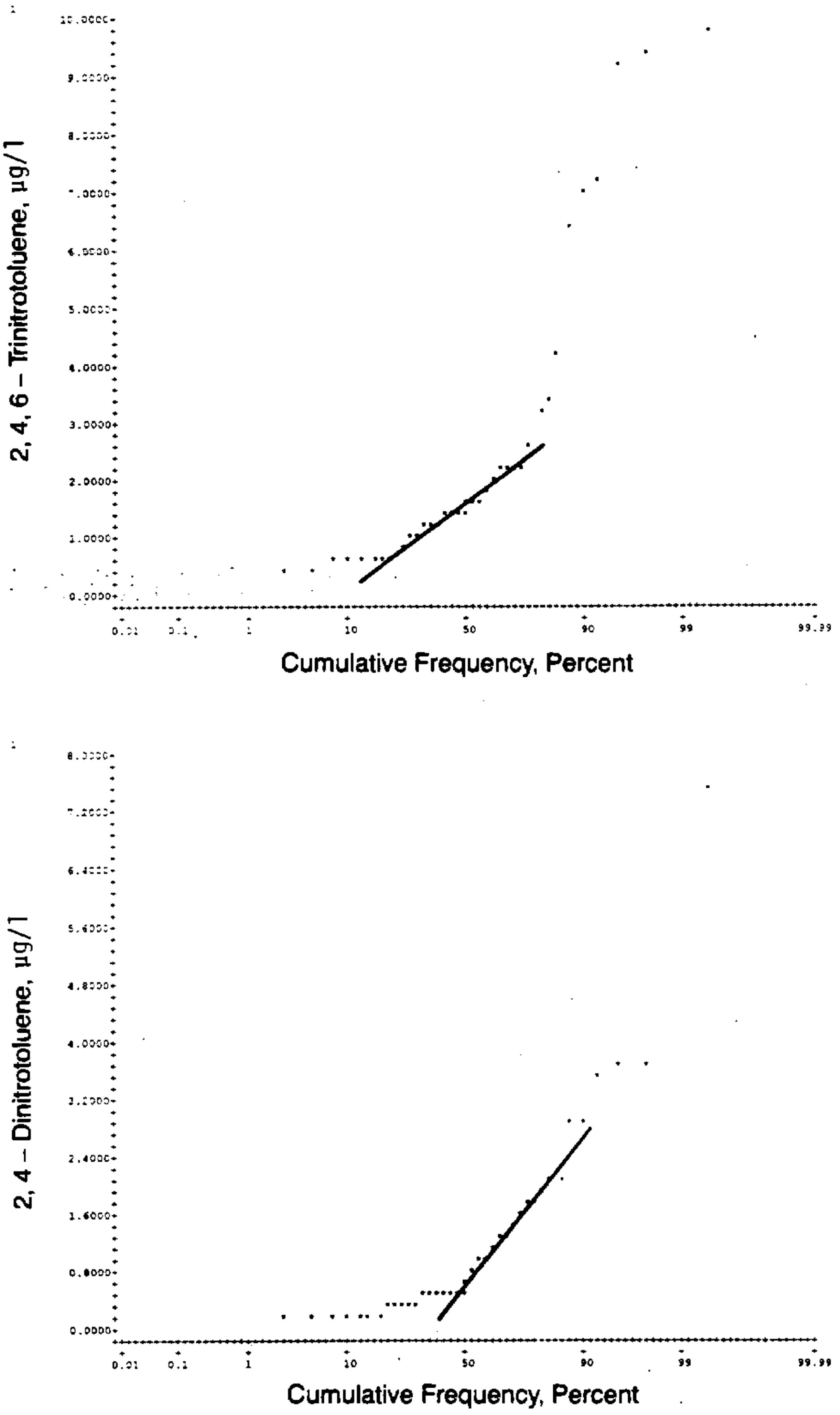

FIGURE B - 5

Cumulative Frequency Distributions

2, 4 - Dinitrotoluene and 2, 4, 6 - Trinitrotoluene

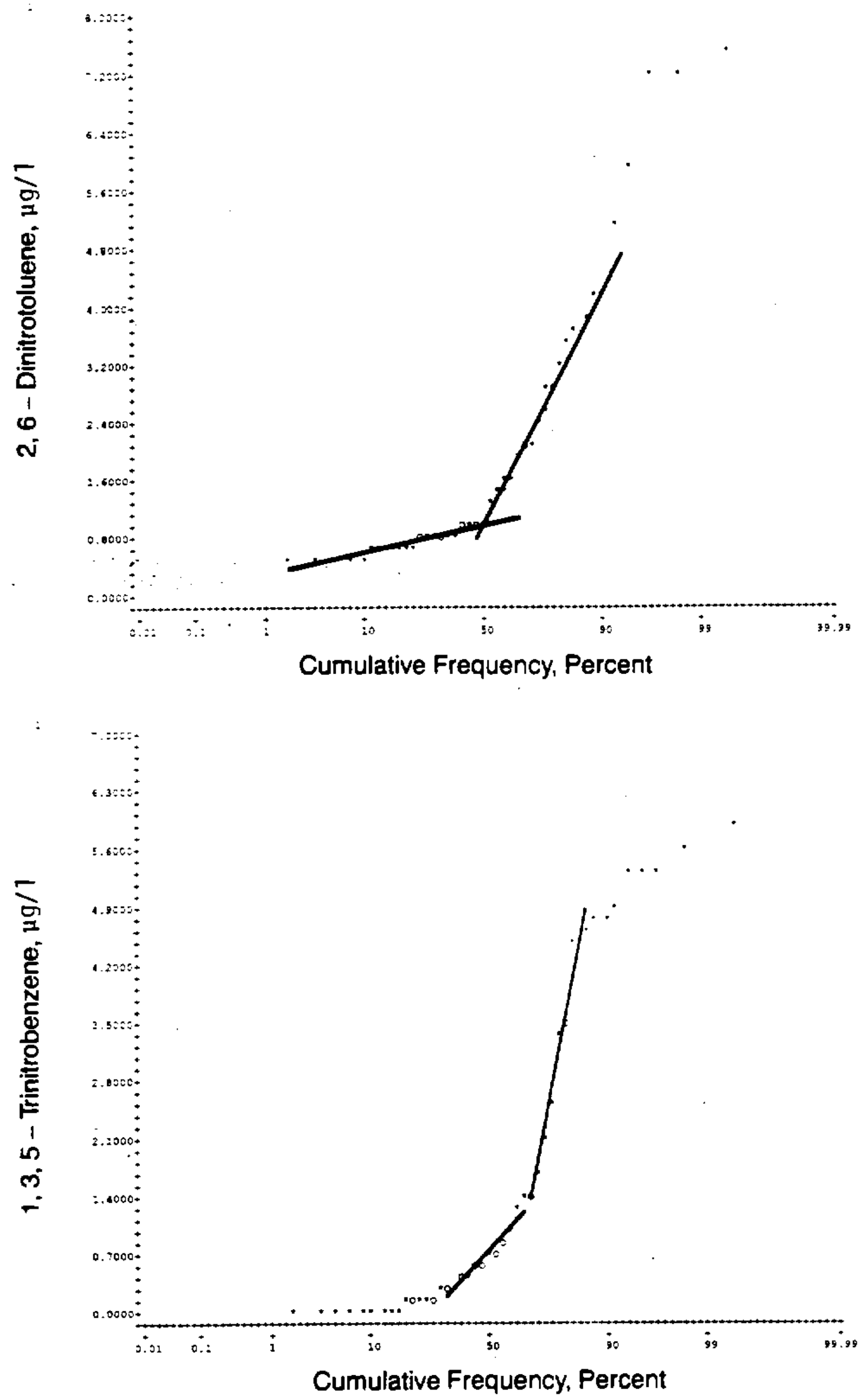

FIGURE B - 6

Cumulative Frequency Distributions

1, 3, 5 - Trinitrobenzene and 2, 6 - Dinitrotoluene

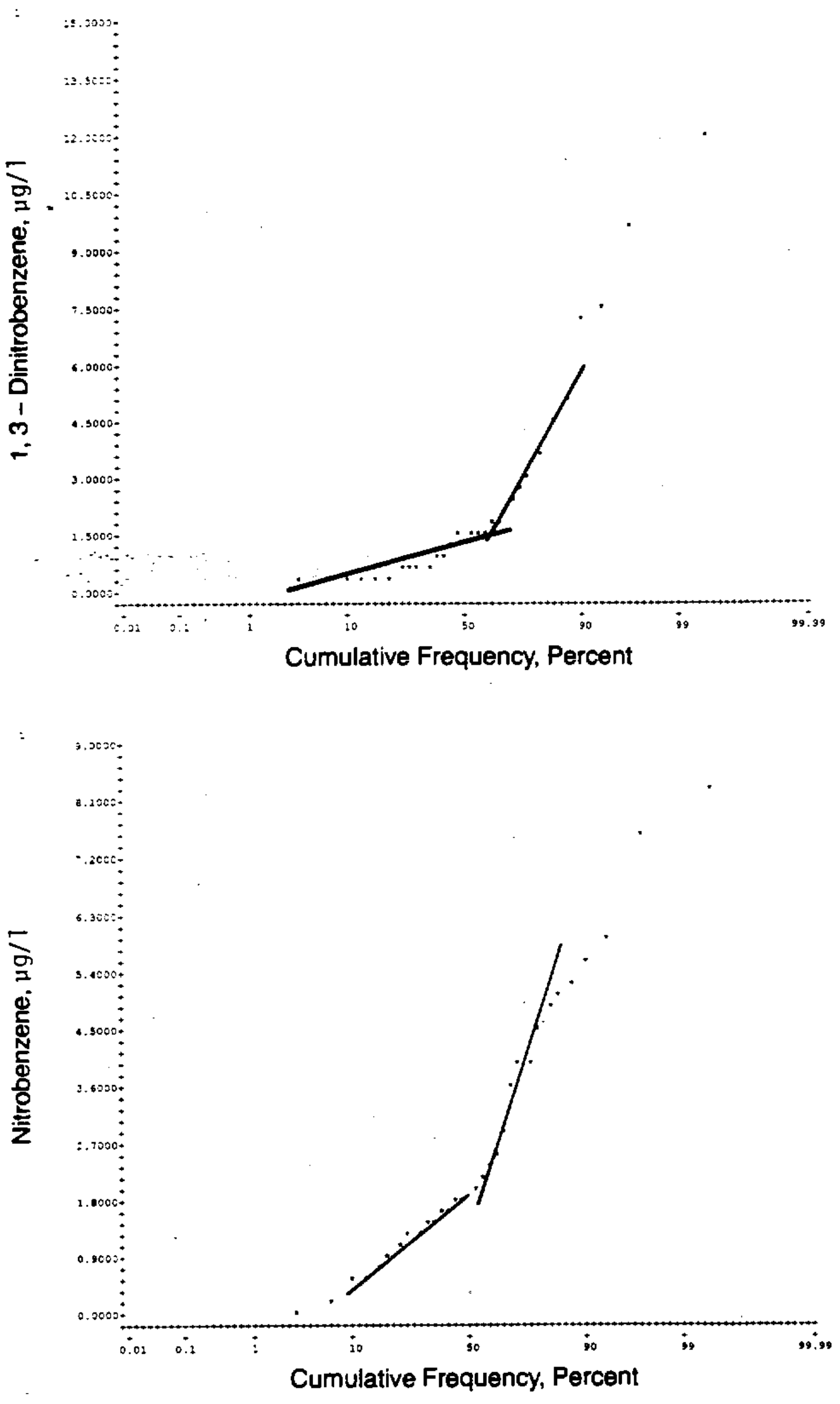

FIGURE B-7

Cumulative Frequency Distributions

Nitrobenzene and 1, 3 Dinitrobenzene

References Cited

Connor, J.J. and R.J. Ebens, 1980. Geochemistry of Bedrock Units in Missouri and Parts of Adjacent States. Geochemical Survey of Missouri. U.S. Geological Survey Professional Paper 954–F.

Ebens, R.J. and J.J. Connor, 1980. Geochemistry of Loess and Carbonate Residuum. Geochemical Survey of Missouri. U.S. Geological Survey Professional Paper 954-G.

Feder, G.L., 1979. Geochemical Survey of Waters of Missouri. Geochemical Survey of Missouri. U.S. Geological Survey Professional Paper 954-E.

Nuelle, L.M., 1988. Distribution of Radionuclides in Missouri Geologic Terranes: A Summary of Available Data and Need for More Data. In: Marikos, M.A. and Hansman, R.H. (eds.) 1988. Geological Causes of Natural Radionuclide Anomalies. Proceedings of the GEORAD Conference, April 21-22 1987, St. Louis, Missouri, Missouri Department of Natural Resources Division of Geology and Land Survey Special Publication No. 4.

Sinclair, J.A., 1976. Applications of Probability Graphs in Mineral Exploration. Association of Exploration Geochemists.

APPENDIX C

GEOCHEMICAL DATA ANALYSIS USING PHREEQE

APPENDIX C

GEOCHEMICAL DATA ANALYSIS USING PHREEQE

PHREEQE (PH REaction EQuilibrium Evaluation) (Parkhurst et al. 1980) is a thermodynamic geochemical software package used for geochemical data analysis of surface water and groundwater. During the remedial investigation, PHREEQE was used to 1) estimate the bicarbonate concentration by adding bicarbonate to achieve charge balance, 2) predict the redox potential (Eh) by assuming that the redox potential is controlled by equilibrium between the ferric hydroxide mineral and the measured dissolved iron concentrations, 3) determine the predominant aqueous species of the elements, 4) predict the precipitation and dissolution of solid phases in contact with groundwater, and 5) determine the reactions which control the observed water quality.

PHREEQE is based upon a speciation-solubility model that calculates the Eh, pH, the distribution of aqueous species, and the saturation indexes of minerals. These capabilities are derived from WATEQ (Truesdell and Jones 1974). In addition, PHREEQE can calculate the mass transfer of elements between the solid and dissolved phases.

As a first step, PHREEQE calculates the distribution of aqueous species from the dissolved concentrations, pH, and Eh of the water. The mass balance constraint requires that the sum of the uncomplexed element and its derived complexes equals the total concentration of the element. For example, (Ca^{+2}) total = (Ca^{+2}) + ($CaHCO_3^-$) + $(CaCO_3)_{(aq)}$ + $(CaSO_4)_{(aq)}$, where (Ca^{+2}) total is the concentration determined by chemical analysis and the calcium complexes are the forms that are predicted to exist in the groundwater sample. The equilibrium constraint requires that the aqueous distribution represents the most stable (minimum Gibbs free energy) state as computed from the equilibrium constants for all aqueous complexes.

From the distribution of aqueous species, PHREEQE calculates the degree to which equilibrium is approached with respect to specified minerals. The result is expressed as a saturation index. The saturation index (SI) is defined as the logarithm of the ratio of the ion activity product (IAP) of the component ions of the solid in solution to the equilibrium solubility product (K_{eq}) of the solid. For example, assuming the activity of water is 1.0, the SI of uraninite is calculated according to the following equations:

$$UO_2 + 4H^+ = U^{+4} + 2H_2O \qquad (1)$$

$$IAP = \frac{[aH^+]^4}{aU{+}4} \qquad (2)$$

$$SI = \log\left(\frac{IAP}{K_{eq}}\right) \tag{3}$$

where a is the chemical activity of the given component and K_{eq} is the thermodynamic solubility product of Equation 1. An SI of zero indicates equilibrium, an SI of less than zero indicates undersaturation, and an SI of greater than zero indicates supersaturation.

Therefore, if the SI is near zero, a steady state is established between the mineral and the water chemistry, and the mineral is neither undergoing net dissolution or precipitation. If the SI is greater than zero, precipitation should occur. If the SI is less than zero, dissolution of the mineral should occur, if the mineral is present in the soil/rock phase (Equations 4, 5, and 6).

No Mineral Dissolved:	$SI = 0$	(4)
Mineral Dissolving:	$SI < 0$	(5)
Mineral Precipitating:	$SI > 0$	(6)

The distribution of aqueous species plays an important role in the determination of the SI of a specific mineral and the concentration of a given element that can exist in solution before precipitation occurs. For example, the distribution of uranium species may include $UO_2(CO_3)_3^{-4}$, $UO_2(CO_3)_2^{-2}$, $UO_2(OH)_2$, $UO_2(SO_4)_2^{-2}$, UO_2^{+2}, $UO_2(OH)^{+}$, and U^{+4}. The activity of U^{+4} used in the calculation of the saturation index of uraninite is significantly less than the total concentration of uranium. A greater proportion of complexed uranium species relative to the uranium ion (U^{+4}) allows greater concentrations of uranium in groundwater which is in equilibrium with the precipitated form, uraninite.

For the water quality analyses discussed in Sections 5 and 6, groundwater characteristics were modeled using PHREEQE based on water quality data presented in those sections. Several sample calculation outputs are attached as Tables C-2 through C-7. A summary of the output is presented in Table C-1. The groundwater samples included in Table C-1 were chosen to represent different water types as follows:

- MW-3008 - seepage from raffinate pits impacted by contaminated soil from the ordnance works
- MW-2004 - unimpacted groundwater
- MW-2006 - groundwater impacted by nitroaromatics and nickel

- MW-2017 - groundwater impacted by sulfate
- LY-3605 - vadose zone impacted by raffinate pits and contaminated soil from the ordnance works
- SW-2008 - Burgermeister Spring

Table C-1 lists the chemical concentrations used as input and the results calculated by PHREEQE: the dominant aqueous species and the mineral saturation indexes. The dominant aqueous species for the various elements are important because the aqueous species have different chemical behavior (i.e., adsorption coefficient) and the formation of aqueous complexes increases the contaminant solubility. The saturation index predicts the mineral forms most likely to control the chemistry of the groundwater.

The bicarbonate concentrations and pH of the lysimeter samples were not measured. These parameters were calculated with PHREEQE by assuming 1) the cation-anion ratio can be balanced using bicarbonate as the missing anion, and 2) the aqueous solution is in thermodynamic equilibrium with the mineral calcite. The high pH conditions are buffered by a high carbonate/bicarbonate ratio. The Eh was calculated assuming equilibrium between the iron concentrations and solid ferric hydroxide. Calculated Eh values indicate a chemically reducing environment established by the carbonaceous matter in the unconsolidated materials. The presence of carbonaceous matter is indicated by high total organic carbon values in many of the groundwater samples.

The pH of groundwater samples was measured and used as input for PHREEQE calculations. Bicarbonate concentrations and Eh were estimated as outlined above.

TABLE C-1 Summary of Calculations by PHREEQE on Selected Water Samples

	MW3008 1Q87	MW2004 1Q87	MW2006 1Q87	LW2017 1Q87	LY3605 1Q87	SW2008 1Q87
Solution Chemistry						
pH	6.6	7.2	7.1	7	7[c]	6.9
Eh[a], mV	110	15	29	67	-42	59
Ca, mg/l	254	55.3	101	126	134.5	53.9
Mg, mg/l	143	31.5	40	82	26.2	12
Na, mg/l	214	11	42	36	56.3	21.1
K, mg/l	3.3	1.1	6.4	3.3	7.8	2.3
SO_4, mg/l	100	25.2	31	462	765	55.9
Cl, mg/l	31.7	1.1	8.7	11	83.1	13.22
NO_3, mg/l	2,654	1.9	39	4	4.5	56.1
HCO_3[b], mg/l	5,507	365	553	348	1,092	308
F, mg/l	1.5	<0.25	<0.25	0.62	1.1	<0.25
Al, µg/l	382	18	111	123	126	110
Cr, µg/l	137	42	36	37	47	26
Cu, µg/l	27	4	<25	<25	21	<25
Fe, µg/l	128	23	160	64	16,220	0.096
Ni, µg/l	107	<40	74	<40	92	<40
Zn, µg/l	21	28	<10	26	48	18
U, pCi/l	11.2	<2	1.9	3.7	130	160
Dominant Aqueous Species						
Al	AlF_2^+ $Al(OH)_3$	$Al(OH)_3$ $Al(OH)_4^-$	$Al(OH)_3$ $Al(OH)_4^-$	$Al(OH)_3$ $Al(OH)_4^-$	$Al(OH)_3$ $Al(OH)_4^-$	$Al(OH)_3$
Cr	$Cr(OH)_2^+$	$Cr(OH)_2^+$	$Cr(OH)_2^+$	$Cr(OH)_2^+$	$Cr(OH)_2^+$	$Cr(OH)_2^+$
Cu	$CuCO_3^-$ $CuHCO_3$	Cu^+	Cu^+ $CuCl_2^-$	Cu^+	Cu^+ $CuCl_2^-$	Cu^+
N	NH_4^+	NH_4^+	NH_4^+	NH_4^+	NH_4^+	NH_4^+
Ni	$NiHCO_3^+$	Ni^{+2} $NiHCO_3^+$	Ni^{+2} $NiHCO_3^+$	Ni^{+2} $NiSO_4$ $NiHCO_3^+$	Ni^{+2} $NiSO_4$ $NiHCO_3^+$	Ni^{+2} $NiHCO_3^+$
$\underset{2}{U}$	$UO_2(CO_3)_3^{-4}$	$UO_2(CO_3)_2^{-2}$	$UO_2(CO_3)_2^{-2}$	$UO_2(CO_3)_2^{-2}$	$UO_2(CO_3)_2^{-2}$	$UO_2(CO_3)_2^-$
Zn	$ZnHCO_3^+$	Zn^{+2} $ZnHCO_3^+$	Zn^{+2} $ZnHCO_3^+$	Zn^{+2}	Zn^{+2} $ZnHCO_3^+$ $ZnSO_4$	Zn^{+2} $ZnHCO_3^+$

TABLE C-1 Summary of Calculations by PHREEQE on Selected Water Samples (Continued)

	MW3008 1Q87	MW2004 1Q87	MW2006 1Q87	LW2017 1Q87	LY3605 1Q87	SW2008 1Q87
Saturation Indexes						
Gypsum $CaSO_4 \cdot 2H_2O$	-2.4	-3.1	-1.9	-0.8	-0.7	-1.8
Calcite $CaCO_3$	-0.2	0.3	0.2	-0.1	0.3	-0.5
Magnesite $MgCO_3$	0.5	-0.0	-0.2	-0.3	-0.4	-1.3
Uraninite UO_2	-7.4	-4.0	-4.1	-3.4	-3.4	-2.4
$Fe(OH)_3$	0	0	0	0	0	0
$Ni(FeO_2)_2$	1.7	3.3	3.1	2.6	2.8	2.6
$Zn(FeO_2)_2$	-0.7	1.8	0.6	0.8	0.8	0.6
$Cu(FeO_2)_2$	-0.9	-0.9	-0.6	0.1	-0.7	-0.2
$Cr(OH)_3$	-1.6	-2.0	-1.6	-1.7	-1.6	-1.9
$Al(OH)_3$	-0.1	-1.0	-0.1	-0.1	-0.1	-0.1

(a) Eh (mV) calculated by PHREEQE by assuming equilibrium between the water quality and the mineral, $Fe(OH)_3$.

(b) Bicarbonate concentration calculated by assuming bicarbonate to be the missing anion in the cation/anion balance.

(c) pH calculated by assuming equilibrium with calcite.

PHREEQE Sample Calculation Outputs

TABLE C-2 PHREEQE CALCULATIONS, MW 3008 1Q87

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TOTAL CONCENTRATION OF AQUEOUS COMPONENTS     *******************************

                   TOTAL           TOTAL          TOTAL
COMPONENTS        MOLALITY      LOG MOLALITY      MG/KG
-----------------------------------------------------------

AL               1.4206E-05       -4.8475      3.7956E-01
BA               2.3673E-06       -5.6257      3.2193E-01
HCO3             1.0582E-01       -0.9754      6.3939E+03

CA               6.3740E-03       -2.1956      2.5297E+02
CL               8.9720E-04       -3.0471      3.1497E+01
CR               2.6438E-06       -5.5778      1.3612E-01

CU               4.2638E-07       -6.3702      2.6827E-02
F                7.9224E-05       -4.1011      1.4904E+00
FE               3.1171E-06       -5.5062      1.7238E-01

K                8.4683E-05       -4.0722      3.2789E+00
MG               5.9020E-03       -2.2290      1.4209E+02
MN               1.4612E-06       -5.8353      7.9488E-02

NO3              4.2949E-02       -1.3670      2.6370E+03
NA               9.3403E-03       -2.0296      2.1263E+02
NI               1.8287E-06       -5.7378      1.0632E-01

PB               2.4215E-08       -7.6159      4.9680E-03
SO4              1.0446E-03       -2.9811      9.9361E+01
U                7.1663E-08       -7.1447      1.6891E-02

V                1.2605E-06       -5.8995      6.3591E-02
ZN               3.2235E-07       -6.4917      2.0866E-02

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DESCRIPTION OF SOLUTION             *****************************************

pH                                       6.600
EH  (mV)                               111.302
PE                                       1.882

ACTIVITY OF H2O                          0.997
IONIC STRENGTH (M)                       0.082
TEMPERATURE (C)                         25.000

CATION CONC.(EQ/KG H2O)                  7.283E-02
ANION CONC.(EQ/KG H2O)                  -7.283E-02
CHARGE BALANCE              (%)         -1.476E-08

TOTAL ALKALINITY (EQ/KG H2O)             7.391E-02

TDS (MG/KG)                              9.776E+03
DENSITY                                  1.010

ITERATIONS                              36

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DISTRIBUTION OF AQUEOUS SPECIES       ****************************************

                                LOG                       LOG                      LOG
SPECIES           MOLALITY   MOLALITY    ACTIVITY     ACTIVITY      GAMMA         GAMMA
-----------------------------------------------------------------------------------------

AL(OH)2+         5.949E-07    -6.226    4.757E-07     -6.323     7.996E-01    -0.097
AL(OH)3          2.498E-06    -5.602    2.546E-06     -5.594     1.019E+00     0.008
AL(OH)4-         4.003E-07    -6.398    3.158E-07     -6.501     7.890E-01    -0.103

AL(SO4)2-        5.286E-12   -11.277    4.170E-12    -11.380     7.890E-01    -0.103
AL+3             3.360E-09    -8.474    6.495E-10     -9.187     1.933E-01    -0.714
ALF+2            6.100E-07    -6.215    2.493E-07     -6.603     4.087E-01    -0.389

ALF2+            6.427E-06    -5.192    5.139E-06     -5.289     7.996E-01    -0.097
ALF3             3.522E-06    -5.453    3.589E-06     -5.445     1.019E+00     0.008
ALF4-            8.553E-08    -7.068    6.748E-08     -7.171     7.890E-01    -0.103

ALOH+2           6.456E-08    -7.190    2.638E-08     -7.579     4.087E-01    -0.389
ALSO4+           2.395E-10    -9.621    1.890E-10     -9.724     7.890E-01    -0.103
BA+2             2.310E-06    -5.636    9.225E-07     -6.035     3.994E-01    -0.399

BAOH+            7.657E-12   -11.116    6.087E-12    -11.216     7.950E-01    -0.100
BASO4            5.772E-08    -7.239    5.882E-08     -7.230     1.019E+00     0.008
CA+2             4.604E-03    -2.337    1.897E-03     -2.722     4.121E-01    -0.385

CACO3            3.369E-05    -4.472    3.434E-05     -4.464     1.019E+00     0.008
CAF+             7.797E-07    -6.108    6.198E-07     -6.208     7.950E-01    -0.100
CAHCO3+          1.631E-03    -2.788    1.314E-03     -2.881     8.060E-01    -0.094

CAOH+            2.358E-09    -8.627    1.901E-09     -8.721     8.060E-01    -0.094
CASO4            1.054E-04    -3.977    1.074E-04     -3.969     1.019E+00     0.008
CL-              8.930E-04    -3.049    6.948E-04     -3.158     7.780E-01    -0.109

CO2(AQ)          3.206E-02    -1.494    3.268E-02     -1.486     1.019E+00     0.008
CO3-2            2.556E-05    -4.592    1.045E-05     -4.981     4.087E-01    -0.389
CR(OH)+2         4.127E-07    -6.384    1.623E-07     -6.790     3.933E-01    -0.405

CR(OH)2+         2.229E-06    -5.652    1.765E-06     -5.753     7.919E-01    -0.101
CR+2             1.560E-18   -17.807    6.134E-19    -18.212     3.933E-01    -0.405
CR+3             2.014E-09    -8.696    3.893E-10     -9.410     1.933E-01    -0.714

CRCL2+           1.830E-16   -15.738    1.449E-16    -15.839     7.919E-01    -0.101
CRCL2+2          2.736E-12   -11.563    1.076E-12    -11.968     3.933E-01    -0.405
CRO2-            1.183E-11   -10.927    9.370E-12    -11.028     7.919E-01    -0.101

CRO4-2           5.992E-27   -26.222    2.357E-27    -26.628     3.933E-01    -0.405
CU(CO3)2-2       1.260E-08    -7.899    4.958E-09     -8.305     3.933E-01    -0.405
CU(OH)2          1.008E-09    -8.996    1.028E-09     -8.988     1.019E+00     0.008

CU(OH)3-         3.104E-16   -15.508    2.458E-16    -15.609     7.919E-01    -0.101
CU(OH)4-2        4.950E-22   -21.305    1.947E-22    -21.711     3.933E-01    -0.405
CU+              2.716E-08    -7.566    2.151E-08     -7.667     7.919E-01    -0.101

CU+2             7.394E-09    -8.131    3.121E-09     -8.506     4.221E-01    -0.375
CU2(OH)2+2       1.708E-14   -13.768    6.718E-15    -14.173     3.933E-01    -0.405
CUCL+            7.371E-12   -11.132    5.837E-12    -11.234     7.919E-01    -0.101

CUCL2            2.137E-15   -14.670    2.178E-15    -14.662     1.019E+00     0.008
CUCL2-           4.146E-09    -8.382    3.283E-09     -8.484     7.919E-01    -0.101
CUCL3-           6.780E-21   -20.169    5.369E-21    -20.270     7.919E-01    -0.101

CUCL3-2          9.192E-12   -11.037    3.616E-12    -11.442     3.933E-01    -0.405
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CUCO3	2.627E-07	-6.581	2.677E-07	-6.572	1.019E+00	0.008
CUF+	2.690E-12	-11.570	2.131E-12	-11.672	7.919E-01	-0.101
CUHCO3+	1.110E-07	-6.955	8.792E-08	-7.056	7.919E-01	-0.101
CUOH+	1.565E-10	-9.806	1.239E-10	-9.907	7.919E-01	-0.101
CUSO4	1.737E-10	-9.760	1.771E-10	-9.752	1.019E+00	0.008
E-	1.313E-02	-1.882	1.313E-02	-1.882	1.000E+00	0.000
F-	4.835E-05	-4.316	3.751E-05	-4.426	7.758E-01	-0.110
FE(OH)2	1.985E-12	-11.702	2.024E-12	-11.694	1.019E+00	0.008
FE(OH)2+	2.042E-11	-10.690	1.632E-11	-10.787	7.996E-01	-0.097
FE(OH)3	2.832E-07	-6.548	2.887E-07	-6.540	1.019E+00	0.008
FE(OH)3-	6.912E-19	-18.160	5.495E-19	-18.260	7.950E-01	-0.100
FE(OH)4-	4.733E-13	-12.325	3.784E-13	-12.422	7.996E-01	-0.097
FE(SO4)2-	1.555E-19	-18.808	1.232E-19	-18.910	7.919E-01	-0.101
FE+2	2.022E-06	-5.694	8.534E-07	-6.069	4.221E-01	-0.375
FE+3	3.208E-17	-16.494	6.200E-18	-17.208	1.933E-01	-0.714
FE2(OH)2+4	2.718E-23	-22.566	6.506E-25	-24.187	2.393E-02	-1.621
FE3(OH)4+5	9.258E-30	-29.033	2.715E-32	-31.566	2.932E-03	-2.533
FECL+2	3.187E-19	-18.497	1.273E-19	-18.895	3.994E-01	-0.399
FECL2+	4.969E-22	-21.304	3.950E-22	-21.403	7.950E-01	-0.100
FECL3	2.693E-26	-25.570	2.745E-26	-25.562	1.019E+00	0.008
FEF+2	9.973E-16	-15.001	3.864E-16	-15.413	3.875E-01	-0.412
FEF2+	7.314E-16	-15.136	5.770E-16	-15.239	7.890E-01	-0.103
FEF3	3.141E-17	-16.503	3.201E-17	-16.495	1.019E+00	0.008
FEOH+	7.707E-07	-6.113	6.127E-07	-6.213	7.950E-01	-0.100
FEOH+2	3.893E-13	-12.410	1.555E-13	-12.808	3.994E-01	-0.399
FESO4	4.137E-08	-7.383	4.217E-08	-7.375	1.019E+00	0.008
FESO4+	1.763E-17	-16.754	1.402E-17	-16.853	7.950E-01	-0.100
H+	3.015E-07	-6.521	2.512E-07	-6.600	8.331E-01	-0.079
H2VO4-	1.177E-06	-5.929	9.321E-07	-6.031	7.919E-01	-0.101
H3VO4	1.491E-09	-8.826	1.520E-09	-8.818	1.019E+00	0.008
HCO3-	7.029E-02	-1.153	5.620E-02	-1.250	7.996E-01	-0.097
HCRO4-	2.380E-27	-26.624	1.884E-27	-26.725	7.919E-01	-0.101
HSO4-	8.585E-09	-8.066	6.773E-09	-8.169	7.890E-01	-0.103
HVO4-2	8.132E-08	-7.090	3.199E-08	-7.495	3.933E-01	-0.405
K+	8.448E-05	-4.073	6.573E-05	-4.182	7.780E-01	-0.109
KCL	3.707E-08	-7.431	3.778E-08	-7.423	1.019E+00	0.008
KOH	2.211E-12	-11.656	2.253E-12	-11.647	1.019E+00	0.008
KSO4-	1.617E-07	-6.791	1.293E-07	-6.888	7.996E-01	-0.097
MG+2	4.257E-03	-2.371	1.817E-03	-2.741	4.269E-01	-0.370
MGCO3	1.786E-05	-4.748	1.820E-05	-4.740	1.019E+00	0.008
MGF+	5.708E-06	-5.244	4.503E-06	-5.346	7.890E-01	-0.103
MGHCO3+	1.533E-03	-2.814	1.200E-03	-2.921	7.826E-01	-0.106
MGOH+	1.429E-08	-7.845	1.159E-08	-7.936	8.111E-01	-0.091
MGSO4	8.809E-05	-4.055	8.978E-05	-4.047	1.019E+00	0.008
MN(OH)2	3.810E-16	-15.419	3.883E-16	-15.411	1.019E+00	0.008
MN(OH)3-	4.870E-22	-21.312	3.872E-22	-21.412	7.950E-01	-0.100
MN(OH)4-2	1.236E-28	-27.908	4.860E-29	-28.313	3.933E-01	-0.405
MN+2	9.250E-07	-6.034	3.905E-07	-6.408	4.221E-01	-0.375

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MN2(OH)+3      1.361E-16   -15.866   1.667E-17   -16.778   1.225E-01   -0.912
MN2(OH)3+      1.516E-17   -16.819   1.201E-17   -16.921   7.919E-01   -0.101

MNCL+          1.381E-09    -8.860   1.098E-09    -8.960   7.950E-01   -0.100
MNCL2          2.033E-13   -12.692   2.072E-13   -12.684   1.019E+00    0.008
MNCL3-         8.162E-17   -16.088   6.489E-17   -16.188   7.950E-01   -0.100

MNF+           1.304E-10    -9.885   1.037E-10    -9.984   7.950E-01   -0.100
MNHCO3+        5.152E-07    -6.288   4.096E-07    -6.388   7.950E-01   -0.100
MNOH+          5.012E-11   -10.300   3.984E-11   -10.400   7.950E-01   -0.100

MNSO4          1.937E-08    -7.713   1.974E-08    -7.705   1.019E+00    0.008
NA+            9.096E-03    -2.041   7.221E-03    -2.141   7.938E-01   -0.100
NA2CO3         4.418E-10    -9.355   4.502E-10    -9.347   1.019E+00    0.008

NA2SO4         4.621E-07    -6.335   4.709E-07    -6.327   1.019E+00    0.008
NACL           4.123E-06    -5.385   4.202E-06    -5.377   1.019E+00    0.008
NACO3-         1.756E-06    -5.756   1.404E-06    -5.853   7.996E-01   -0.097

NAHCO3         2.244E-04    -3.649   2.287E-04    -3.641   1.019E+00    0.008
NAOH           4.918E-11   -10.308   5.012E-11   -10.300   1.019E+00    0.008
NASO4-         1.258E-05    -4.900   1.005E-05    -4.998   7.996E-01   -0.097

NH3(AQ)        7.192E-05    -4.143   7.330E-05    -4.135   1.019E+00    0.008
NH4+           4.273E-02    -1.369   3.251E-02    -1.488   7.609E-01   -0.119
NH4SO4-        1.474E-04    -3.831   1.172E-04    -3.931   7.950E-01   -0.100

NI(OH)2        2.314E-13   -12.636   2.358E-13   -12.627   1.019E+00    0.008
NI(OH)3-       1.182E-17   -16.927   9.361E-18   -17.029   7.919E-01   -0.101
NI(SO4)2-2     3.075E-13   -12.512   1.209E-13   -12.917   3.933E-01   -0.405

NI+2           3.545E-07    -6.450   1.496E-07    -6.825   4.221E-01   -0.375
NICL+          3.297E-10    -9.482   2.611E-10    -9.583   7.919E-01   -0.101
NICL2          6.464E-13   -12.190   6.587E-13   -12.181   1.019E+00    0.008

NIF+           1.414E-10    -9.850   1.120E-10    -9.951   7.919E-01   -0.101
NIHCO3+        1.466E-06    -5.834   1.161E-06    -5.935   7.919E-01   -0.101
NIOH+          1.035E-10    -9.985   8.199E-11   -10.086   7.919E-01   -0.101

NISO4          7.953E-09    -8.099   8.106E-09    -8.091   1.019E+00    0.008
NO2-           1.612E-28   -27.793   1.239E-28   -27.907   7.686E-01   -0.114
NO3-           3.977E-40   -39.400   3.057E-40   -39.515   7.686E-01   -0.114

OH-            5.141E-08    -7.289   3.988E-08    -7.399   7.758E-01   -0.110
PB(OH)2        4.795E-14   -13.319   4.887E-14   -13.311   1.019E+00    0.008
PB(OH)3-       2.812E-18   -17.551   2.227E-18   -17.652   7.919E-01   -0.101

PB(OH)4-2      5.150E-23   -22.288   2.026E-23   -22.693   3.933E-01   -0.405
PB(SO4)2-2     2.368E-13   -12.626   9.312E-14   -13.031   3.933E-01   -0.405
PB+2           1.055E-09    -8.977   4.088E-10    -9.389   3.875E-01   -0.412

PB2OH+3        2.363E-18   -17.627   2.895E-19   -18.538   1.225E-01   -0.912
PB3(OH)4+2     5.685E-26   -25.245   2.236E-26   -25.651   3.933E-01   -0.405
PBCL+          1.428E-11   -10.845   1.131E-11   -10.947   7.919E-01   -0.101

PBCL2          1.222E-14   -13.913   1.245E-14   -13.905   1.019E+00    0.008
PBCL3-         8.676E-18   -17.062   6.871E-18   -17.163   7.919E-01   -0.101
PBCL4-2        5.809E-21   -20.236   2.285E-21   -20.641   3.933E-01   -0.405

PBF+           3.443E-13   -12.463   2.727E-13   -12.564   7.919E-01   -0.101
PBF2           2.049E-16   -15.688   2.088E-16   -15.680   1.019E+00    0.008
PBF3-          7.165E-20   -19.145   5.674E-20   -19.246   7.919E-01   -0.101

PBF4-2         2.590E-24   -23.587   1.019E-24   -23.992   3.933E-01   -0.405
PBHCO3+        2.304E-08    -7.637   1.825E-08    -7.739   7.919E-01   -0.101
PBOH+          3.995E-11   -10.398   3.164E-11   -10.500   7.919E-01   -0.101
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PBSO4           6.266E-11   -10.203   6.386E-11   -10.195   1.019E+00   0.008
SO4-2           6.904E-04    -3.161   2.778E-04    -3.556   4.025E-01  -0.395
U(OH)4          5.862E-18   -17.232   5.974E-18   -17.224   1.019E+00   0.008

U(OH)5-         7.396E-16   -15.131   5.835E-16   -15.234   7.890E-01  -0.103
U+4             1.177E-34   -33.929   8.302E-36   -35.081   7.056E-02  -1.151
UF+3            6.611E-25   -24.180   1.170E-25   -24.932   1.770E-01  -0.752

UF2+2           1.817E-24   -23.741   8.056E-25   -24.094   4.433E-01  -0.353
UF3+            6.570E-25   -24.182   5.223E-25   -24.282   7.950E-01  -0.100
UF4             3.322E-25   -24.479   3.386E-25   -24.470   1.019E+00   0.008

UF5-            6.331E-28   -27.199   5.033E-28   -27.298   7.950E-01  -0.100
UF6-2           9.136E-30   -29.039   4.050E-30   -29.393   4.433E-01  -0.353
UO2(CO3)2-2     3.247E-08    -7.489   1.406E-08    -7.852   4.329E-01  -0.364

UO2(CO3)3-4     3.920E-08    -7.407   2.766E-09    -8.558   7.056E-02  -1.151
UO2(OH)2        5.841E-16   -15.233   5.953E-16   -15.225   1.019E+00   0.008
UO2(OH)3-       2.048E-20   -19.689   1.622E-20   -19.790   7.919E-01  -0.101

UO2(OH)4-2      1.090E-27   -26.963   4.286E-28   -27.368   3.933E-01  -0.405
UO2(SO4)2-2     3.172E-19   -18.499   1.267E-19   -18.897   3.994E-01  -0.399
UO2+            1.890E-17   -16.723   1.491E-17   -16.826   7.890E-01  -0.103

UO2+2           4.375E-15   -14.359   1.885E-15   -14.725   4.308E-01  -0.366
UO2CL+          1.480E-19   -18.830   1.167E-19   -18.933   7.890E-01  -0.103
UO2F+           4.118E-16   -15.385   3.274E-16   -15.485   7.950E-01  -0.100

UO2F2           2.822E-16   -15.549   2.876E-16   -15.541   1.019E+00   0.008
UO2F3-          5.718E-18   -17.243   4.545E-18   -17.342   7.950E-01  -0.100
UO2F4-2         8.616E-21   -20.065   3.441E-21   -20.463   3.994E-01  -0.399

UO2OH+          3.577E-15   -14.446   2.844E-15   -14.546   7.950E-01  -0.100
UO2SO4          1.478E-17   -16.830   1.507E-17   -16.822   1.019E+00   0.008
UOH+3           1.050E-28   -27.979   2.030E-29   -28.692   1.933E-01  -0.714

V(OH)2+         6.181E-13   -12.209   4.895E-13   -12.310   7.919E-01  -0.101
V(OH)3          1.438E-11   -10.842   1.466E-11   -10.834   1.019E+00   0.008
V+3             2.034E-19   -18.692   2.071E-20   -19.684   1.018E-01  -0.992

VO+2            1.282E-10    -9.892   5.043E-11   -10.297   3.933E-01  -0.405
VO4-3           5.585E-14   -13.253   6.842E-15   -14.165   1.225E-01  -0.912
VOH2+           1.220E-15   -14.914   4.798E-16   -15.319   3.933E-01  -0.405

VOOH+           5.465E-10    -9.262   4.328E-10    -9.364   7.919E-01  -0.101
ZN(OH)2         5.516E-12   -11.258   5.621E-12   -11.250   1.019E+00   0.008
ZN(OH)3-        8.911E-17   -16.050   7.057E-17   -16.151   7.919E-01  -0.101

ZN(OH)4-2       1.129E-22   -21.947   4.440E-23   -22.353   3.933E-01  -0.405
ZN(SO4)2-2      1.060E-11   -10.975   4.168E-12   -11.380   3.933E-01  -0.405
ZN+2            6.712E-08    -7.173   2.833E-08    -7.548   4.221E-01  -0.375

ZNCL+           6.691E-11   -10.175   5.299E-11   -10.276   7.919E-01  -0.101
ZNCL2           3.783E-14   -13.422   3.855E-14   -13.414   1.019E+00   0.008
ZNCL3-          3.795E-17   -16.421   3.005E-17   -16.522   7.919E-01  -0.101

ZNCL4-2         2.661E-20   -19.575   1.046E-20   -19.980   3.933E-01  -0.405
ZNF+            1.896E-11   -10.722   1.501E-11   -10.824   7.919E-01  -0.101
ZNHCO3+         2.531E-07    -6.597   2.005E-07    -6.698   7.919E-01  -0.101

ZNOH+           1.557E-10    -9.808   1.233E-10    -9.909   7.919E-01  -0.101
ZNOHCL          2.539E-12   -11.595   2.588E-12   -11.587   1.019E+00   0.008
ZNSO4           1.811E-09    -8.742   1.845E-09    -8.734   1.019E+00   0.008
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STABILITY OF SOLID AND GAS PHASES     ****************************************

PHASE                                    LOG IAP       LOG KT      LOG IAP/KT
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GOETHITE       alpha-FeOOH                 2.590        0.113          2.477
GIBBSITE       gamma-Al(OH)3              10.609        8.175          2.434
BOEHMITE       gamma-AlOOH                10.610        8.402          2.208

DAWSONITE      NaAlCO3(OH)2               -3.112       -5.173          2.061
TREVORITE      alpha-Ni(FeO2)2            37.596       35.990          1.606
DOLOMITE       CaMg(CO3)2                -15.425      -17.020          1.595

CA.97MG.03CO                              -7.703       -8.540          0.836
CALCITE        CaCO3                      -7.703       -8.481          0.779
CA.98MG.02CO                              -7.703       -8.469          0.766

ARAGONITE      CaCO3                      -7.703       -8.338          0.635
CA.931MG.069                              -7.704       -8.313          0.608
MAGNESITE      MgCO3                      -7.722       -8.240          0.518

CA.896MG.104                              -7.705       -7.958          0.253
CA.873MG.127                              -7.705       -7.843          0.137
CO2(GAS)       ideal gas                  -1.486       -1.610          0.124

FE(OH)3        Fe(OH)3-crystalline         2.589        2.589          0.000
AL(OH)3(AM)                               10.609       10.741         -0.132
CA.821MG.179                              -7.706       -7.459         -0.247

CA.808MG.192                              -7.706       -7.332         -0.374
CA.733MG.267                              -7.708       -7.288         -0.420
SIDERITE       FeCO3                     -11.050      -10.550         -0.500

CA.756MG.244                              -7.707       -7.198         -0.509
CA.764MG.236                              -7.707       -7.192         -0.516
FRANKLINITE    Zn(FeO2)2                  36.873       37.594         -0.721

ALSTONITE      BaCa(CO3)2                -18.719      -17.988         -0.731
a-CU(FEO2)2    alpha-Cu(FeO2)2             9.874       10.842         -0.967
RHODOCHROSIT   MnCO3                     -11.389      -10.410         -0.979

WITHERITE      alpha-BaCO3               -11.016      -10.020         -0.996
BARITE         BaSO4                      -9.591       -8.519         -1.072
CERUSSITE      PbCO3                     -14.370      -13.130         -1.240

GYPSUM         CaSO4*2H2O                 -6.281       -4.759         -1.522
NH3(GAS)       ammonia, ideal gas       -113.965     -112.429         -1.536
CR(OH)3        CR(OH)3                    10.387       12.020         -1.633

ZNCO3*H2O                                -12.530      -10.260         -2.270
FE(OH)3(AM)                                2.589        4.891         -2.302
SMITHSONITE    ZnCO3                     -12.529      -10.000         -2.529

PARAMONTROSE   V2O4                       17.191       19.933         -2.742
DUTTONITE      VO(OH)2                     8.594       11.533         -2.939
URANINITE      UO2                        -8.683       -1.265         -7.418

CHALCOCITE     CuS                       -46.259      -34.619        -11.640
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TABLE C-3 **PHREEQE CALCULATIONS, MW 2004 1Q87**

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TOTAL CONCENTRATION OF AQUEOUS COMPONENTS      ********************************


                        TOTAL           TOTAL             TOTAL
COMPONENTS             MOLALITY      LOG MOLALITY         MG/KG
-----------------------------------------------------------------

AL                    6.6721E-07      -6.1757          1.7991E-02
BA                    1.0924E-06      -5.9616          1.4993E-01
HCO3                  7.8670E-03      -2.1042          4.7973E+02

CA                    1.7218E-03      -2.7640          6.8967E+01
CL                    3.3852E-05      -4.4704          1.1994E+00
CR                    1.9235E-07      -6.7159          9.9952E-03

CU                    6.2961E-08      -7.2009          3.9981E-03
F                     2.6321E-05      -4.5797          4.9976E-01
FE                    1.7869E-06      -5.7479          9.9735E-02

K                     1.2789E-04      -3.8932          4.9976E+00
MG                    1.6044E-03      -2.7947          3.8981E+01
MN                    1.0923E-07      -6.9617          5.9971E-03

MO                    1.0005E-07      -6.9998          1.5992E-02
NO3                   1.2904E-05      -4.8893          7.9962E-01
NA                    4.7853E-04      -3.3201          1.0995E+01

NI                    6.8140E-07      -6.1666          3.9981E-02
PB                    2.4136E-08      -7.6173          4.9976E-03
SO4                   2.4987E-05      -4.6023          2.3988E+00

U                     1.2605E-08      -7.8995          2.9986E-03
V                     2.5520E-07      -6.5931          1.2994E-02
ZN                    9.1797E-07      -6.0372          5.9971E-02


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DESCRIPTION OF SOLUTION      ****************************************************

pH                                       7.300
EH  (mV)                                16.132
PE                                       0.273

ACTIVITY OF H2O                          1.000
IONIC STRENGTH (M)                       0.010
TEMPERATURE (C)                         25.000

CATION CONC.(EQ/KG H2O)                  7.056E-03
ANION CONC.(EQ/KG H2O)                  -7.056E-03
CHARGE BALANCE          (%)              9.672E-09

TOTAL ALKALINITY (EQ/KG H2O)             7.169E-03

TDS (MG/KG)                              6.090E+02
DENSITY                                  1.001

ITERATIONS                              15

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DISTRIBUTION OF AQUEOUS SPECIES       ********************************************

                                    LOG                       LOG                    LOG
SPECIES             MOLALITY    MOLALITY    ACTIVITY     ACTIVITY       GAMMA      GAMMA
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AL(OH)2+           1.577E-08     -7.802    1.426E-08      -7.846    9.041E-01   -0.044
AL(OH)3            3.826E-07     -6.417    3.835E-07      -6.416    1.002E+00    0.001
AL(OH)4-           2.651E-07     -6.577    2.391E-07      -6.621    9.017E-01   -0.045

AL(SO4)2-          1.223E-17    -16.913    1.103E-17     -16.957    9.017E-01   -0.045
AL+3               1.757E-12    -11.755    7.710E-13     -12.113    4.388E-01   -0.358
ALF+2              2.595E-10     -9.586    1.734E-10      -9.761    6.682E-01   -0.175

ALF2+              2.316E-09     -8.635    2.094E-09      -8.679    9.041E-01   -0.044
ALF3               8.550E-10     -9.068    8.571E-10      -9.067    1.002E+00    0.001
ALF4-              1.047E-11    -10.980    9.441E-12     -11.025    9.017E-01   -0.045

ALOH+2             2.356E-10     -9.628    1.574E-10      -9.803    6.682E-01   -0.175
ALSO4+             1.174E-14    -13.930    1.059E-14     -13.975    9.017E-01   -0.045
BA+2               1.090E-06     -5.962    7.251E-07      -6.140    6.651E-01   -0.177

BAOH+              2.663E-11    -10.575    2.404E-11     -10.619    9.031E-01   -0.044
BASO4              2.177E-09     -8.662    2.182E-09      -8.661    1.002E+00    0.001
CA+2               1.616E-03     -2.792    1.079E-03      -2.967    6.677E-01   -0.175

CACO3              1.090E-05     -4.963    1.092E-05      -4.962    1.002E+00    0.001
CAF+               2.287E-07     -6.641    2.065E-07      -6.685    9.031E-01   -0.044
CAHCO3+            9.213E-05     -4.036    8.344E-05      -4.079    9.056E-01   -0.043

CAMOO4             7.088E-11    -10.149    7.105E-11     -10.148    1.002E+00    0.001
CAOH+              5.996E-09     -8.222    5.431E-09      -8.265    9.056E-01   -0.043
CASO4              2.875E-06     -5.541    2.882E-06      -5.540    1.002E+00    0.001

CL-                3.384E-05     -4.471    3.043E-05      -4.517    8.993E-01   -0.046
CO2(AQ)            7.242E-04     -3.140    7.259E-04      -3.139    1.002E+00    0.001
CO3-2              8.748E-06     -5.058    5.845E-06      -5.233    6.682E-01   -0.175

CR(OH)+2           4.695E-09     -8.328    3.093E-09      -8.510    6.587E-01   -0.181
CR(OH)2+           1.876E-07     -6.727    1.690E-07      -6.772    9.009E-01   -0.045
CR+2               1.435E-19    -18.843    9.453E-20     -19.024    6.587E-01   -0.181

CR+3               3.364E-12    -11.473    1.476E-12     -11.831    4.388E-01   -0.358
CRCL2+             1.170E-21    -20.932    1.054E-21     -20.977    9.009E-01   -0.045
CRCL2+2            2.713E-16    -15.567    1.787E-16     -15.748    6.587E-01   -0.181

CRO2-              2.501E-11    -10.602    2.254E-11     -10.647    9.009E-01   -0.045
CRO4-2             8.129E-29    -28.090    5.355E-29     -28.271    6.587E-01   -0.181
CU(CO3)2-2         1.274E-10     -9.895    8.391E-11     -10.076    6.587E-01   -0.181

CU(OH)2            1.400E-09     -8.854    1.403E-09      -8.853    1.002E+00    0.001
CU(OH)3-           1.872E-15    -14.728    1.687E-15     -14.773    9.009E-01   -0.045
CU(OH)4-2          1.019E-20    -19.992    6.713E-21     -20.173    6.587E-01   -0.181

CU+                5.246E-08     -7.280    4.726E-08      -7.325    9.009E-01   -0.045
CU+2               2.509E-10     -9.601    1.688E-10      -9.773    6.727E-01   -0.172
CU2(OH)2+2         7.527E-16    -15.123    4.958E-16     -15.305    6.587E-01   -0.181

CUCL+              1.534E-14    -13.814    1.382E-14     -13.859    9.009E-01   -0.045
CUCL2              2.253E-19    -18.647    2.259E-19     -18.646    1.002E+00    0.001
CUCL2-             1.536E-11    -10.814    1.384E-11     -10.859    9.009E-01   -0.045

CUCL3-             2.707E-26    -25.568    2.439E-26     -25.613    9.009E-01   -0.045
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CUCL3-2        1.013E-15   -14.994   6.675E-16   -15.176   6.587E-01   -0.181
CUCO3          8.080E-09    -8.093   8.099E-09    -8.092   1.002E+00    0.001

CUF+           7.491E-14   -13.125   6.749E-14   -13.171   9.009E-01   -0.045
CUHCO3+        5.890E-10    -9.230   5.307E-10    -9.275   9.009E-01   -0.045
CUOH+          3.737E-11   -10.428   3.366E-11   -10.473   9.009E-01   -0.045

CUSO4          4.508E-13   -12.346   4.518E-13   -12.345   1.002E+00    0.001
E-             5.337E-01    -0.273   5.337E-01    -0.273   1.000E+00    0.000
F-             2.445E-05    -4.612   2.198E-05    -4.658   8.990E-01   -0.046

FE(OH)2        1.633E-11   -10.787   1.637E-11   -10.786   1.002E+00    0.001
FE(OH)2+       3.593E-12   -11.445   3.249E-12   -11.488   9.041E-01   -0.044
FE(OH)3        2.880E-07    -6.541   2.887E-07    -6.540   1.002E+00    0.001

FE(OH)3-       2.473E-17   -16.607   2.233E-17   -16.651   9.031E-01   -0.044
FE(OH)4-       2.103E-12   -11.677   1.902E-12   -11.721   9.041E-01   -0.044
FE(SO4)2-      2.400E-24   -23.620   2.162E-24   -23.665   9.009E-01   -0.045

FE+2           4.064E-07    -6.391   2.733E-07    -6.563   6.727E-01   -0.172
FE+3           1.113E-19   -18.953   4.886E-20   -19.311   4.388E-01   -0.358
FE2(OH)2+4     5.419E-27   -26.266   1.020E-27   -26.991   1.883E-01   -0.725

FECL+2         6.605E-23   -22.180   4.393E-23   -22.357   6.651E-01   -0.177
FECL2+         6.612E-27   -26.180   5.971E-27   -26.224   9.031E-01   -0.044
FEF+2          2.698E-18   -17.569   1.784E-18   -17.749   6.612E-01   -0.180

FEF2+          1.731E-18   -17.762   1.561E-18   -17.807   9.017E-01   -0.045
FEF3           5.063E-20   -19.296   5.075E-20   -19.295   1.002E+00    0.001
FEOH+          1.092E-06    -5.962   9.861E-07    -6.006   9.031E-01   -0.044

FEOH+2         9.257E-15   -14.034   6.157E-15   -14.211   6.651E-01   -0.177
FESO4          6.359E-10    -9.197   6.374E-10    -9.196   1.002E+00    0.001
FESO4+         5.774E-21   -20.239   5.214E-21   -20.283   9.031E-01   -0.044

H+             5.492E-08    -7.260   5.012E-08    -7.300   9.125E-01   -0.040
H2(MOO4)       3.003E-15   -14.522   3.010E-15   -14.521   1.002E+00    0.001

H2MOO4         1.162E-15   -14.935   1.164E-15   -14.934   1.002E+00    0.001
H2VO4-         2.065E-07    -6.685   1.860E-07    -6.730   9.009E-01   -0.045

H3(MOO4)2-     4.005E-22   -21.397   3.608E-22   -21.443   9.009E-01   -0.045
H3VO4          6.039E-11   -10.219   6.053E-11   -10.218   1.002E+00    0.001
HCO3-          6.940E-03    -2.159   6.274E-03    -2.202   9.041E-01   -0.044

HCRO4-         9.483E-30   -29.023   8.544E-30   -29.068   9.009E-01   -0.045

HMOO4-         3.726E-10    -9.429   3.357E-10    -9.474   9.009E-01   -0.045
HSO4-          7.074E-11   -10.150   6.379E-11   -10.195   9.017E-01   -0.045
HVO4-2         4.857E-08    -7.314   3.200E-08    -7.495   6.587E-01   -0.181

K+             1.279E-04    -3.893   1.150E-04    -3.939   8.993E-01   -0.046
KCL            2.888E-09    -8.539   2.895E-09    -8.538   1.002E+00    0.001
KOH            1.976E-11   -10.704   1.981E-11   -10.703   1.002E+00    0.001

KSO4-          1.181E-08    -7.928   1.068E-08    -7.972   9.041E-01   -0.044
MG+2           1.511E-03    -2.821   1.016E-03    -2.993   6.721E-01   -0.173
MGCO3          5.680E-06    -5.246   5.694E-06    -5.245   1.002E+00    0.001

MGF+           1.636E-06    -5.786   1.475E-06    -5.831   9.017E-01   -0.045
MGHCO3+        8.317E-05    -4.080   7.489E-05    -4.126   9.004E-01   -0.046
MGOH+          3.591E-08    -7.445   3.256E-08    -7.487   9.069E-01   -0.042

MGSO4          2.363E-06    -5.626   2.369E-06    -5.625   1.002E+00    0.001
MN(OH)2        1.689E-15   -14.772   1.693E-15   -14.771   1.002E+00    0.001
MN(OH)3-       9.397E-21   -20.027   8.486E-21   -20.071   9.031E-01   -0.044
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MN(OH)4-2        8.127E-27   -26.090   5.353E-27   -26.271   6.587E-01   -0.181
MN+2             1.003E-07    -6.999   6.744E-08    -7.171   6.727E-01   -0.172
MN2(OH)+3        6.393E-18   -17.194   2.499E-18   -17.602   3.909E-01   -0.408

MN2(OH)3+        5.046E-17   -16.297   4.546E-17   -16.342   9.009E-01   -0.045
MNCL+            9.194E-12   -11.036   8.303E-12   -11.081   9.031E-01   -0.044
MNCL2            6.848E-17   -16.164   6.864E-17   -16.163   1.002E+00    0.001

MNCL3-           1.043E-21   -20.982   9.416E-22   -21.026   9.031E-01   -0.044
MNF+             1.162E-11   -10.935   1.049E-11   -10.979   9.031E-01   -0.044
MNHCO3+          8.746E-09    -8.058   7.898E-09    -8.102   9.031E-01   -0.044

MNOH+            3.829E-11   -10.417   3.458E-11   -10.461   9.031E-01   -0.044
MNSO4            1.606E-10    -9.794   1.609E-10    -9.793   1.002E+00    0.001
MOO2(OH)+        7.069E-22   -21.151   6.384E-22   -21.195   9.031E-01   -0.044

MOO2+2           1.371E-28   -27.863   9.068E-29   -28.043   6.612E-01   -0.180
MOO4-2           9.961E-08    -7.002   6.586E-08    -7.181   6.612E-01   -0.180
NA+              4.769E-04    -3.322   4.302E-04    -3.366   9.020E-01   -0.045

NA2CO3           8.919E-13   -12.050   8.940E-13   -12.049   1.002E+00    0.001
NA2SO4           7.870E-11   -10.104   7.889E-11   -10.103   1.002E+00    0.001
NACL             1.094E-08    -7.961   1.096E-08    -7.960   1.002E+00    0.001

NACO3-           5.176E-08    -7.286   4.680E-08    -7.330   9.041E-01   -0.044
NAHCO3           1.518E-06    -5.819   1.521E-06    -5.818   1.002E+00    0.001
NAOH             1.497E-11   -10.825   1.501E-11   -10.824   1.002E+00    0.001

NASO4-           3.127E-08    -7.505   2.827E-08    -7.549   9.041E-01   -0.044
NH3(AQ)          1.290E-07    -6.889   1.293E-07    -6.888   1.002E+00    0.001
NH4+             1.277E-05    -4.894   1.144E-05    -4.941   8.960E-01   -0.048

NH4SO4-          2.156E-09    -8.666   1.947E-09    -8.711   9.031E-01   -0.044
NI(OH)2          1.102E-11   -10.958   1.105E-11   -10.957   1.002E+00    0.001
NI(OH)3-         2.447E-15   -14.611   2.204E-15   -14.657   9.009E-01   -0.045

NI(SO4)2-2       7.590E-16   -15.120   5.000E-16   -15.301   6.587E-01   -0.181
NI+2             4.128E-07    -6.384   2.776E-07    -6.557   6.727E-01   -0.172
NICL+            2.356E-11   -10.628   2.122E-11   -10.673   9.009E-01   -0.045

NICL2            2.339E-15   -14.631   2.345E-15   -14.630   1.002E+00    0.001
NIF+             1.351E-10    -9.869   1.218E-10    -9.915   9.009E-01   -0.045
NINCO3+          2.669E-07    -6.574   2.405E-07    -6.619   9.009E-01   -0.045

NIOH+            8.487E-10    -9.071   7.645E-10    -9.117   9.009E-01   -0.045
NISO4            7.083E-10    -9.150   7.099E-10    -9.149   1.002E+00    0.001
NO3-             1.623E-49   -48.790   1.457E-49   -48.837   8.975E-01   -0.047

OH-              2.229E-07    -6.652   2.004E-07    -6.698   8.990E-01   -0.046
PB(OH)2          9.707E-12   -11.013   9.730E-12   -11.012   1.002E+00    0.001
PB(OH)3-         2.474E-15   -14.607   2.228E-15   -14.652   9.009E-01   -0.045

PB(OH)4-2        1.546E-19   -18.811   1.018E-19   -18.992   6.587E-01   -0.181
PB(SO4)2-2       2.483E-15   -14.605   1.636E-15   -14.786   6.587E-01   -0.181
PB+2             4.874E-09    -8.312   3.223E-09    -8.492   6.612E-01   -0.180

PB2ON+3          2.314E-16   -15.636   9.046E-17   -16.044   3.909E-01   -0.408
PB3(OH)4+2       1.061E-20   -19.974   6.990E-21   -20.156   6.587E-01   -0.181
PBCL+            4.334E-12   -11.363   3.905E-12   -11.408   9.009E-01   -0.045

PBCL2            1.879E-16   -15.726   1.883E-16   -15.725   1.002E+00    0.001
PBCL3-           5.052E-21   -20.296   4.552E-21   -20.342   9.009E-01   -0.045
PBCL4-2          1.006E-25   -24.997   6.630E-26   -25.179   6.587E-01   -0.181

PBF+             1.398E-12   -11.854   1.260E-12   -11.900   9.009E-01   -0.045
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PBF2             5.639E-16    -15.249    5.652E-16    -15.248    1.002E+00    0.001
PBF3-            9.989E-20    -19.000    8.999E-20    -19.046    9.009E-01   -0.045

PBF4-2           1.437E-24    -23.843    9.467E-25    -24.024    6.587E-01   -0.181
PBHCO3+          1.783E-08     -7.749    1.606E-08     -7.794    9.009E-01   -0.045
PBOH+            1.392E-09     -8.856    1.254E-09     -8.902    9.009E-01   -0.045

PBSO4            2.371E-11    -10.625    2.377E-11    -10.624    1.002E+00    0.001
SO4-2            1.970E-05     -4.706    1.311E-05     -4.882    6.657E-01   -0.177
U(OH)4           1.474E-14    -13.831    1.478E-14    -13.830    1.002E+00    0.001

U(OH)5-          8.043E-12    -11.095    7.253E-12    -11.139    9.017E-01   -0.045
U+4              1.297E-34    -33.887    3.221E-35    -34.492    2.483E-01   -0.605
UF+3             6.192E-25    -24.208    2.659E-25    -24.575    4.294E-01   -0.367

UF2+2            1.578E-24    -23.802    1.073E-24    -23.970    6.799E-01   -0.168
UF3+             4.513E-25    -24.346    4.075E-25    -24.390    9.031E-01   -0.044
UF4              1.544E-25    -24.811    1.548E-25    -24.810    1.002E+00    0.001

UF5-             1.493E-28    -27.826    1.348E-28    -27.870    9.031E-01   -0.044
UO2(CO3)2-2      9.691E-09     -8.014    6.554E-09     -8.183    6.763E-01   -0.170
UO2(CO3)3-4      2.906E-09     -8.537    7.216E-10     -9.142    2.483E-01   -0.605

UO2(OH)2         2.234E-14    -13.651    2.239E-14    -13.650    1.002E+00    0.001
UO2(OH)3-        3.403E-18    -17.468    3.066E-18    -17.513    9.009E-01   -0.045
UO2(OH)4-2       6.180E-25    -24.209    4.071E-25    -24.390    6.587E-01   -0.181

UO2(SO4)2-2      6.320E-22    -21.199    4.204E-22    -21.376    6.651E-01   -0.177
UO2+             1.001E-15    -14.999    9.028E-16    -15.044    9.017E-01   -0.045
UO2+2            4.155E-15    -14.381    2.807E-15    -14.552    6.756E-01   -0.170

UO2CL+           8.445E-21    -20.073    7.615E-21    -20.118    9.017E-01   -0.045
UO2F+            3.164E-16    -15.500    2.857E-16    -15.544    9.031E-01   -0.044
UO2F2            1.467E-16    -15.833    1.471E-16    -15.832    1.002E+00    0.001

UO2F3-           1.508E-18    -17.822    1.362E-18    -17.866    9.031E-01   -0.044
UO2F4-2          9.082E-22    -21.042    6.041E-22    -21.219    6.651E-01   -0.177
UO2OH+           2.357E-14    -13.628    2.128E-14    -13.672    9.031E-01   -0.044

UO2SO4           1.057E-18    -17.976    1.059E-18    -17.975    1.002E+00    0.001
UOH+3            9.019E-28    -27.045    3.958E-28    -27.403    4.388E-01   -0.358
V(OH)2+          2.824E-13    -12.549    2.544E-13    -12.594    9.009E-01   -0.045

V(OH)3           3.819E-11    -10.418    3.828E-11    -10.417    1.002E+00    0.001
V+3              1.112E-21    -20.954    4.263E-22    -21.370    3.835E-01   -0.416
VO+2             9.765E-13    -12.010    6.433E-13    -12.192    6.587E-01   -0.181

VO4-3            8.774E-14    -13.057    3.430E-14    -13.465    3.909E-01   -0.408
VOH2+            7.534E-17    -16.123    4.963E-17    -16.304    6.587E-01   -0.181
VOOH+            3.079E-11    -10.512    2.774E-11    -10.557    9.009E-01   -0.045

ZN(OH)2          1.915E-09     -8.718    1.919E-09     -8.717    1.002E+00    0.001
ZN(OH)3-         1.344E-13    -12.872    1.211E-13    -12.917    9.009E-01   -0.045
ZN(OH)4-2        5.811E-19    -18.236    3.828E-19    -18.417    6.587E-01   -0.181

ZN(SO4)2-2       1.906E-13    -12.720    1.255E-13    -12.901    6.587E-01   -0.181
ZN+2             5.695E-07     -6.244    3.831E-07     -6.417    6.727E-01   -0.172
ZNCL+            3.483E-11    -10.458    3.138E-11    -10.503    9.009E-01   -0.045

ZNCL2            9.975E-16    -15.001    9.998E-16    -15.000    1.002E+00    0.001
ZNCL3-           3.789E-20    -19.421    3.414E-20    -19.467    9.009E-01   -0.045
ZNCL4-2          7.904E-25    -24.102    5.206E-25    -24.283    6.587E-01   -0.181

ZNF+             1.320E-10     -9.879    1.189E-10     -9.925    9.009E-01   -0.045
ZNHCO3+          3.359E-07     -6.474    3.026E-07     -6.519    9.009E-01   -0.045
ZNOH+            9.301E-09     -8.031    8.380E-09     -8.077    9.009E-01   -0.045
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ZNOHCL          7.683E-12   -11.114   7.701E-12   -11.113   1.002E+00   0.001
ZNSO4           1.175E-09    -8.930   1.178E-09    -8.929   1.002E+00   0.001

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STABILITY OF SOLID AND GAS PHASES         ****************************************

PHASE                                     LOG IAP        LOG KT        LOG IAP/KT
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TREVORITE      alpha-Ni(FeO2)2             39.262        35.990           3.272
GOETHITE       alpha-FeOOH                  2.589         0.113           2.476
FRANKLINITE    Zn(FeO2)2                   39.402        37.594           1.808

GIBBSITE       gamma-Al(OH)3                9.787         8.175           1.612
BOEHMITE       gamma-AlOOH                  9.787         8.402           1.384
DOLOMITE       CaMg(CO3)2                 -16.427       -17.020           0.593

CA.97MG.03CO                               -8.201        -8.540           0.338
CALCITE        CaCO3                       -8.200        -8.481           0.281
CA.98MG.02CO                               -8.201        -8.469           0.268

WULFENITE      PbMoO4                     -15.673       -15.865           0.192
ARAGONITE      CaCO3                       -8.200        -8.338           0.138
CA.931MG.069                               -8.202        -8.313           0.111

MAGNESITE      MgCO3                       -8.226        -8.240           0.014
FE(OH)3        Fe(OH)3-crystalline          2.589         2.589           0.000
CA.896MG.104                               -8.203        -7.958          -0.245

CA.873MG.127                               -8.204        -7.843          -0.361
CERUSSITE      PbCO3                      -13.725       -13.130          -0.595
CA.821MG.179                               -8.205        -7.459          -0.746

a-CU(FEO2)2    alpha-Cu(FeO2)2             10.005        10.842          -0.837
CA.808MG.192                               -8.205        -7.332          -0.873
CA.733MG.267                               -8.207        -7.288          -0.919

DAWSONITE      NaAlCO3(OH)2                -6.113        -5.173          -0.940
AL(OH)3(AM)                                 9.787        10.741          -0.954
CA.756MG.244                               -8.207        -7.198          -1.008

CA.764MG.236                               -8.206        -7.192          -1.015
SIDERITE       FeCO3                      -11.796       -10.550          -1.246
WITHERITE      alpha-BaCO3                -11.373       -10.020          -1.353

ZNCO3*H2O                                 -11.650       -10.260          -1.390
CO2(GAS)       ideal gas                   -3.139        -1.610          -1.529
ALSTONITE      BaCa(CO3)2                 -19.573       -17.988          -1.585

SMITHSONITE    ZnCO3                      -11.650       -10.000          -1.650
CR(OH)3        CR(OH)3                     10.069        12.020          -1.951
RHODOCHROSIT   MnCO3                      -12.404       -10.410          -1.994

FE(OH)3(AM)                                 2.589         4.891          -2.302
POWELLITE      CaMoO4                     -10.148        -7.691          -2.458
BARITE         BaSO4                      -11.022        -8.519          -2.503

GYPSUM         CaSO4*2H2O                  -7.850        -4.759          -3.091
DUTTONITE      VO(OH)2                      8.102        11.533          -3.431
PARAMONTROSE   V2O4                        16.205        19.933          -3.728

URANINITE      UO2                         -5.292        -1.265          -4.027
NH3(GAS)       ammonia, ideal gas        -116.718      -112.429          -4.289
CHALCOCITE     CuS                        -41.585       -34.619          -6.966

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TABLE C-4   PHREEQE CALCULATIONS, MW 2006 1Q87

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TOTAL CONCENTRATION OF AQUEOUS COMPONENTS     ********************************


                 TOTAL          TOTAL          TOTAL
COMPONENTS      MOLALITY     LOG MOLALITY      MG/KG
-------------------------------------------------------


AL              4.1154E-06      -5.3856     1.1094E-01
BA              1.8211E-06      -5.7397     2.4986E-01
HCO3            9.0590E-03      -2.0429     5.5226E+02

CA              2.5208E-03      -2.5985     1.0094E+02
CL              2.4548E-03      -2.6100     8.6952E+01
CR              6.9260E-07      -6.1595     3.5980E-02

CU              3.9359E-07      -6.4050     2.4986E-02
F               1.3164E-05      -4.8806     2.4986E-01
FE              3.0849E-06      -5.5108     1.7213E-01

K               1.6373E-04      -3.7859     6.3965E+00
MG              1.6458E-03      -2.7836     3.9978E+01
MN              8.0118E-07      -6.0963     4.3976E-02

NO3             6.2920E-04      -3.2012     3.8978E+01
NA              1.8275E-03      -2.7381     4.1977E+01
NI              1.2609E-06      -5.8993     7.3959E-02

PB              2.4141E-08      -7.6172     4.9972E-03
SO4             3.2282E-04      -3.4910     3.0983E+01
U               1.2608E-08      -7.8994     2.9983E-03

V               9.8175E-07      -6.0080     4.9972E-02
ZN              1.5303E-07      -6.8152     9.9945E-03

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DESCRIPTION OF SOLUTION       ************************************************

pH                                       7.100
EH (mV)                                 28.597
PE                                       0.483

ACTIVITY OF H2O                          1.000
IONIC STRENGTH (M)                       0.015
TEMPERATURE (C)                         25.000

CATION CONC.(EQ/KG H2O)                  1.056E-02
ANION CONC.(EQ/KG H2O)                  -1.056E-02
CHARGE BALANCE           (%)             3.032E-09

TOTAL ALKALINITY (EQ/KG H2O)             7.856E-03

TDS (MG/KG)                              8.995E+02
DENSITY                                  1.001

ITERATIONS                              25

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DISTRIBUTION OF AQUEOUS SPECIES      *****************************************

                                 LOG                        LOG                  LOG
SPECIES           MOLALITY    MOLALITY    ACTIVIYY     ACTIVIYY      GAMMA      GAMMA
-----------------------------------------------------------------------------------

AL(OH)2+         1.798E-07    -6.745     1.599E-07     -6.796     8.893E-01   -0.051
AL(OH)3          2.704E-06    -5.568     2.713E-06     -5.566     1.003E+00    0.001
AL(OH)4-         1.204E-06    -5.919     1.067E-06     -5.972     8.862E-01   -0.052

AL(SO4)2-        4.856E-14   -13.314     4.303E-14    -13.366     8.862E-01   -0.052
AL+3             5.583E-11   -10.253     2.172E-11    -10.663     3.890E-01   -0.410
ALF+2            3.822E-09    -8.418     2.391E-09     -8.621     6.256E-01   -0.204

ALF2+            1.590E-08    -7.799     1.414E-08     -7.850     8.893E-01   -0.051
ALF3             2.822E-09    -8.549     2.832E-09     -8.548     1.003E+00    0.001
ALF4-            1.723E-11   -10.764     1.527E-11    -10.816     8.862E-01   -0.052

ALOH+2           4.472E-09    -8.350     2.798E-09     -8.553     6.256E-01   -0.204
ALSO4+           3.961E-12   -11.402     3.510E-12    -11.455     8.862E-01   -0.052
BA+2             1.782E-06    -5.749     1.108E-06     -5.956     6.217E-01   -0.206

BAOH+            2.610E-11   -10.583     2.318E-11    -10.635     8.880E-01   -0.052
BASO4            3.911E-08    -7.408     3.924E-08     -7.406     1.003E+00    0.001
CA+2             2.329E-03    -2.633     1.456E-03     -2.837     6.252E-01   -0.204

CACO3            9.961E-06    -5.002     9.995E-06     -5.000     1.003E+00    0.001
CAF+             1.537E-07    -6.813     1.364E-07     -6.865     8.880E-01   -0.052
CAHCO3+          1.357E-04    -3.867     1.210E-04     -3.917     8.914E-01   -0.050

CAOH+            5.189E-09    -8.285     4.625E-09     -8.335     8.914E-01   -0.050
CASO4            4.563E-05    -4.341     4.578E-05     -4.339     1.003E+00    0.001
CL-              2.451E-03    -2.611     2.164E-03     -2.665     8.829E-01   -0.054

CO2(AQ)          1.232E-03    -2.909     1.236E-03     -2.908     1.003E+00    0.001
CO3-2            6.333E-06    -5.198     3.962E-06     -5.402     6.256E-01   -0.204
CR(OH)+2         2.779E-08    -7.556     1.707E-08     -7.768     6.141E-01   -0.212

CR(OH)2+         6.647E-07    -6.177     5.884E-07     -6.230     8.852E-01   -0.053
CR+2             8.288E-19   -18.082     5.090E-19    -18.293     6.141E-01   -0.212
CR+3             3.319E-11   -10.479     1.291E-11    -10.889     3.890E-01   -0.410

CRCL2+           5.267E-17   -16.278     4.663E-17    -16.331     8.852E-01   -0.053
CRCL2+2          1.810E-13   -12.742     1.112E-13    -12.954     6.141E-01   -0.212
CRO2-            3.528E-11   -10.452     3.123E-11    -10.505     8.852E-01   -0.053

CRO4-2           8.211E-29   -28.086     5.042E-29    -28.297     6.141E-01   -0.212
CU(CO3)2-2       2.782E-10    -9.556     1.708E-10     -9.767     6.141E-01   -0.212
CU(OH)2          2.467E-09    -8.608     2.475E-09     -8.606     1.003E+00    0.001

CU(OH)3-         2.120E-15   -14.674     1.877E-15    -14.727     8.852E-01   -0.053
CU(OH)4-2        7.676E-21   -20.115     4.713E-21    -20.327     6.141E-01   -0.212
CU+              1.456E-07    -6.837     1.289E-07     -6.890     8.852E-01   -0.053

CU+2             1.185E-09    -8.926     7.479E-10     -9.126     6.313E-01   -0.200
CU2(OH)2+2       6.312E-15   -14.200     3.876E-15    -14.412     6.141E-01   -0.212
CUCL+            4.921E-12   -11.308     4.356E-12    -11.361     8.852E-01   -0.053

CUCL2            5.046E-15   -14.297     5.063E-15    -14.296     1.003E+00    0.001
CUCL2-           2.157E-07    -6.666     1.910E-07     -6.719     8.852E-01   -0.053
CUCL3-           4.392E-20   -19.357     3.888E-20    -19.410     8.852E-01   -0.053

CUCL3-2          1.067E-09    -8.972     6.550E-10     -9.184     6.141E-01   -0.212
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 CUCO3            2.424E-08     -7.615    2.433E-08     -7.614    1.003E+00    0.001

CUF+              1.654E-13    -12.782    1.464E-13    -12.834    8.852E-01   -0.053
CUHCO3+           2.854E-09     -8.545    2.526E-09     -8.598    8.852E-01   -0.053
CUOH+             1.063E-10     -9.973    9.412E-11    -10.026    8.852E-01   -0.053

CUSO4             2.349E-11    -10.629    2.357E-11    -10.628    1.003E+00    0.001
E-                3.285E-01     -0.483    3.285E-01     -0.483    1.000E+00    0.000
F-                1.219E-05     -4.914    1.076E-05     -4.968    8.824E-01   -0.054

FE(OH)2           1.591E-11    -10.798    1.597E-11    -10.797    1.003E+00    0.001
FE(OH)2+          5.790E-12    -11.237    5.149E-12    -11.288    8.893E-01   -0.051
FE(OH)3           2.877E-07     -6.541    2.887E-07     -6.540    1.003E+00    0.001

FE(OH)3-          1.548E-17    -16.810    1.375E-17    -16.862    8.880E-01   -0.052
FE(OH)4-          1.349E-12    -11.870    1.200E-12    -11.921    8.893E-01   -0.051
FE(SO4)2-         1.347E-21    -20.871    1.193E-21    -20.924    8.852E-01   -0.053

FE+2              1.061E-06     -5.974    6.700E-07     -6.174    6.313E-01   -0.200
FE+3              5.001E-19    -18.301    1.946E-19    -18.711    3.890E-01   -0.410
FE2(OH)2+4        4.529E-26    -25.344    6.440E-27    -26.191    1.422E-01   -0.847

FECL+2            2.001E-20    -19.699    1.244E-20    -19.905    6.217E-01   -0.206
FECL2+            1.354E-22    -21.868    1.203E-22    -21.920    8.880E-01   -0.052
FECL3             2.594E-26    -25.586    2.603E-26    -25.585    1.003E+00    0.001

FEF+2             5.639E-18    -17.249    3.478E-18    -17.459    6.167E-01   -0.210
FEF2+             1.681E-18    -17.774    1.489E-18    -17.827    8.862E-01   -0.052
FEF3              2.362E-20    -19.627    2.370E-20    -19.625    1.003E+00    0.001

FEOH+             1.717E-06     -5.765    1.525E-06     -5.817    8.880E-01   -0.052
FEOH+2            2.488E-14    -13.604    1.547E-14    -13.811    6.217E-01   -0.206
FESO4             1.833E-08     -7.737    1.839E-08     -7.735    1.003E+00    0.001

FESO4+            2.752E-19    -18.560    2.444E-19    -18.612    8.880E-01   -0.052
H+                8.822E-08     -7.054    7.943E-08     -7.100    9.004E-01   -0.046

H2VO4-            8.481E-07     -6.072    7.508E-07     -6.124    8.852E-01   -0.053
H3VO4             3.859E-10     -9.414    3.872E-10     -9.412    1.003E+00    0.001

HCO3-             7.578E-03     -2.120    6.740E-03     -2.171    8.893E-01   -0.051
HCRO4-            1.440E-29    -28.842    1.275E-29    -28.894    8.852E-01   -0.053

HSO4-             1.343E-09     -8.872    1.190E-09     -8.925    8.862E-01   -0.052
HVO4-2            1.327E-07     -6.877    8.148E-08     -7.089    6.141E-01   -0.212

K+                1.633E-04     -3.787    1.442E-04     -3.841    8.829E-01   -0.054
KCL               2.572E-07     -6.590    2.581E-07     -6.588    1.003E+00    0.001
KOH               1.561E-11    -10.807    1.567E-11    -10.805    1.003E+00    0.001

KSO4-             1.771E-07     -6.752    1.575E-07     -6.803    8.893E-01   -0.051
MG+2              1.529E-03     -2.816    9.643E-04     -3.016    6.308E-01   -0.200
MGCO3             3.651E-06     -5.438    3.663E-06     -5.436    1.003E+00    0.001

MGF+              7.734E-07     -6.112    6.854E-07     -6.164    8.862E-01   -0.052
MGHCO3+           8.634E-05     -4.064    7.636E-05     -4.117    8.843E-01   -0.053
MGOH+             2.184E-08     -7.661    1.950E-08     -7.710    8.930E-01   -0.049

MGSO4             2.637E-05     -4.579    2.646E-05     -4.577    1.003E+00    0.001
MN(OH)2           4.524E-15    -14.345    4.539E-15    -14.343    1.003E+00    0.001
MN(OH)3-          1.616E-20    -19.792    1.435E-20    -19.843    8.880E-01   -0.052

MN(OH)4-2         9.300E-27    -26.032    5.711E-27    -26.243    6.141E-01   -0.212
MN+2              7.194E-07     -6.143    4.542E-07     -6.343    6.313E-01   -0.200
MN2(OH)+3         2.142E-16    -15.669    7.150E-17    -16.146    3.338E-01   -0.476
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MN2(OH)3+      5.848E-16   -15.233   5.177E-16   -15.286   8.852E-01  -0.053
MNCL+          4.476E-09    -8.349   3.976E-09    -8.401   8.880E-01  -0.052
MNCL2          2.330E-12   -11.633   2.338E-12   -11.631   1.003E+00   0.001

MNCL3-         2.568E-15   -14.590   2.281E-15   -14.642   8.880E-01  -0.052
MNF+           3.895E-11   -10.409   3.459E-11   -10.461   8.880E-01  -0.052
MNHCO3+        6.434E-08    -7.192   5.713E-08    -7.243   8.880E-01  -0.052

MNOH+          1.655E-10    -9.781   1.469E-10    -9.833   8.880E-01  -0.052
MNSO4          1.271E-08    -7.896   1.275E-08    -7.894   1.003E+00   0.001
NA+            1.817E-03    -2.741   1.611E-03    -2.793   8.866E-01  -0.052

NA2CO3         8.469E-12   -11.072   8.497E-12   -11.071   1.003E+00   0.001
NA2SO4         1.298E-08    -7.887   1.302E-08    -7.885   1.003E+00   0.001
NACL           2.910E-06    -5.536   2.920E-06    -5.535   1.003E+00   0.001

NACO3-         1.336E-07    -6.874   1.188E-07    -6.925   8.893E-01  -0.051
NAHCO3         6.099E-06    -5.215   6.119E-06    -5.213   1.003E+00   0.001
NAOH           3.533E-11   -10.452   3.545E-11   -10.450   1.003E+00   0.001

NASO4-         1.401E-06    -5.854   1.246E-06    -5.904   8.893E-01  -0.051
NH3(AQ)        3.895E-06    -5.409   3.908E-06    -5.408   1.003E+00   0.001
NH4+           6.241E-04    -3.205   5.482E-04    -3.261   8.785E-01  -0.056

NH4SO4-        1.236E-06    -5.908   1.097E-06    -5.960   8.880E-01  -0.052
NI(OH)2        7.445E-12   -11.128   7.470E-12   -11.127   1.003E+00   0.001
NI(OH)3-       1.062E-15   -14.974   9.402E-16   -15.027   8.852E-01  -0.053

NI(SO4)2-2     1.915E-13   -12.718   1.176E-13   -12.930   6.141E-01  -0.212
NI+2           7.471E-07    -6.127   4.716E-07    -6.326   6.313E-01  -0.200
NICL+          2.896E-09    -8.538   2.564E-09    -8.591   8.852E-01  -0.053

NICL2          2.008E-11   -10.697   2.014E-11   -10.696   1.003E+00   0.001
NIF+           1.144E-10    -9.942   1.012E-10    -9.995   8.852E-01  -0.053
NIHCO3+        4.957E-07    -6.305   4.388E-07    -6.358   8.852E-01  -0.053

NIOH+          9.256E-10    -9.034   8.193E-10    -9.087   8.852E-01  -0.053
NISO4          1.414E-08    -7.849   1.419E-08    -7.848   1.003E+00   0.001
NO3-           3.843E-48   -47.415   3.384E-48   -47.471   8.805E-01  -0.055

OH-            1.433E-07    -6.844   1.264E-07    -6.898   8.824E-01  -0.054
PB(OH)2        3.555E-12   -11.449   3.567E-12   -11.448   1.003E+00   0.001
PB(OH)3-       5.823E-16   -15.235   5.154E-16   -15.288   8.852E-01  -0.053

PB(OH)4-2      2.420E-20   -19.616   1.486E-20   -19.828   6.141E-01  -0.212
PB(SO4)2-2     3.398E-13   -12.469   2.087E-13   -12.681   6.141E-01  -0.212
PB+2           4.814E-09    -8.318   2.969E-09    -8.527   6.167E-01  -0.210

PB2OH+3        1.450E-16   -15.839   4.842E-17   -16.315   3.338E-01  -0.476
PB3(OH)4+2     1.409E-21   -20.851   8.653E-22   -21.063   6.141E-01  -0.212
PBCL+          2.889E-10    -9.539   2.558E-10    -9.592   8.852E-01  -0.053

PBCL2          8.743E-13   -12.058   8.773E-13   -12.057   1.003E+00   0.001
PBCL3-         1.704E-15   -14.769   1.508E-15   -14.822   8.852E-01  -0.053
PBCL4-2        2.544E-18   -17.595   1.562E-18   -17.806   6.141E-01  -0.212

PBF+           6.415E-13   -12.193   5.679E-13   -12.246   8.852E-01  -0.053
PBF2           1.243E-16   -15.905   1.247E-16   -15.904   1.003E+00   0.001
PBF3-          1.098E-20   -19.959   9.722E-21   -20.012   8.852E-01  -0.053

PBF4-2         8.152E-26   -25.089   5.006E-26   -25.301   6.141E-01  -0.212
PBHCO3+        1.795E-08    -7.746   1.589E-08    -7.799   8.852E-01  -0.053
PBOH+          8.230E-10    -9.085   7.285E-10    -9.138   8.852E-01  -0.053

PBSO4          2.568E-10    -9.590   2.576E-10    -9.589   1.003E+00   0.001
SO4-2          2.479E-04    -3.606   1.543E-04    -3.812   6.225E-01  -0.206
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U(OH)4          1.206E-14   -13.919   1.210E-14   -13.917   1.003E+00   0.001

U(OH)5-         4.228E-12   -11.374   3.747E-12   -11.426   8.862E-01  -0.052
U+4             8.125E-34   -33.090   1.664E-34   -33.779   2.049E-01  -0.689
UF+3            1.779E-24   -23.750   6.727E-25   -24.172   3.781E-01  -0.422

UF2+2           2.074E-24   -23.683   1.328E-24   -23.877   6.404E-01  -0.194
UF3+            2.782E-25   -24.556   2.470E-25   -24.607   8.880E-01  -0.052
UF4             4.577E-26   -25.339   4.593E-26   -25.338   1.003E+00   0.001

UF5-            2.205E-29   -28.657   1.958E-29   -28.708   8.880E-01  -0.052
UO2(CO3)2-2     1.023E-08    -7.990   6.507E-09    -8.187   6.359E-01  -0.197
UO2(CO3)3-4     2.370E-09    -8.625   4.856E-10    -9.314   2.049E-01  -0.689

UO2(OH)2        1.920E-14   -13.717   1.926E-14   -13.715   1.003E+00   0.001
UO2(OH)3-       1.880E-18   -17.726   1.664E-18   -17.779   8.852E-01  -0.053
UO2(OH)4-2      2.270E-25   -24.644   1.394E-25   -24.856   6.141E-01  -0.212

UO2(SO4)2-2     2.024E-19   -18.694   1.258E-19   -18.900   6.217E-01  -0.206
UO2+            1.355E-15   -14.868   1.201E-15   -14.920   8.862E-01  -0.052
UO2+2           9.555E-15   -14.020   6.067E-15   -14.217   6.350E-01  -0.197

UO2CL+          1.321E-18   -17.879   1.170E-18   -17.932   8.862E-01  -0.052
UO2F+           3.404E-16   -15.468   3.023E-16   -15.520   8.880E-01  -0.052
UO2F2           7.590E-17   -16.120   7.616E-17   -16.118   1.003E+00   0.001

UO2F3-          3.887E-19   -18.410   3.452E-19   -18.462   8.880E-01  -0.052
UO2F4-2         1.206E-22   -21.919   7.495E-23   -22.125   6.217E-01  -0.206
UO2OH+          3.269E-14   -13.486   2.902E-14   -13.537   8.880E-01  -0.052

UO2SO4          2.685E-17   -16.571   2.694E-17   -16.570   1.003E+00   0.001
UOH+3           3.317E-27   -26.479   1.290E-27   -26.889   3.890E-01  -0.410
V(OH)2+         2.774E-12   -11.557   2.455E-12   -11.610   8.852E-01  -0.053

V(OH)3          2.323E-10    -9.634   2.331E-10    -9.633   1.003E+00   0.001
V+3             3.185E-20   -19.497   1.034E-20   -19.986   3.245E-01  -0.489
VO+2            1.642E-11   -10.785   1.009E-11   -10.996   6.141E-01  -0.212

VO4-3           1.651E-13   -12.782   5.511E-14   -13.259   3.338E-01  -0.476
VOH2+           1.236E-15   -14.908   7.591E-16   -15.120   6.141E-01  -0.212
VOOH+           3.100E-10    -9.509   2.744E-10    -9.562   8.852E-01  -0.053

ZN(OH)2         1.168E-10    -9.933   1.172E-10    -9.931   1.003E+00   0.001
ZN(OH)3-        5.269E-15   -14.278   4.664E-15   -14.331   8.852E-01  -0.053
ZN(OH)4-2       1.515E-20   -19.820   9.303E-21   -20.031   6.141E-01  -0.212

ZN(SO4)2-2      4.343E-12   -11.362   2.667E-12   -11.574   6.141E-01  -0.212
ZN+2            9.309E-08    -7.031   5.877E-08    -7.231   6.313E-01  -0.200
ZNCL+           3.867E-10    -9.413   3.423E-10    -9.466   8.852E-01  -0.053

ZNCL2           7.731E-13   -12.112   7.757E-13   -12.110   1.003E+00   0.001
ZNCL3-          2.128E-15   -14.672   1.884E-15   -14.725   8.852E-01  -0.053
ZNCL4-2         3.327E-18   -17.478   2.043E-18   -17.690   6.141E-01  -0.212

ZNF+            1.009E-11   -10.996   8.930E-12   -11.049   8.852E-01  -0.053
ZNHCO3+         5.633E-08    -7.249   4.986E-08    -7.302   8.852E-01  -0.053
ZNOH+           9.161E-10    -9.038   8.110E-10    -9.091   8.852E-01  -0.053

ZNOHCL          5.282E-11   -10.277   5.300E-11   -10.276   1.003E+00   0.001
ZNSO4           2.119E-09    -8.674   2.126E-09    -8.672   1.003E+00   0.001

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STABILITY OF SOLID AND GAS PHASES      ****************************************

PHASE                                    LOG IAP        LOG KT       LOG IAP/KT
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TREVORITE      alpha-Ni(FeO2)2            39.092        35.990           3.103
GOETHITE       alpha-FeOOH                 2.589         0.113           2.476
GIBBSITE       gamma-Al(OH)3              10.637         8.175           2.461

BOEHMITE       gamma-AlOOH                10.637         8.402           2.234
FRANKLINITE    Zn(FeO2)2                  38.188        37.594           0.594
DAWSONITE      NaAlCO3(OH)2               -4.658        -5.173           0.515

DOLOMITE       CaMg(CO3)2                -16.657       -17.020           0.363
CA.97MG.03CO                              -8.244        -8.540           0.295
CALCITE        CaCO3                      -8.239        -8.481           0.243

CA.98MG.02CO                              -8.242        -8.469           0.227
ARAGONITE      CaCO3                      -8.239        -8.338           0.099
CA.931MG.069                              -8.251        -8.313           0.061

FE(OH)3        Fe(OH)3-crystalline         2.589         2.589           0.000
AL(OH)3(AM)                               10.637        10.741          -0.105
MAGNESITE      MgCO3                      -8.418        -8.240          -0.178

CA.896MG.104                              -8.258        -7.958          -0.300
CA.873MG.127                              -8.262        -7.843          -0.419
a-CU(FEO2)2    alpha-Cu(FeO2)2            10.252        10.842          -0.590

CERUSSITE      PbCO3                     -13.930       -13.130          -0.800
CA.821MG.179                              -8.271        -7.459          -0.812
CA.808MG.192                              -8.273        -7.332          -0.941

CA.733MG.267                              -8.287        -7.288          -0.998
SIDERITE       FeCO3                     -11.576       -10.550          -1.026
CA.756MG.244                              -8.283        -7.198          -1.084

CA.764MG.236                              -8.281        -7.192          -1.089
BARITE         BaSO4                      -9.767        -8.519          -1.248
CO2(GAS)       ideal gas                  -2.908        -1.610          -1.298

RHODOCHROSIT   MnCO3                     -11.745       -10.410          -1.335
WITHERITE      alpha-BaCO3               -11.358       -10.020          -1.338
ALSTONITE      BaCa(CO3)2                -19.597       -17.988          -1.609

CR(OH)3        CR(OH)3                    10.411        12.020          -1.609
GYPSUM         CaSO4*2H2O                 -6.649        -4.759          -1.890
PARAMONTROSE   V2O4                       17.795        19.933          -2.137

FE(OH)3(AM)                                2.589         4.891          -2.302
ZNCO3*H2O                                -12.633       -10.260          -2.373
SMITHSONITE    ZnCO3                     -12.633       -10.000          -2.633

DUTTONITE      VO(OH)2                     8.897        11.533          -2.636
NH3(GAS)       ammonia, ideal gas       -115.238      -112.429          -2.809
URANINITE      UO2                        -5.379        -1.265          -4.114

CHALCOCITE     CuS                       -39.953       -34.619          -5.334

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TABLE C-5 PHREEQE CALCULATIONS, MW 2017 1Q87

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TOTAL CONCENTRATION OF AQUEOUS COMPONENTS     *******************************

                   TOTAL          TOTAL          TOTAL
COMPONENTS        MOLALITY     LOG MOLALITY      MG/KG
-------------------------------------------------------------


AL               4.5620E-06       -5.3408      1.2296E-01
BA               1.0202E-06       -5.9913      1.3995E-01
HCO3             5.7052E-03       -2.2437      3.4774E+02

CA               3.1460E-03       -2.5022      1.2596E+02
CL               3.1050E-04       -3.5079      1.0996E+01
CR               7.1211E-07       -6.1475      3.6987E-02

CU               3.9374E-07       -6.4048      2.4991E-02
F                3.2658E-05       -4.4860      6.1978E-01
FE               1.5819E-06       -5.8008      8.8248E-02

K                8.4456E-05       -4.0734      3.2989E+00
MG               3.3753E-03       -2.4717      8.1971E+01
MN               8.3792E-07       -6.0768      4.5984E-02

NO3              6.4558E-05       -4.1901      3.9986E+00
NA               1.5670E-03       -2.8049      3.5987E+01
NI               6.8181E-07       -6.1663      3.9986E-02

PB               2.4150E-08       -7.6171      4.9983E-03
SO4              4.8129E-03       -2.3176      4.6184E+02
U                2.3123E-07       -6.6360      5.4981E-02

V                4.7142E-06       -5.3266      2.3992E-01
ZN               3.9802E-07       -6.4001      2.5991E-02

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DESCRIPTION OF SOLUTION        *************************************************

pH                                      7.000
EH (mV)                                65.913
PE                                      1.114

ACTIVITY OF H2O                         1.000
IONIC STRENGTH (M)                      0.021
TEMPERATURE (C)                        25.000

CATION CONC.(EQ/KG H2O)                 1.218E-02
ANION CONC.(EQ/KG H2O)                 -1.218E-02
CHARGE BALANCE           (%)            1.025E-08

TOTAL ALKALINITY (EQ/KG H2O)            4.798E-03

TDS (MG/KG)                             1.073E+03
DENSITY                                 1.001

ITERATIONS                             22

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DISTRIBUTION OF AQUEOUS SPECIES      *****************************************

                                   LOG                     LOG                    LOG
SPECIES           MOLALITY      MOLALITY   ACTIVITY     ACTIVITY     GAMMA       GAMMA
----------------------------------------------------------------------------------------

AL(OH)2+          2.519E-07     -6.599     2.200E-07     -6.658     8.733E-01   -0.059
AL(OH)3           2.951E-06     -5.530     2.966E-06     -5.528     1.005E+00    0.002
AL(OH)4-          1.066E-06     -5.972     9.266E-07     -6.033     8.692E-01   -0.061

AL(SO4)2-         1.966E-11    -10.706     1.709E-11    -10.767     8.692E-01   -0.061
AL+3              1.384E-10     -9.859     4.733E-11    -10.325     3.420E-01   -0.466
ALF+2             2.064E-08     -7.685     1.201E-08     -7.921     5.817E-01   -0.235

ALF2+             1.873E-07     -6.728     1.636E-07     -6.786     8.733E-01   -0.059
ALF3              7.513E-08     -7.124     7.550E-08     -7.122     1.005E+00    0.002
ALF4-             1.079E-09     -8.967     9.379E-10     -9.028     8.692E-01   -0.061

ALOH+2            8.326E-09     -8.080     4.843E-09     -8.315     5.817E-01   -0.235
ALSO4+            1.188E-10     -9.925     1.033E-10     -9.986     8.692E-01   -0.061
BA+2              8.004E-07     -6.097     4.618E-07     -6.336     5.769E-01   -0.239

BAOH+             8.807E-12    -11.055     7.675E-12    -11.115     8.715E-01   -0.060
BASO4             2.197E-07     -6.658     2.208E-07     -6.656     1.005E+00    0.002
CA+2              2.457E-03     -2.610     1.429E-03     -2.845     5.815E-01   -0.235

CACO3             4.622E-06     -5.335     4.644E-06     -5.333     1.005E+00    0.002
CAF+              3.539E-07     -6.451     3.084E-07     -6.511     8.715E-01   -0.060
CAHCO3+           8.077E-05     -4.093     7.075E-05     -4.150     8.760E-01   -0.058

CAOH+             4.116E-09     -8.386     3.605E-09     -8.443     8.760E-01   -0.058
CASO4             6.034E-04     -3.219     6.063E-04     -3.217     1.005E+00    0.002
CL-               3.102E-04     -3.508     2.682E-04     -3.571     8.648E-01   -0.063

CO2(AQ)           9.229E-04     -3.035     9.273E-04     -3.033     1.005E+00    0.002
CO3-2             3.226E-06     -5.491     1.876E-06     -5.727     5.817E-01   -0.235
CR(OH)+2          3.762E-08     -7.425     2.137E-08     -7.670     5.682E-01   -0.246

CR(OH)2+          6.744E-07     -6.171     5.855E-07     -6.232     8.682E-01   -0.061
CR+2              3.303E-19    -18.481     1.877E-19    -18.727     5.682E-01   -0.246
CR+3              5.950E-11    -10.225     2.035E-11    -10.691     3.420E-01   -0.466

CRCL2+            1.301E-18    -17.886     1.129E-18    -17.947     8.682E-01   -0.061
CRCL2+2           3.822E-14    -13.418     2.172E-14    -13.663     5.682E-01   -0.246
CRO2-             2.260E-11    -10.646     1.962E-11    -10.707     8.682E-01   -0.061

CRO4-2            1.735E-27    -26.761     9.856E-28    -27.006     5.682E-01   -0.246
CU(CO3)2-2        5.103E-10     -9.292     2.900E-10     -9.538     5.682E-01   -0.246
CU(OH)2           1.177E-08     -7.929     1.182E-08     -7.927     1.005E+00    0.002

CU(OH)3-          8.205E-15    -14.086     7.124E-15    -14.147     8.682E-01   -0.061
CU(OH)4-2         2.502E-20    -19.602     1.421E-20    -19.847     5.682E-01   -0.246
CU+               2.629E-07     -6.580     2.283E-07     -6.642     8.682E-01   -0.061

CU+2              9.613E-09     -8.017     5.660E-09     -8.247     5.887E-01   -0.230
CU2(OH)2+2        2.466E-13    -12.608     1.401E-13    -12.853     5.682E-01   -0.246
CUCL+             4.706E-12    -11.327     4.086E-12    -11.389     8.682E-01   -0.061

CUCL2             5.858E-16    -15.232     5.886E-16    -15.230     1.005E+00    0.002
CUCL2-            5.982E-09     -8.223     5.194E-09     -8.285     8.682E-01   -0.061
CUCL3-            6.453E-22    -21.190     5.602E-22    -21.252     8.682E-01   -0.061

CUCL3-2           3.886E-12    -11.410     2.208E-12    -11.656     5.682E-01   -0.246
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CUCO3          8.677E-08    -7.062   8.719E-08    -7.060   1.005E+00   0.002

CUF+           2.940E-12   -11.532   2.553E-12   -11.593   8.682E-01  -0.061
CUHCO3+        1.313E-08    -7.882   1.140E-08    -7.943   8.682E-01  -0.061
CUOH+          6.518E-10    -9.186   5.659E-10    -9.247   8.682E-01  -0.061

CUSO4          2.396E-09    -8.621   2.407E-09    -8.618   1.005E+00   0.002
E-             7.685E-02    -1.114   7.685E-02    -1.114   1.000E+00   0.000
F-             2.868E-05    -4.542   2.479E-05    -4.606   8.642E-01  -0.063

FE(OH)2        4.679E-12   -11.330   4.702E-12   -11.328   1.005E+00   0.002
FE(OH)2+       7.421E-12   -11.130   6.481E-12   -11.188   8.733E-01  -0.059
FE(OH)3        2.873E-07    -6.542   2.887E-07    -6.540   1.005E+00   0.002

FE(OH)3-       3.690E-18   -17.433   3.216E-18   -17.493   8.715E-01  -0.060
FE(OH)4-       1.091E-12   -11.962   9.532E-13   -12.021   8.733E-01  -0.059
FE(SO4)2-      4.991E-19   -18.302   4.333E-19   -18.363   8.682E-01  -0.061

FE+2           5.309E-07    -6.275   3.125E-07    -6.505   5.887E-01  -0.230
FE+3           1.134E-18   -17.945   3.879E-19   -18.411   3.420E-01  -0.466
FE2(OH)2+4     1.551E-25   -24.810   1.616E-26   -25.792   1.042E-01  -0.982

FECL+2         5.330E-21   -20.273   3.075E-21   -20.512   5.769E-01  -0.239
FECL2+         4.227E-24   -23.374   3.684E-24   -23.434   8.715E-01  -0.060
FECL3          9.834E-29   -28.007   9.882E-29   -28.005   1.005E+00   0.002

FEF+2          2.800E-17   -16.553   1.598E-17   -16.796   5.707E-01  -0.244
FEF2+          1.814E-17   -16.741   1.577E-17   -16.802   8.692E-01  -0.061
FEF3           5.753E-19   -18.240   5.781E-19   -18.238   1.005E+00   0.002

FEOH+          6.485E-07    -6.188   5.652E-07    -6.248   8.715E-01  -0.060
FEOH+2         4.248E-14   -13.372   2.450E-14   -13.611   5.769E-01  -0.239
FESO4          1.152E-07    -6.938   1.158E-07    -6.936   1.005E+00   0.002

FESO4+         7.546E-18   -17.122   6.577E-18   -17.182   8.715E-01  -0.060
H+             1.126E-07    -6.948   9.997E-08    -7.000   8.876E-01  -0.052

H2VO4-         4.163E-06    -5.381   3.614E-06    -5.442   8.682E-01  -0.061
H3VO4          2.334E-09    -8.632   2.346E-09    -8.630   1.005E+00   0.002

HCO3-          4.600E-03    -2.337   4.018E-03    -2.396   8.733E-01  -0.059
HCRO4-         3.613E-28   -27.442   3.137E-28   -27.503   8.682E-01  -0.061

HSO4-          2.326E-08    -7.633   2.021E-08    -7.694   8.692E-01  -0.061
HVO4-2         5.484E-07    -6.261   3.116E-07    -6.506   5.682E-01  -0.246

K+             8.322E-05    -4.080   7.198E-05    -4.143   8.648E-01  -0.063
KCL            1.589E-08    -7.799   1.597E-08    -7.797   1.005E+00   0.002
KOH            6.184E-12   -11.209   6.214E-12   -11.207   1.005E+00   0.002

KSO4-          1.216E-06    -5.915   1.062E-06    -5.974   8.733E-01  -0.059
MG+2           2.698E-03    -2.569   1.588E-03    -2.799   5.885E-01  -0.230
MGCO3          2.843E-06    -5.546   2.857E-06    -5.544   1.005E+00   0.002

MGF+           2.992E-06    -5.524   2.600E-06    -5.585   8.692E-01  -0.061
MGHCO3+        8.647E-05    -4.063   7.494E-05    -4.125   8.667E-01  -0.062
MGOH+          2.905E-08    -7.537   2.551E-08    -7.593   8.781E-01  -0.056

MGSO4          5.854E-04    -3.233   5.882E-04    -3.230   1.005E+00   0.002
MN(OH)2        2.432E-15   -14.614   2.443E-15   -14.612   1.005E+00   0.002
MN(OH)3-       7.042E-21   -20.152   6.137E-21   -20.212   8.715E-01  -0.060

MN(OH)4-2      3.415E-27   -26.467   1.941E-27   -26.712   5.682E-01  -0.246
MN+2           6.578E-07    -6.182   3.873E-07    -6.412   5.887E-01  -0.230
MN2(OH)+3      1.474E-16   -15.832   4.131E-17   -16.384   2.803E-01  -0.552
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MN2(OH)3+      2.175E-16   -15.663   1.888E-16   -15.724   8.682E-01   -0.061
MNCL+          4.823E-10    -9.317   4.203E-10    -9.376   8.715E-01   -0.060
MNCL2          3.048E-14   -13.516   3.063E-14   -13.514   1.005E+00    0.002

MNCL3-         4.249E-18   -17.372   3.703E-18   -17.431   8.715E-01   -0.060
MNF+           7.798E-11   -10.108   6.796E-11   -10.168   8.715E-01   -0.060
MNHCO3+        3.332E-08    -7.477   2.904E-08    -7.537   8.715E-01   -0.060

MNOH+          1.142E-10    -9.942   9.954E-11   -10.002   8.715E-01   -0.060
MNSO4          1.461E-07    -6.835   1.468E-07    -6.833   1.005E+00    0.002
NA+            1.547E-03    -2.810   1.346E-03    -2.871   8.699E-01   -0.061

NA2CO3         2.796E-12   -11.553   2.810E-12   -11.551   1.005E+00    0.002
NA2SO4         1.221E-07    -6.913   1.227E-07    -6.911   1.005E+00    0.002
NACL           3.009E-07    -6.522   3.024E-07    -6.519   1.005E+00    0.002

NACO3-         5.382E-08    -7.269   4.700E-08    -7.328   8.733E-01   -0.059
NAHCO3         3.033E-06    -5.518   3.048E-06    -5.516   1.005E+00    0.002
NAOH           2.342E-11   -10.630   2.354E-11   -10.628   1.005E+00    0.002

NASO4-         1.609E-05    -4.793   1.405E-05    -4.852   8.733E-01   -0.059
NH3(AQ)        3.030E-07    -6.519   3.045E-07    -6.516   1.005E+00    0.002
NH4+           6.259E-05    -4.204   5.375E-05    -4.270   8.589E-01   -0.066

NH4SO4-        1.667E-06    -5.778   1.453E-06    -5.838   8.715E-01   -0.060
NI(OH)2        2.472E-12   -11.607   2.484E-12   -11.605   1.005E+00    0.002
NI(OH)3-       2.861E-16   -15.543   2.484E-16   -15.605   8.682E-01   -0.061

NI(SO4)2-2     1.987E-11   -10.702   1.129E-11   -10.947   5.682E-01   -0.246
NI+2           4.219E-07    -6.375   2.484E-07    -6.605   5.887E-01   -0.230
NICL+          1.928E-10    -9.715   1.674E-10    -9.776   8.682E-01   -0.061

NICL2          1.622E-13   -12.790   1.630E-13   -12.788   1.005E+00    0.002
NIF+           1.415E-10    -9.849   1.229E-10    -9.911   8.682E-01   -0.061
NIHCO3+        1.587E-07    -6.799   1.378E-07    -6.861   8.682E-01   -0.061

NIOH+          3.949E-10    -9.403   3.429E-10    -9.465   8.682E-01   -0.061
NISO4          1.004E-07    -6.998   1.009E-07    -6.996   1.005E+00    0.002
NO3-           4.302E-45   -44.366   3.707E-45   -44.431   8.616E-01   -0.065

OH-            1.162E-07    -6.935   1.005E-07    -6.998   8.642E-01   -0.063
PB(OH)2        2.660E-12   -11.575   2.672E-12   -11.573   1.005E+00    0.002
PB(OH)3-       3.534E-16   -15.452   3.068E-16   -15.513   8.682E-01   -0.061

PB(OH)4-2      1.237E-20   -19.908   7.028E-21   -20.153   5.682E-01   -0.246
PB(SO4)2-2     7.942E-11   -10.100   4.513E-11   -10.346   5.682E-01   -0.246
PB+2           6.173E-09    -8.209   3.523E-09    -8.453   5.707E-01   -0.244

PB2OH+3        1.933E-16   -15.714   5.418E-17   -16.266   2.803E-01   -0.552
PB3(OH)4+2     1.014E-21   -20.994   5.764E-22   -21.239   5.682E-01   -0.246
PBCL+          4.333E-11   -10.363   3.762E-11   -10.425   8.682E-01   -0.061

PBCL2          1.592E-14   -13.798   1.600E-14   -13.796   1.005E+00    0.002
PBCL3-         3.925E-18   -17.406   3.408E-18   -17.467   8.682E-01   -0.061
PBCL4-2        7.701E-22   -21.113   4.376E-22   -21.359   5.682E-01   -0.246

PBF+           1.789E-12   -11.747   1.553E-12   -11.809   8.682E-01   -0.061
PBF2           7.822E-16   -15.107   7.860E-16   -15.105   1.005E+00    0.002
PBF3-          1.626E-19   -18.789   1.412E-19   -18.850   8.682E-01   -0.061

PBF4-2         2.947E-24   -23.531   1.675E-24   -23.776   5.682E-01   -0.246
PBHCO3+        1.295E-08    -7.888   1.124E-08    -7.949   8.682E-01   -0.061
PBOH+          7.912E-10    -9.102   6.869E-10    -9.163   8.682E-01   -0.061

PBSO4          4.108E-09    -8.386   4.128E-09    -8.384   1.005E+00    0.002
SO4-2          3.604E-03    -2.443   2.083E-03    -2.681   5.780E-01   -0.238
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U(OH)4          5.513E-14    -13.259    5.540E-14    -13.257    1.005E+00    0.002

U(OH)5-         1.568E-11    -10.805    1.363E-11    -10.866    8.692E-01   -0.061
U+4             1.143E-32    -31.942    1.912E-33    -32.718    1.673E-01   -0.777
UF+3            5.403E-23    -22.267    1.781E-23    -22.749    3.296E-01   -0.482

UF2+2           1.351E-22    -21.869    8.103E-23    -22.091    6.000E-01   -0.222
UF3+            3.984E-23    -22.400    3.472E-23    -22.459    8.715E-01   -0.060
UF4             1.480E-23    -22.830    1.488E-23    -22.828    1.005E+00    0.002

UF5-            1.677E-26    -25.776    1.461E-26    -25.835    8.715E-01   -0.060
UF6-2           1.295E-28    -27.888    7.771E-29    -28.110    6.000E-01   -0.222
UO2(CO3)2-2     2.054E-07     -6.687    1.221E-07     -6.913    5.944E-01   -0.226

UO2(CO3)3-4     2.580E-08     -7.588    4.315E-09     -8.365    1.673E-01   -0.777
UO2(OH)2        1.012E-12    -11.995    1.017E-12    -11.993    1.005E+00    0.002
UO2(OH)3-       8.040E-17    -16.095    6.981E-17    -16.156    8.682E-01   -0.061

UO2(OH)4-2      8.179E-24    -23.087    4.647E-24    -23.333    5.682E-01   -0.246
UO2(SO4)2-2     3.325E-15    -14.478    1.918E-15    -14.717    5.769E-01   -0.239
UO2+            2.705E-14    -13.568    2.351E-14    -13.629    8.692E-01   -0.061

UO2+2           8.554E-13    -12.068    5.075E-13    -12.295    5.933E-01   -0.227
UO2CL+          1.396E-17    -16.855    1.214E-17    -16.916    8.692E-01   -0.061
UO2F+           6.685E-14    -13.175    5.826E-14    -13.235    8.715E-01   -0.060

UO2F2           3.366E-14    -13.473    3.383E-14    -13.471    1.005E+00    0.002
UO2F3-          4.054E-16    -15.392    3.533E-16    -15.452    8.715E-01   -0.060
UO2F4-2         3.064E-19    -18.514    1.768E-19    -18.753    5.769E-01   -0.239

UO2OH+          2.213E-12    -11.655    1.929E-12    -11.715    8.715E-01   -0.060
UO2SO4          3.028E-14    -13.519    3.042E-14    -13.517    1.005E+00    0.002
UOH+3           3.444E-26    -25.463    1.178E-26    -25.929    3.420E-01   -0.466

V(OH)2+         1.870E-12    -11.728    1.623E-12    -11.790    8.682E-01   -0.061
V(OH)3          1.218E-10     -9.914    1.224E-10     -9.912    1.005E+00    0.002
V+3             4.026E-20    -19.395    1.083E-20    -19.966    2.689E-01   -0.570

VO+2            5.016E-11    -10.300    2.850E-11    -10.545    5.682E-01   -0.246
VO4-3           5.974E-13    -12.224    1.675E-13    -12.776    2.803E-01   -0.552
VOH2+           1.112E-15    -14.954    6.317E-16    -15.199    5.682E-01   -0.246

VOOH+           7.096E-10     -9.149    6.161E-10     -9.210    8.682E-01   -0.061
ZN(OH)2         1.783E-10     -9.749    1.791E-10     -9.747    1.005E+00    0.002
ZN(OH)3-        6.525E-15    -14.185    5.665E-15    -14.247    8.682E-01   -0.061

ZN(OH)4-2       1.580E-20    -19.801    8.978E-21    -20.047    5.682E-01   -0.246
ZN(SO4)2-2      2.071E-09     -8.684    1.177E-09     -8.929    5.682E-01   -0.246
ZN+2            2.417E-07     -6.617    1.423E-07     -6.847    5.887E-01   -0.230

ZNCL+           1.183E-10     -9.927    1.027E-10     -9.988    8.682E-01   -0.061
ZNCL2           2.872E-14    -13.542    2.886E-14    -13.540    1.005E+00    0.002
ZNCL3-          1.000E-17    -17.000    8.686E-18    -17.061    8.682E-01   -0.061

ZNCL4-2         2.055E-21    -20.687    1.168E-21    -20.933    5.682E-01   -0.246
ZNF+            5.739E-11    -10.241    4.983E-11    -10.303    8.682E-01   -0.061
ZNHCO3+         8.291E-08     -7.081    7.198E-08     -7.143    8.682E-01   -0.061

ZNOH+           1.797E-09     -8.745    1.560E-09     -8.807    8.682E-01   -0.061
ZNOHCL          1.258E-11    -10.900    1.264E-11    -10.898    1.005E+00    0.002
ZNSO4           6.917E-08     -7.160    6.950E-08     -7.158    1.005E+00    0.002

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STABILITY OF SOLID AND GAS PHASES         ****************************************

PHASE                                      LOG IAP        LOG KT       LOG IAP/KT
-----                                      -------        ------       ----------

TREVORITE      alpha-Ni(FeO2)2             38.614         35.990          2.624
GIBBSITE       gamma-Al(OH)3               10.675          8.175          2.500
GOETHITE       alpha-FeOOH                  2.589          0.113          2.476

BOEHMITE       gamma-AlOOH                 10.675          8.402          2.273
FRANKLINITE    Zn(FeO2)2                   38.372         37.594          0.778
DAWSONITE      NaAlCO3(OH)2                -4.923         -5.173          0.250

a-CU(FEO2)2    alpha-Cu(FeO2)2             10.931         10.842          0.089
FE(OH)3        Fe(OH)3-crystalline          2.589          2.589          0.000
CA.97MG.03CO                               -8.570         -8.540         -0.031

AL(OH)3(AM)                                10.675         10.741         -0.066
DOLOMITE       CaMg(CO3)2                 -17.098        -17.020         -0.078
CALCITE        CaCO3                       -8.572         -8.481         -0.090

CA.98MG.02CO                               -8.571         -8.469         -0.102
ARAGONITE      CaCO3                       -8.572         -8.338         -0.234
CA.931MG.069                               -8.569         -8.313         -0.256

MAGNESITE      MgCO3                       -8.526         -8.240         -0.286
BARITE         BaSO4                       -9.017         -8.519         -0.498
CA.896MG.104                               -8.567         -7.958         -0.609

CA.873MG.127                               -8.566         -7.843         -0.723
GYPSUM         CaSO4*2H2O                  -5.527         -4.759         -0.768
CERUSSITE      PbCO3                      -14.180        -13.130         -1.050

CA.821MG.179                               -8.564         -7.459         -1.104
CA.808MG.192                               -8.563         -7.332         -1.231
CA.733MG.267                               -8.560         -7.288         -1.271

CA.756MG.244                               -8.561         -7.198         -1.362
CA.764MG.236                               -8.561         -7.192         -1.369
CO2(GAS)       ideal gas                   -3.033         -1.610         -1.423

PARAMONTROSE   V2O4                        18.298         19.933         -1.635
SIDERITE       FeCO3                      -12.232        -10.550         -1.682
CR(OH)3        CR(OH)3                     10.309         12.020         -1.711

RHODOCHROSIT   MnCO3                      -12.139        -10.410         -1.729
WITHERITE      alpha-BaCO3                -12.062        -10.020         -2.042
FE(OH)3(AM)                                 2.589          4.891         -2.302

ZNCO3*H2O                                 -12.574        -10.260         -2.314
DUTTONITE      VO(OH)2                      9.149         11.533         -2.384
SMITHSONITE    ZnCO3                      -12.573        -10.000         -2.573

ALSTONITE      BaCa(CO3)2                 -20.634        -17.988         -2.646
URANINITE      UO2                         -4.718         -1.265         -3.453
NH3(GAS)       ammonia, ideal gas        -116.346       -112.429         -3.917

CHALCOCITE     CuS                        -42.192        -34.619         -7.573

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TABLE C-6 PHREEQE CALCULATIONS, LY3605 1Q87

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TOTAL CONCENTRATION OF AQUEOUS COMPONENTS     ********************************

                    TOTAL         TOTAL          TOTAL
COMPONENTS         MOLALITY    LOG MOLALITY      MG/KG
----------------------------------------------------------

AL                4.6773E-06     -5.3300      1.2586E-01
BA                5.1053E-07     -6.2920      6.9922E-02
HCO3              1.8269E-02     -1.7383      1.1117E+03

CA                3.3611E-03     -2.4735      1.3435E+02
CL                2.3477E-03     -2.6294      8.3008E+01
CR                9.0535E-07     -6.0432      4.6948E-02

CU                3.1526E-07     -6.5013      1.9978E-02
F                 5.7992E-05     -4.2366      1.0988E+00
FE                3.2238E-06     -5.4916      1.7955E-01

K                 1.9980E-04     -3.6994      7.7913E+00
MG                1.0794E-03     -2.9668      2.6171E+01
MN                4.5578E-05     -4.3412      2.4972E+00

NO3               7.2690E-05     -4.1385      4.4950E+00
NA                2.4528E-02     -1.6103      5.6237E+02
NI                1.5695E-06     -5.8042      9.1898E-02

PB                2.7071E-07     -6.5675      5.5938E-02
SO4               7.9763E-03     -2.0982      7.6415E+02
U                 8.2053E-07     -6.0859      1.9478E-01

V                 1.6121E-06     -5.7926      8.1909E-02
ZN                7.3545E-07     -6.1334      4.7947E-02

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DESCRIPTION OF SOLUTION       ***********************************************

pH                                     7.000
EH  (mV)                              48.157
PE                                     0.814

ACTIVITY OF H2O                        0.999
IONIC STRENGTN (M)                     0.041
TEMPERATURE (C)                       25.000

CATION CONC.(EQ/KG H2O)                3.081E-02
ANION CONC.(EQ/KG H2O)                -3.081E-02
CHARGE BALANCE          (%)            1.192E-09

TOTAL ALKALINITY (EQ/KG H2O)           1.543E-02

TDS (MG/KG)                            2.699E+03
DENSITY                                1.003

ITERATIONS                            24

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DISTRIBUTION OF AQUEOUS SPECIES      ******************************************

                                    LOG                          LOG                       LOG
SPECIES           MOLALITY       MOLALITY     ACTIVITY       ACTIVITY       GAMMA        GAMMA
------------------------------------------------------------------------------------------------

AL(OH)2+          2.257E-07      -6.646      1.896E-07      -6.722      8.399E-01    -0.076
AL(OH)3           2.530E-06      -5.597      2.554E-06      -5.593      1.009E+00     0.004
AL(OH)4-          9.568E-07      -6.019      7.972E-07      -6.098      8.332E-01    -0.079

AL(SO4)2-         4.236E-11     -10.373      3.529E-11     -10.452      8.332E-01    -0.079
AL+3              1.554E-10      -9.808      4.087E-11     -10.389      2.629E-01    -0.580
ALF+2             3.729E-08      -7.428      1.855E-08      -7.732      4.976E-01    -0.303

ALF2+             5.386E-07      -6.269      4.523E-07      -6.345      8.399E-01    -0.076
ALF3              3.702E-07      -6.432      3.737E-07      -6.427      1.009E+00     0.004
ALF4-             9.973E-09      -8.001      8.309E-09      -8.080      8.332E-01    -0.079

ALOH+2            8.396E-09      -8.076      4.178E-09      -8.379      4.976E-01    -0.303
ALSO4+            1.655E-10      -9.781      1.379E-10      -9.860      8.332E-01    -0.079
BA+2              3.755E-07      -6.425      1.843E-07      -6.735      4.907E-01    -0.309

BAOH+             3.656E-12     -11.437      3.060E-12     -11.514      8.370E-01    -0.077
BASO4             1.350E-07      -6.870      1.363E-07      -6.866      1.009E+00     0.004
CA+2              2.366E-03      -2.626      1.179E-03      -2.928      4.983E-01    -0.302

CACO3             1.185E-05      -4.926      1.196E-05      -4.922      1.009E+00     0.004
CAF+              5.444E-07      -6.264      4.556E-07      -6.341      8.370E-01    -0.077
CAHCO3+           2.160E-04      -3.666      1.823E-04      -3.739      8.441E-01    -0.074

CAOH+             3.522E-09      -8.453      2.973E-09      -8.527      8.441E-01    -0.074
CASO4             7.668E-04      -3.115      7.739E-04      -3.111      1.009E+00     0.004
CL-               2.315E-03      -2.635      1.913E-03      -2.718      8.262E-01    -0.083

CO2(AQ)           2.871E-03      -2.542      2.898E-03      -2.538      1.009E+00     0.004
CO3-2             1.177E-05      -4.929      5.857E-06      -5.232      4.976E-01    -0.303
CR(OH)+2          5.383E-08      -7.269      2.591E-08      -7.587      4.812E-01    -0.318

CR(OH)2+          8.514E-07      -6.070      7.091E-07      -6.149      8.329E-01    -0.079
CR+2              9.445E-19     -18.025      4.545E-19     -18.342      4.812E-01    -0.318
CR+3              9.391E-11     -10.027      2.469E-11     -10.607      2.629E-01    -0.580

CRCL2+            8.364E-17     -16.078      6.967E-17     -16.157      8.329E-01    -0.079
CRCL2+2           3.904E-13     -12.408      1.879E-13     -12.726      4.812E-01    -0.318
CRO2-             2.851E-11     -10.545      2.375E-11     -10.624      8.329E-01    -0.079

CRO4-2            3.110E-28     -27.507      1.497E-28     -27.825      4.812E-01    -0.318
CU(CO3)2-2        1.211E-09      -8.917      5.826E-10      -9.235      4.812E-01    -0.318
CU(OH)2           2.411E-09      -8.618      2.434E-09      -8.614      1.009E+00     0.004

CU(OH)3-          1.759E-15     -14.755      1.465E-15     -14.834      8.329E-01    -0.079
CU(OH)4-2         6.069E-21     -20.217      2.921E-21     -20.535      4.812E-01    -0.318
CU+               1.128E-07      -6.948      9.395E-08      -7.027      8.329E-01    -0.079

CU+2              2.299E-09      -8.638      1.167E-09      -8.933      5.076E-01    -0.295
CU2(OH)2+2        1.236E-14     -13.908      5.948E-15     -14.226      4.812E-01    -0.318
CUCL+             7.214E-12     -11.142      6.009E-12     -11.221      8.329E-01    -0.079

CUCL2             6.115E-15     -14.214      6.173E-15     -14.210      1.009E+00     0.004
CUCL2-            1.305E-07      -6.884      1.087E-07      -6.964      8.329E-01    -0.079
CUCL3-            5.030E-20     -19.298      4.190E-20     -19.378      8.329E-01    -0.079

CUCL3-2           6.850E-10      -9.164      3.296E-10      -9.482      4.812E-01    -0.318
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CUCO3          5.560E-08    -7.255    5.612E-08    -7.251    1.009E+00    0.004

CUF+           1.131E-12   -11.946    9.421E-13   -12.026    8.329E-01   -0.079
CUHCO3+        8.809E-09    -8.055    7.337E-09    -8.134    8.329E-01   -0.079
CUOH+          1.400E-10    -9.854    1.166E-10    -9.933    8.329E-01   -0.079

CUSO4          7.607E-10    -9.119    7.678E-10    -9.115    1.009E+00    0.004
E-             1.534E-01    -0.814    1.534E-01    -0.814    1.000E+00    0.000
F-             5.377E-05    -4.269    4.437E-05    -4.353    8.250E-01   -0.084

FE(OH)2        9.306E-12   -11.031    9.394E-12   -11.027    1.009E+00    0.004
FE(OH)2+       7.723E-12   -11.112    6.486E-12   -11.188    8.399E-01   -0.076
FE(OH)3        2.860E-07    -6.544    2.887E-07    -6.540    1.009E+00    0.004

FE(OH)3-       7.671E-18   -17.115    6.420E-18   -17.192    8.370E-01   -0.077
FE(OH)4-       1.134E-12   -11.945    9.524E-13   -12.021    8.399E-01   -0.076
FE(SO4)2-      1.248E-18   -17.904    1.039E-18   -17.983    8.329E-01   -0.079

FE+2           1.232E-06    -5.909    6.255E-07    -6.204    5.076E-01   -0.295
FE+3           1.479E-18   -17.830    3.889E-19   -18.410    2.629E-01   -0.580
FE2(OH)2+4     3.024E-25   -24.519    1.622E-26   -25.790    5.364E-02   -1.271

FECL+2         4.480E-20   -19.349    2.198E-20   -19.658    4.907E-01   -0.309
FECL2+         2.244E-22   -21.649    1.878E-22   -21.726    8.370E-01   -0.077
FECL3          3.560E-26   -25.449    3.593E-26   -25.444    1.009E+00    0.004

FEF+2          5.950E-17   -16.226    2.867E-17   -16.543    4.819E-01   -0.317
FEF2+          6.078E-17   -16.216    5.064E-17   -16.296    8.332E-01   -0.079
FEF3           3.292E-18   -17.483    3.323E-18   -17.478    1.009E+00    0.004

FEOH+          1.350E-06    -5.870    1.130E-06    -5.947    8.370E-01   -0.077
FEOH+2         5.002E-14   -13.301    2.455E-14   -13.610    4.907E-01   -0.309
FESO4          3.551E-07    -6.450    3.584E-07    -6.446    1.009E+00    0.004

FESO4+         1.219E-17   -16.914    1.020E-17   -16.991    8.370E-01   -0.077
H+             1.160E-07    -6.936    1.000E-07    -7.000    8.620E-01   -0.064

H2VO4-         1.402E-06    -5.853    1.167E-06    -5.933    8.329E-01   -0.079
H3VO4          7.508E-10    -9.124    7.578E-10    -9.120    1.009E+00    0.004

HCO3-          1.494E-02    -1.826    1.254E-02    -1.902    8.399E-01   -0.076
HCRO4-         5.721E-29   -28.243    4.765E-29   -28.322    8.329E-01   -0.079

HSO4-          3.753E-08    -7.426    3.127E-08    -7.505    8.332E-01   -0.079
HVO4-2         2.091E-07    -6.680    1.006E-07    -6.997    4.812E-01   -0.318

K+             1.952E-04    -3.710    1.612E-04    -3.793    8.262E-01   -0.083
KCL            2.528E-07    -6.597    2.551E-07    -6.593    1.009E+00    0.004
KOH            1.378E-11   -10.861    1.391E-11   -10.857    1.009E+00    0.004

KSO4-          4.380E-06    -5.359    3.678E-06    -5.434    8.399E-01   -0.076
MG+2           7.800E-04    -3.108    3.968E-04    -3.401    5.087E-01   -0.294
MGCO3          2.208E-06    -5.656    2.228E-06    -5.652    1.009E+00    0.004

MGF+           1.396E-06    -5.855    1.163E-06    -5.934    8.332E-01   -0.079
MGHCO3+        7.052E-05    -4.152    5.848E-05    -4.233    8.292E-01   -0.081
MGOH+          7.517E-09    -8.124    6.370E-09    -8.196    8.474E-01   -0.072

MGSO4          2.252E-04    -3.647    2.274E-04    -3.643    1.009E+00    0.004
MN(OH)2        1.001E-13   -13.000    1.010E-13   -12.995    1.009E+00    0.004
MN(OH)3-       3.030E-19   -18.519    2.536E-19   -18.596    8.370E-01   -0.077

MN(OH)4-2      1.665E-25   -24.779    8.012E-26   -25.096    4.812E-01   -0.318
MN+2           3.161E-05    -4.500    1.604E-05    -4.795    5.076E-01   -0.295

MN2(OH)+3      3.672E-13   -12.435    7.083E-14   -13.150    1.929E-01   -0.715
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MN2(OH)3+         3.880E-13   -12.411   3.232E-13   -12.491   8.329E-01  -0.079
MNCL+             1.484E-07    -6.829   1.242E-07    -6.906   8.370E-01  -0.077

MNCL2             6.392E-11   -10.194   6.452E-11   -10.190   1.009E+00   0.004
MNCL3-            6.648E-14   -13.177   5.565E-14   -13.255   8.370E-01  -0.077
MNF+              6.021E-09    -8.220   5.039E-09    -8.298   8.370E-01  -0.077

MNHCO3+           4.488E-06    -5.348   3.756E-06    -5.425   8.370E-01  -0.077
MNOH+             4.923E-09    -8.308   4.120E-09    -8.385   8.370E-01  -0.077
MNSO4             9.320E-06    -5.031   9.408E-06    -5.027   1.009E+00   0.004

NA+               2.389E-02    -1.622   1.995E-02    -1.700   8.350E-01  -0.078
NA2CO3            1.908E-09    -8.719   1.926E-09    -8.715   1.009E+00   0.004
NA2SO4            4.129E-05    -4.384   4.168E-05    -4.380   1.009E+00   0.004

NACL              3.166E-05    -4.499   3.196E-05    -4.495   1.009E+00   0.004
NACO3-            2.589E-06    -5.587   2.174E-06    -5.663   8.399E-01  -0.076
NAHCO3            1.397E-04    -3.855   1.410E-04    -3.851   1.009E+00   0.004

NAOH              3.453E-10    -9.462   3.485E-10    -9.458   1.009E+00   0.004
NASO4-            3.836E-04    -3.416   3.221E-04    -3.492   8.399E-01  -0.076
NH3(AQ)           3.184E-07    -6.497   3.213E-07    -6.493   1.009E+00   0.004

NH4+              6.954E-05    -4.158   5.675E-05    -4.246   8.161E-01  -0.088
NH4SO4-           2.834E-06    -5.548   2.372E-06    -5.625   8.370E-01  -0.077
NI(OH)2           3.316E-12   -11.479   3.347E-12   -11.475   1.009E+00   0.004

NI(OH)3-          4.015E-16   -15.396   3.344E-16   -15.476   8.329E-01  -0.079
NI(SO4)2-2        7.576E-11   -10.121   3.646E-11   -10.438   4.812E-01  -0.318
NI+2              6.607E-07    -6.180   3.353E-07    -6.475   5.076E-01  -0.295

NICL+             1.935E-09    -8.713   1.611E-09    -8.793   8.329E-01  -0.079
NICL2             1.109E-11   -10.955   1.119E-11   -10.951   1.009E+00   0.004
NIF+              3.564E-10    -9.448   2.968E-10    -9.527   8.329E-01  -0.079

NIHCO3+           6.972E-07    -6.157   5.807E-07    -6.236   8.329E-01  -0.079
NIOH+             5.553E-10    -9.256   4.625E-10    -9.335   8.329E-01  -0.079
NISO4             2.087E-07    -6.680   2.107E-07    -6.676   1.009E+00   0.004

NO3-              1.884E-47   -46.725   1.546E-47   -46.811   8.207E-01  -0.086
OH-               1.217E-07    -6.915   1.004E-07    -6.998   8.250E-01  -0.084
PB(OH)2           1.252E-11   -10.903   1.263E-11   -10.898   1.009E+00   0.004

PB(OH)3-          1.740E-15   -14.759   1.449E-15   -14.839   8.329E-01  -0.079
PB(OH)4-2         6.893E-20   -19.162   3.317E-20   -19.479   4.812E-01  -0.318
PB(SO4)2-2        1.062E-09    -8.974   5.113E-10    -9.291   4.812E-01  -0.318

PB+2              3.462E-08    -7.461   1.669E-08    -7.778   4.819E-01  -0.317
PB2OH+3           6.295E-15   -14.201   1.214E-15   -14.916   1.929E-01  -0.715
PB3(OH)4+2        1.268E-19   -18.897   6.102E-20   -19.215   4.812E-01  -0.318

PBCL+             1.526E-09    -8.817   1.271E-09    -8.896   8.329E-01  -0.079
PBCL2             3.817E-12   -11.418   3.853E-12   -11.414   1.009E+00   0.004
PBCL3-            7.029E-15   -14.153   5.854E-15   -14.233   8.329E-01  -0.079

PBCL4-2           1.114E-17   -16.953   5.360E-18   -17.271   4.812E-01  -0.318
PBF+              1.581E-11   -10.801   1.316E-11   -10.881   8.329E-01  -0.079
PBF2              1.181E-14   -13.928   1.192E-14   -13.924   1.009E+00   0.004

PBF3-             4.601E-18   -17.337   3.833E-18   -17.417   8.329E-01  -0.079
PBF4-2            1.691E-22   -21.772   8.138E-23   -22.089   4.812E-01  -0.318
PBHCO3+           1.996E-07    -6.700   1.663E-07    -6.779   8.329E-01  -0.079

PBOH+             3.903E-09    -8.409   3.250E-09    -8.488   8.329E-01  -0.079
PBSO4             2.995E-08    -7.524   3.024E-08    -7.519   1.009E+00   0.004
SO4-2             6.542E-03    -2.184   3.222E-03    -2.492   4.926E-01  -0.308
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U(OH)4          5.143E-14   -13.289   5.192E-14   -13.285   1.009E+00    0.004
U(OH)5-         1.532E-11   -10.815   1.276E-11   -10.894   8.332E-01   -0.079
U+4             1.612E-32   -31.793   1.798E-33   -32.745   1.116E-01   -0.952

UF+3            1.208E-22   -21.918   2.997E-23   -22.523   2.481E-01   -0.605
UF2+2           4.664E-22   -21.331   2.441E-22   -21.612   5.234E-01   -0.281
UF3+            2.237E-22   -21.650   1.872E-22   -21.728   8.370E-01   -0.077

UF4             1.422E-22   -21.847   1.435E-22   -21.843   1.009E+00    0.004
UF5-            3.015E-25   -24.521   2.524E-25   -24.598   8.370E-01   -0.077
UF6-2           4.590E-27   -26.338   2.402E-27   -26.619   5.234E-01   -0.281

UO2(CO3)2-2     5.434E-07    -6.265   2.802E-07    -6.553   5.156E-01   -0.288
UO2(CO3)3-4     2.771E-07    -6.557   3.091E-08    -7.510   1.116E-01   -0.952
UO2(OH)2        2.369E-13   -12.625   2.391E-13   -12.621   1.009E+00    0.004

UO2(OH)3-       1.969E-17   -16.706   1.640E-17   -16.785   8.329E-01   -0.079
UO2(OH)4-2      2.266E-24   -23.645   1.091E-24   -23.962   4.812E-01   -0.318
UO2(SO4)2-2     2.202E-15   -14.657   1.081E-15   -14.966   4.907E-01   -0.309

UO2+            1.326E-14   -13.877   1.105E-14   -13.957   8.332E-01   -0.079
UO2+2           2.325E-13   -12.634   1.195E-13   -12.923   5.140E-01   -0.289
UO2CL+          2.446E-17   -16.611   2.038E-17   -16.691   8.332E-01   -0.079

UO2F+           2.934E-14   -13.533   2.456E-14   -13.610   8.370E-01   -0.077
UO2F2           2.528E-14   -13.597   2.552E-14   -13.593   1.009E+00    0.004
UO2F3-          5.699E-16   -15.244   4.770E-16   -15.322   8.370E-01   -0.077

UO2F4-2         8.704E-19   -18.060   4.271E-19   -18.369   4.907E-01   -0.309
UO2OH+          5.423E-13   -12.266   4.539E-13   -12.343   8.370E-01   -0.077
UO2SO4          1.098E-14   -13.959   1.108E-14   -13.955   1.009E+00    0.004

UOH+3           4.210E-26   -25.376   1.107E-26   -25.956   2.629E-01   -0.580
V(OH)2+         2.514E-12   -11.600   2.094E-12   -11.679   8.329E-01   -0.079
V(OH)3          1.563E-10    -9.806   1.578E-10    -9.802   1.009E+00    0.004

V+3             7.896E-20   -19.103   1.399E-20   -19.854   1.771E-01   -0.752
VO+2            3.830E-11   -10.417   1.843E-11   -10.734   4.812E-01   -0.318
VO4-3           2.803E-13   -12.552   5.407E-14   -13.267   1.929E-01   -0.715

VOH2+           1.695E-15   -14.771   8.155E-16   -15.089   4.812E-01   -0.318
VOOH+           4.779E-10    -9.321   3.980E-10    -9.400   8.329E-01   -0.079
ZN(OH)2         1.957E-10    -9.708   1.976E-10    -9.704   1.009E+00    0.004

ZN(OH)3-        7.494E-15   -14.125   6.242E-15   -14.205   8.329E-01   -0.079
ZN(OH)4-2       2.054E-20   -19.687   9.884E-21   -20.005   4.812E-01   -0.318
ZN(SO4)2-2      6.464E-09    -8.189   3.111E-09    -8.507   4.812E-01   -0.318

ZN+2            3.098E-07    -6.509   1.572E-07    -6.803   5.076E-01   -0.295
ZNCL+           9.719E-10    -9.012   8.095E-10    -9.092   8.329E-01   -0.079
ZNCL2           1.606E-12   -11.794   1.622E-12   -11.790   1.009E+00    0.004

ZNCL3-          4.179E-15   -14.379   3.480E-15   -14.458   8.329E-01   -0.079
ZNCL4-2         6.934E-18   -17.159   3.337E-18   -17.477   4.812E-01   -0.318
ZNF+            1.183E-10    -9.927   9.853E-11   -10.006   8.329E-01   -0.079

ZNHCO3+         2.981E-07    -6.526   2.483E-07    -6.605   8.329E-01   -0.079
ZNOH+           2.068E-09    -8.684   1.722E-09    -8.764   8.329E-01   -0.079
ZNOHCL          9.858E-11   -10.006   9.950E-11   -10.002   1.009E+00    0.004

ZNSO4           1.177E-07    -6.929   1.188E-07    -6.925   1.009E+00    0.004

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STABILITY OF SOLID AND GAS PHASES        ****************************************

PHASE                                       LOG IAP       LOG KT      LOG IAP/KT
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TREVORITE     alpha-Ni(FeO2)2               38.745        35.990        2.755
GOETHITE      alpha-FeOOH                    2.589         0.113        2.476
GIBBSITE      gamma-Al(OH)3                 10.610         8.175        2.435

BOEHMITE      gamma-AlOOH                   10.611         8.402        2.208
DAWSONITE     NaAlCO3(OH)2                  -3.322        -5.173        1.851
FRANKLINITE   Zn(FeO2)2                     38.416        37.594        0.822

RHODOCHROSIT  MnCO3                        -10.027       -10.410        0.383
CA.97MG.03CO                                -8.175        -8.540        0.365
CALCITE       CaCO3                         -8.161        -8.481        0.321

CA.98MG.02CO                                -8.170        -8.469        0.299
DOLOMITE      CaMg(CO3)2                   -16.795       -17.020        0.225
ARAGONITE     CaCO3                         -8.161        -8.338        0.177

CERUSSITE     PbCO3                        -13.010       -13.130        0.120
CA.931MG.069                                -8.193        -8.313        0.119
FE(OH)3       Fe(OH)3-crystalline            2.589         2.589        0.000

AL(OH)3(AM)                                 10.610        10.741       -0.131
CA.896MG.104                                -8.210        -7.958       -0.252
CA.873MG.127                                -8.221        -7.843       -0.378

MAGNESITE     MgCO3                         -8.634        -8.240       -0.394
a-CU(FEO2)2   alpha-Cu(FeO2)2               10.245        10.842       -0.596
GYPSUM        CaSO4*2H2O                    -5.421        -4.759       -0.662

BARITE        BaSO4                         -9.226        -8.519       -0.707
CA.821MG.179                                -8.245        -7.459       -0.786
SIDERITE      FeCO3                        -11.436       -10.550       -0.886

CA.808MG.192                                -8.252        -7.332       -0.919
CO2(GAS)      ideal gas                     -2.538        -1.610       -0.928
CA.733MG.267                                -8.287        -7.288       -0.999

CA.756MG.244                                -8.276        -7.198       -1.078
CA.764MG.236                                -8.272        -7.192       -1.081
CR(OH)3       CR(OH)3                       10.391        12.020       -1.629

ZNCO3*H2O                                  -12.036       -10.260       -1.776
WITHERITE     alpha-BaCO3                  -11.967       -10.020       -1.947
PARAMONTROSE  V2O4                          17.918        19.933       -2.014

SMITHSONITE   ZnCO3                        -12.036       -10.000       -2.036
ALSTONITE     BaCa(CO3)2                   -20.128       -17.988       -2.140
FE(OH)3(AM)                                  2.589         4.891       -2.302

DUTTONITE     VO(OH)2                        8.959        11.533       -2.574
URANINITE     UO2                           -4.746        -1.265       -3.480
NH3(GAS)      ammonia, ideal gas          -116.323      -112.429       -3.894

CHALCOCITE    CuS                          -40.284       -34.619       -5.665

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TABLE C-7   PHREEQE CALCULATIONS, SW 2008 1Q87

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TOTAL CONCENTRATION OF AQUEOUS COMPONENTS       ********************************

                    TOTAL           TOTAL          TOTAL
COMPONENTS        MOLALITY      LOG MOLALITY       MG/KG
---------------------------------------------------------

AL                4.1148E-06       -5.3856      1.1097E-01
BA                1.0998E-06       -5.9587      1.5095E-01
HCO3              5.0601E-03       -2.2958      3.0859E+02

CA                1.3451E-03       -2.8712      5.3883E+01
CL                3.7240E-04       -3.4290      1.3196E+01
CR                5.0015E-07       -6.3009      2.5992E-02

CU                3.9354E-07       -6.4050      2.4992E-02
F                 1.3162E-05       -4.8807      2.4992E-01
FE                2.1458E-06       -5.6684      1.1977E-01

K                 5.8833E-05       -4.2304      2.2993E+00
MG                4.9369E-04       -3.3065      1.1996E+01
MN                2.0391E-06       -5.6906      1.1197E-01

NO3               9.0496E-04       -3.0434      5.6083E+01
NA                9.1800E-04       -3.0372      2.1093E+01
NI                6.8146E-07       -6.1666      3.9988E-02

PB                2.4138E-08       -7.6173      4.9985E-03
SO4               5.8204E-04       -3.2350      5.5883E+01
U                 1.0085E-06       -5.9963      2.3993E-01

V                 9.8162E-07       -6.0081      4.9985E-02
ZN                2.7542E-07       -6.5600      1.7994E-02

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DESCRIPTION OF SOLUTION         **************************************************

PH                                       6.900
EH  (mV)                                66.506
PE                                       1.124

ACTIVITY OF H2O                          1.000
IONIC STRENGTH (M)                       0.008
TEMPERATURE (C)                         25.000

CATION CONC.(EQ/KG H2O)                  5.335E-03
ANION CONC.(EQ/KG H2O)                  -5.335E-03
CHARGE BALANCE          (%)              7.618E-09

TOTAL ALKALINITY (EQ/KG H2O)             4.023E-03

TDS (MG/KG)                              5.242E+02
DENSITY                                  1.001

ITERATIONS                              29

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DISTRIBUTION OF AQUEOUS SPECIES       ******************************************

                                    LOG                          LOG                      LOG
SPECIES             MOLALITY     MOLALITY     ACTIVITY        ACTIVITY       GAMMA       GAMMA
------------------------------------------------------------------------------------------------

AL(OH)2+           2.973E-07      -6.527     2.721E-07        -6.565     9.153E-01      -0.038
AL(OH)3            2.909E-06      -5.536     2.914E-06        -5.535     1.002E+00       0.001
AL(OH)4-           7.920E-07      -6.101     7.234E-07        -6.141     9.135E-01      -0.039

AL(SO4)2-          1.014E-12     -11.994     9.262E-13       -12.033     9.135E-01      -0.039
AL+3               1.927E-10      -9.715     9.277E-11       -10.033     4.813E-01      -0.318
ALF+2              1.551E-08      -7.809     1.089E-08        -7.963     7.019E-01      -0.154

ALF2+              7.500E-08      -7.125     6.865E-08        -7.163     9.153E-01      -0.038
ALF3               1.464E-08      -7.835     1.466E-08        -7.834     1.002E+00       0.001
ALF4-              9.228E-11     -10.035     8.430E-11       -10.074     9.135E-01      -0.039

ALOH+2             1.074E-08      -7.969     7.542E-09        -8.123     7.019E-01      -0.154
ALSO4+             3.684E-11     -10.434     3.366E-11       -10.473     9.135E-01      -0.039
BA+2               1.042E-06      -5.982     7.288E-07        -6.137     6.995E-01      -0.155

BAOH+              1.052E-11     -10.978     9.624E-12       -11.017     9.145E-01      -0.039
BASO4              5.785E-08      -7.238     5.795E-08        -7.237     1.002E+00       0.001
CA+2               1.239E-03      -2.907     8.695E-04        -3.061     7.015E-01      -0.154

CACO3              2.015E-06      -5.696     2.019E-06        -5.695     1.002E+00       0.001
CAF+               9.499E-08      -7.022     8.687E-08        -7.061     9.145E-01      -0.039
CAHCO3+            4.224E-05      -4.374     3.872E-05        -4.412     9.165E-01      -0.038

CAOH+              1.902E-09      -8.721     1.743E-09        -8.759     9.165E-01      -0.038
CASO4              6.125E-05      -4.213     6.136E-05        -4.212     1.002E+00       0.001
CL-                3.721E-04      -3.429     3.392E-04        -3.470     9.116E-01      -0.040

CO2(AQ)            1.048E-03      -2.980     1.050E-03        -2.979     1.002E+00       0.001
CO3-2              1.909E-06      -5.719     1.340E-06        -5.873     7.019E-01      -0.154
CR(OH)+2           2.849E-08      -7.545     1.978E-08        -7.704     6.941E-01      -0.159

CR(OH)2+           4.716E-07      -6.326     4.304E-07        -6.366     9.128E-01      -0.040
CR+2               3.078E-19     -18.512     2.136E-19       -18.670     6.941E-01      -0.159
CR+3               4.925E-11     -10.308     2.370E-11       -10.625     4.813E-01      -0.318

CRCL2+             2.304E-18     -17.637     2.103E-18       -17.677     9.128E-01      -0.040
CRCL2+2            4.609E-14     -13.336     3.199E-14       -13.495     6.941E-01      -0.159
CRO2-              9.970E-12     -11.001     9.100E-12       -11.041     9.128E-01      -0.040

CRO4-2             2.811E-28     -27.551     1.951E-28       -27.710     6.941E-01      -0.159
CU(CO3)2-2         2.443E-10      -9.612     1.696E-10        -9.771     6.941E-01      -0.159
CU(OH)2            8.541E-09      -8.068     8.556E-09        -8.068     1.002E+00       0.001

CU(OH)3-           4.487E-15     -14.348     4.095E-15       -14.388     9.128E-01      -0.040
CU(OH)4-2          9.353E-21     -20.029     6.491E-21       -20.188     6.941E-01      -0.159
CU+                2.802E-07      -6.553     2.557E-07        -6.592     9.128E-01      -0.040

CU+2               9.196E-09      -8.036     6.489E-09        -8.188     7.056E-01      -0.151
CU2(OH)2+2         1.675E-13     -12.776     1.163E-13       -12.935     6.941E-01      -0.159
CUCL+              6.491E-12     -11.188     5.925E-12       -11.227     9.128E-01      -0.040

CUCL2              1.077E-15     -14.968     1.079E-15       -14.967     1.002E+00       0.001
CUCL2-             1.020E-08      -7.992     9.306E-09        -8.031     9.128E-01      -0.040
CUCL3-             1.423E-21     -20.847     1.299E-21       -20.886     9.128E-01      -0.040

CUCL3-2            7.208E-12     -11.142     5.003E-12       -11.301     6.941E-01      -0.159
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CUCO3          7.127E-08    -7.147    7.140E-08    -7.146    1.002E+00    0.001

CUF+           1.484E-12   -11.829    1.354E-12   -11.868    9.128E-01   -0.040
CUHCO3+        1.287E-08    -7.890    1.175E-08    -7.930    9.128E-01   -0.040
CUOH+          5.648E-10    -9.248    5.155E-10    -9.288    9.128E-01   -0.040

CUSO4          4.582E-10    -9.339    4.590E-10    -9.338    1.002E+00    0.001
E-             7.510E-02    -1.124    7.510E-02    -1.124    1.000E+00    0.000
F-             1.259E-05    -4.900    1.147E-05    -4.940    9.113E-01   -0.040

FE(OH)2        5.773E-12   -11.239    5.783E-12   -11.238    1.002E+00    0.001
FE(OH)2+       8.912E-12   -11.050    8.157E-12   -11.088    9.153E-01   -0.038
FE(OH)3        2.882E-07    -6.540    2.887E-07    -6.540    1.002E+00    0.001

FE(OH)3-       3.437E-18   -17.464    3.143E-18   -17.503    9.145E-01   -0.039
FE(OH)4-       8.273E-13   -12.082    7.573E-13   -12.121    9.153E-01   -0.038
FE(SO4)2-      2.618E-20   -19.582    2.390E-20   -19.622    9.128E-01   -0.040

FE+2           8.633E-07    -6.064    6.091E-07    -6.215    7.056E-01   -0.151
FE+3           1.607E-18   -17.794    7.737E-19   -18.111    4.813E-01   -0.318
FE2(OH)2+4     1.748E-25   -24.757    4.057E-26   -25.392    2.321E-01   -0.634

FECL+2         1.109E-20   -19.955    7.755E-21   -20.110    6.995E-01   -0.155
FECL2+         1.285E-23   -22.891    1.175E-23   -22.930    9.145E-01   -0.039
FECL3          3.979E-28   -27.400    3.986E-28   -27.399    1.002E+00    0.001

FEF+2          2.118E-17   -16.674    1.475E-17   -16.831    6.963E-01   -0.157
FEF2+          7.372E-18   -17.132    6.734E-18   -17.172    9.135E-01   -0.039
FEF3           1.141E-19   -18.943    1.143E-19   -18.942    1.002E+00    0.001

FEOH+          9.568E-07    -6.019    8.751E-07    -6.058    9.145E-01   -0.039
FEOH+2         5.551E-14   -13.256    3.883E-14   -13.411    6.995E-01   -0.155
FESO4          3.746E-08    -7.426    3.753E-08    -7.426    1.002E+00    0.001

FESO4+         2.385E-18   -17.622    2.181E-18   -17.661    9.145E-01   -0.039
H+             1.365E-07    -6.865    1.259E-07    -6.900    9.220E-01   -0.035

H2VO4-         8.996E-07    -6.046    8.211E-07    -6.086    9.128E-01   -0.040
H3VO4          6.698E-10    -9.174    6.709E-10    -9.173    1.002E+00    0.001

HCO3-          3.947E-03    -2.404    3.612E-03    -2.442    9.153E-01   -0.038
HCRO4-         8.565E-29   -28.067    7.818E-29   -28.107    9.128E-01   -0.040

HSO4-          4.633E-09    -8.334    4.232E-09    -8.373    9.135E-01   -0.039
HVO4-2         8.102E-08    -7.091    5.623E-08    -7.250    6.941E-01   -0.159

K+             5.867E-05    -4.232    5.349E-05    -4.272    9.116E-01   -0.040
KCL            1.498E-08    -7.824    1.501E-08    -7.824    1.002E+00    0.001
KOH            3.662E-12   -11.436    3.669E-12   -11.436    1.002E+00    0.001

KSO4-          1.433E-07    -6.844    1.312E-07    -6.882    9.153E-01   -0.038
MG+2           4.581E-04    -3.339    3.230E-04    -3.491    7.050E-01   -0.152
MGCO3          4.143E-07    -6.383    4.150E-07    -6.382    1.002E+00    0.001

MGF+           2.680E-07    -6.572    2.448E-07    -6.611    9.135E-01   -0.039
MGHCO3+        1.502E-05    -4.823    1.371E-05    -4.863    9.124E-01   -0.040
MGOH+          4.494E-09    -8.347    4.123E-09    -8.385    9.175E-01   -0.037

MGSO4          1.986E-05    -4.702    1.990E-05    -4.701    1.002E+00    0.001
MN(OH)2        5.210E-15   -14.283    5.219E-15   -14.282    1.002E+00    0.001
MN(OH)3-       1.139E-20   -19.944    1.041E-20   -19.982    9.145E-01   -0.039

MN(OH)4-2      3.769E-27   -26.424    2.616E-27   -26.582    6.941E-01   -0.159
MN+2           1.858E-06    -5.731    1.311E-06    -5.882    7.056E-01   -0.151

MN2(OH)+3      8.548E-16   -15.068    3.759E-16   -15.425    4.397E-01   -0.357
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MN2(OH)3+      1.188E-15   -14.925   1.084E-15   -14.965   9.128E-01  -0.040
MNCL+          1.967E-09    -8.706   1.799E-09    -8.745   9.145E-01  -0.039

MNCL2          1.655E-13   -12.781   1.658E-13   -12.781   1.002E+00   0.001
MNCL3-         2.772E-17   -16.557   2.535E-17   -16.596   9.145E-01  -0.039
MNF+           1.164E-10    -9.934   1.064E-10    -9.973   9.145E-01  -0.039

MNHCO3+        9.663E-08    -7.015   8.837E-08    -7.054   9.145E-01  -0.039
MNOH+          2.927E-10    -9.534   2.676E-10    -9.572   9.145E-01  -0.039
MNSO4          8.249E-08    -7.084   8.263E-08    -7.083   1.002E+00   0.001

NA+            9.144E-04    -3.039   8.354E-04    -3.078   9.136E-01  -0.039
NA2CO3         7.718E-13   -12.113   7.731E-13   -12.112   1.002E+00   0.001
NA2SO4         7.847E-09    -8.105   7.861E-09    -8.105   1.002E+00   0.001

NACL           2.369E-07    -6.625   2.374E-07    -6.625   1.002E+00   0.001
NACO3-         2.276E-08    -7.643   2.084E-08    -7.681   9.153E-01  -0.038
NAHCO3         1.698E-06    -5.770   1.701E-06    -5.769   1.002E+00   0.001

NAOH           1.159E-11   -10.936   1.161E-11   -10.935   1.002E+00   0.001
NASO4-         1.585E-06    -5.800   1.451E-06    -5.838   9.153E-01  -0.038
NH3(AQ)        3.664E-06    -5.436   3.670E-06    -5.435   1.002E+00   0.001

NH4+           8.973E-04    -3.047   8.157E-04    -3.088   9.091E-01  -0.041
NH4SO4-        4.009E-06    -5.397   3.666E-06    -5.436   9.145E-01  -0.039
NI(OH)2        2.111E-12   -11.675   2.115E-12   -11.675   1.002E+00   0.001

NI(OH)3-       1.841E-16   -15.735   1.680E-16   -15.775   9.128E-01  -0.040
NI(SO4)2-2     6.069E-13   -12.217   4.212E-13   -12.376   6.941E-01  -0.159
NI+2           4.750E-07    -6.323   3.351E-07    -6.475   7.056E-01  -0.151

NICL+          3.129E-10    -9.505   2.856E-10    -9.544   9.128E-01  -0.040
NICL2          3.511E-13   -12.455   3.517E-13   -12.454   1.002E+00   0.001
NIF+           8.403E-11   -10.076   7.670E-11   -10.115   9.128E-01  -0.040

NIHCO3+        1.831E-07    -6.737   1.671E-07    -6.777   9.128E-01  -0.040
NIOH+          4.026E-10    -9.395   3.675E-10    -9.435   9.128E-01  -0.040
NISO4          2.260E-08    -7.646   2.264E-08    -7.645   1.002E+00   0.001

NO3-           7.436E-45   -44.129   6.769E-45   -44.170   9.102E-01  -0.041
OH-            8.757E-08    -7.058   7.981E-08    -7.098   9.113E-01  -0.040
PB(OH)2        2.326E-12   -11.633   2.330E-12   -11.633   1.002E+00   0.001

PB(OH)3-       2.328E-16   -15.633   2.125E-16   -15.673   9.128E-01  -0.040
PB(OH)4-2      5.572E-21   -20.254   3.867E-21   -20.413   6.941E-01  -0.159
PB(SO4)2-2     2.484E-12   -11.605   1.724E-12   -11.764   6.941E-01  -0.159

PB+2           6.989E-09    -8.156   4.866E-09    -8.313   6.963E-01  -0.157
PB2OH+3        1.868E-16   -15.729   8.212E-17   -16.086   4.397E-01  -0.357
PB3(OH)4+2     8.718E-22   -21.060   6.051E-22   -21.218   6.941E-01  -0.159

PBCL+          7.200E-11   -10.143   6.572E-11   -10.182   9.128E-01  -0.040
PBCL2          3.527E-14   -13.453   3.533E-14   -13.452   1.002E+00   0.001
PBCL3-         1.043E-17   -16.982   9.521E-18   -17.021   9.128E-01  -0.040

PBCL4-2        2.227E-21   -20.652   1.546E-21   -20.811   6.941E-01  -0.159
PBF+           1.088E-12   -11.964   9.927E-13   -12.003   9.128E-01  -0.040
PBF2           2.321E-16   -15.634   2.325E-16   -15.634   1.002E+00   0.001

PBF3-          2.117E-20   -19.674   1.932E-20   -19.714   9.128E-01  -0.040
PBF4-2         1.528E-25   -24.816   1.061E-25   -24.974   6.941E-01  -0.159
PBHCO3+        1.530E-08    -7.815   1.396E-08    -7.855   9.128E-01  -0.040

PBOH+          8.258E-10    -9.083   7.538E-10    -9.123   9.128E-01  -0.040
PBSO4          9.465E-10    -9.024   9.481E-10    -9.023   1.002E+00   0.001
SO4-2          4.950E-04    -3.305   3.465E-04    -3.460   7.000E-01  -0.155
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U(OH)4          5.705E-13   -12.244   5.715E-13   -12.243   1.002E+00   0.001
U(OH)5-         1.223E-10    -9.913   1.117E-10    -9.952   9.135E-01  -0.039
U+4             1.717E-31   -30.765   4.953E-32   -31.305   2.884E-01  -0.540

UF+3            4.510E-22   -21.346   2.134E-22   -21.671   4.732E-01  -0.325
UF2+2           6.317E-22   -21.200   4.494E-22   -21.347   7.115E-01  -0.148
UF3+            9.744E-23   -22.011   8.911E-23   -22.050   9.145E-01  -0.039

UF4             1.764E-23   -22.754   1.767E-23   -22.753   1.002E+00   0.001
UF5-            8.781E-27   -26.056   8.030E-27   -26.095   9.145E-01  -0.039
UF6-2           2.778E-29   -28.556   1.976E-29   -28.704   7.115E-01  -0.148

UO2(CO3)2-2     9.495E-07    -6.023   6.727E-07    -6.172   7.086E-01  -0.150
UO2(CO3)3-4     5.888E-08    -7.230   1.698E-08    -7.770   2.884E-01  -0.540
UO2(OH)2        6.923E-12   -11.160   6.935E-12   -11.159   1.002E+00   0.001

UO2(OH)3-       4.142E-16   -15.383   3.781E-16   -15.422   9.128E-01  -0.040
UO2(OH)4-2      2.881E-23   -22.541   1.999E-23   -22.699   6.941E-01  -0.159
UO2(SO4)2-2     8.191E-16   -15.087   5.729E-16   -15.242   6.995E-01  -0.155

UO2+            2.716E-13   -12.566   2.481E-13   -12.605   9.135E-01  -0.039
UO2+2           7.743E-12   -11.111   5.482E-12   -11.261   7.080E-01  -0.150
UO2CL+          1.815E-16   -15.741   1.658E-16   -15.780   9.135E-01  -0.039

UO2F+           3.184E-13   -12.497   2.912E-13   -12.536   9.145E-01  -0.039
UO2F2           7.810E-14   -13.107   7.824E-14   -13.107   1.002E+00   0.001
UO2F3-          4.135E-16   -15.384   3.781E-16   -15.422   9.145E-01  -0.039

UO2F4-2         1.252E-19   -18.903   8.754E-20   -19.058   6.995E-01  -0.155
UO2OH+          1.810E-11   -10.742   1.655E-11   -10.781   9.145E-01  -0.039
UO2SO4          5.455E-14   -13.263   5.465E-14   -13.262   1.002E+00   0.001

UOH+3           5.036E-25   -24.298   2.424E-25   -24.615   4.813E-01  -0.318
V(OH)2+         9.689E-13   -12.014   8.843E-13   -12.053   9.128E-01  -0.040
V(OH)3          5.289E-11   -10.277   5.299E-11   -10.276   1.002E+00   0.001

V+3             2.155E-20   -19.667   9.344E-21   -20.029   4.336E-01  -0.363
VO+2            2.289E-11   -10.640   1.589E-11   -10.799   6.941E-01  -0.159
VO4-3           5.459E-14   -13.263   2.401E-14   -13.620   4.397E-01  -0.357

VOH2+           6.241E-16   -15.205   4.332E-16   -15.363   6.941E-01  -0.159
VOOH+           2.989E-10    -9.524   2.728E-10    -9.564   9.128E-01  -0.040
ZN(OH)2         1.088E-10    -9.964   1.089E-10    -9.963   1.002E+00   0.001

ZN(OH)3-        2.998E-15   -14.523   2.737E-15   -14.563   9.128E-01  -0.040
ZN(OH)4-2       4.964E-21   -20.304   3.446E-21   -20.463   6.941E-01  -0.159
ZN(SO4)2-2      4.518E-11   -10.345   3.136E-11   -10.504   6.941E-01  -0.159

ZN+2            1.943E-07    -6.711   1.371E-07    -6.863   7.056E-01  -0.151
ZNCL+           1.372E-10    -9.863   1.252E-10    -9.902   9.128E-01  -0.040
ZNCL2           4.440E-14   -13.353   4.447E-14   -13.352   1.002E+00   0.001

ZNCL3-          1.854E-17   -16.732   1.693E-17   -16.771   9.128E-01  -0.040
ZNCL4-2         4.146E-21   -20.382   2.878E-21   -20.541   6.941E-01  -0.159
ZNF+            2.434E-11   -10.614   2.222E-11   -10.653   9.128E-01  -0.040

ZNHCO3+         6.832E-08    -7.165   6.236E-08    -7.205   9.128E-01  -0.040
ZNOH+           1.309E-09    -8.883   1.194E-09    -8.923   9.128E-01  -0.040
ZNOHCL          1.221E-11   -10.913   1.224E-11   -10.912   1.002E+00   0.001

ZNSO4           1.112E-08    -7.954   1.114E-08    -7.953   1.002E+00   0.001

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STABILITY OF SOLID AND GAS PHASES      ****************************************

PHASE                                     LOG IAP       LOG KT      LOG IAP/KT
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TREVORITE     alpha-Ni(FeO2)2              38.544       35.990           2.554
GIBBSITE      gamma-Al(OH)3                10.668        8.175           2.492
GOETHITE      alpha-FeOOH                   2.589        0.113           2.476

BOEHMITE      gamma-AlOOH                  10.668        8.402           2.265
FRANKLINITE   Zn(FeO2)2                    38.156       37.594           0.562
FE(OH)3       Fe(OH)3-crystalline           2.589        2.589           0.000

DAWSONITE     NaAlCO3(OH)2                 -5.183       -5.173          -0.010
a-CU(FEO2)2   alpha-Cu(FeO2)2              10.790       10.842          -0.052
AL(OH)3(AM)                                10.668       10.741          -0.074

CA.97MG.03CO                               -8.947       -8.540          -0.407
CALCITE       CaCO3                        -8.934       -8.481          -0.452
CA.98MG.02CO                               -8.942       -8.469          -0.473

ARAGONITE     CaCO3                        -8.934       -8.338          -0.596
CA.931MG.069                               -8.963       -8.313          -0.651
CA.896MG.104                               -8.978       -7.958          -1.020

CERUSSITE     PbCO3                       -14.186      -13.130          -1.056
BARITE        BaSO4                        -9.598       -8.519          -1.079
MAGNESITE     MgCO3                        -9.364       -8.240          -1.124

CA.873MG.127                               -8.988       -7.843          -1.146
DOLOMITE      CaMg(CO3)2                  -18.297      -17.020          -1.277
RHODOCHROSIT  MnCO3                       -11.755      -10.410          -1.345

CO2(GAS)      ideal gas                    -2.979       -1.610          -1.369
SIDERITE      FeCO3                       -12.088      -10.550          -1.538
CA.821MG.179                               -9.011       -7.459          -1.551

CA.808MG.192                               -9.016       -7.332          -1.684
CA.733MG.267                               -9.048       -7.288          -1.760
GYPSUM        CaSO4*2H2O                   -6.521       -4.759          -1.762

CA.756MG.244                               -9.039       -7.198          -1.840
CA.764MG.236                               -9.035       -7.192          -1.843
CR(OH)3       CR(OH)3                      10.075       12.020          -1.945

WITHERITE     alpha-BaCO3                 -12.010      -10.020          -1.990
FE(OH)3(AM)                                 2.589        4.891          -2.302
URANINITE     UO2                          -3.705       -1.265          -2.439

ZNCO3*H2O                                 -12.736      -10.260          -2.476
PARAMONTROSE  V2O4                         17.390       19.933          -2.542
SMITHSONITE   ZnCO3                       -12.736      -10.000          -2.736

NH3(GAS)      ammonia, ideal gas         -115.265     -112.429          -2.836
DUTTONITE     VO(OH)2                       8.695       11.533          -2.838
ALSTONITE     BaCa(CO3)2                  -20.944      -17.988          -2.956

CHALCOCITE    CuS                         -42.192      -34.619          -7.573
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APPENDIX D

OPERATIONS OF THE WELDON SPRING ORDNANCE WORKS AND CHEMICAL PLANT

APPENDIX D

OPERATIONS AT THE WELDON SPRING ORDNANCE WORKS AND CHEMICAL PLANT

D.1 Weldon Spring Ordnance Works Operations

The Atlas Powder Company operated the Weldon Spring ordnance works from November 1941 through January 1944. The ordnance works consisted of 18 trinitrotoluene (TNT) and 2 dinitrotoluene (DNT) explosives manufacturing plants. Figures D-1 and D-2 display the original ordnance works layout. The first three TNT plants and a portion of a fourth were built on the portion of the site which is now occupied by the chemical plant and raffinate pit areas (Plate 1).

TNT plants all use the same basic chemical process, i.e., the treatment of liquid toluene with mixed nitric and sulfuric acids followed by removal of undesired isomers and residual dinitrated toluene by conversion to soluble species. The undesired isomers plus residual dinitrated species were removed from the reaction mixture by treatment with aqueous sodium sulfite solution, called "sellite," which reacted with everything except the desired product. The spent sellite solution, known as "red water," contained the extracted sulfonate derivatives and constituted a major inherent waste stream. Red water is a deep red, almost black, aqueous stream containing a complex mixture of nitroaromatics and various inorganic salts.

The various sulfonated derivatives of the three undesired TNT isomers (2,3,5-TNT, 2,3,6-TNT, and 2,4,5-TNT) constitute the majority of the organics in the stream. Other organic constituents include smaller fragments (dissolved a-TNT) and complex, unidentified dye bodies formed from the photolysis of a-TNT by sunlight. The inorganic constituents consist mainly of unreacted sulfite plus nitrite and nitrate formed in the extraction reactions.

Red water varies somewhat in composition from plant to plant and from run to run, but a typical composition is:

- Water
- Na_2SO_3-Na_2SO_4
- $NaNO_2$-$NaNO_3$
- Sulfonated or sellited nitro compounds
- Solids
- Ash

Figure D-3 shows the schematic flow diagram of the batch process which was used at the ordnance works. The functions of numerous processing and support facilities at the ordnance works have been identified. Table D-1 correlates known processing and support functions to

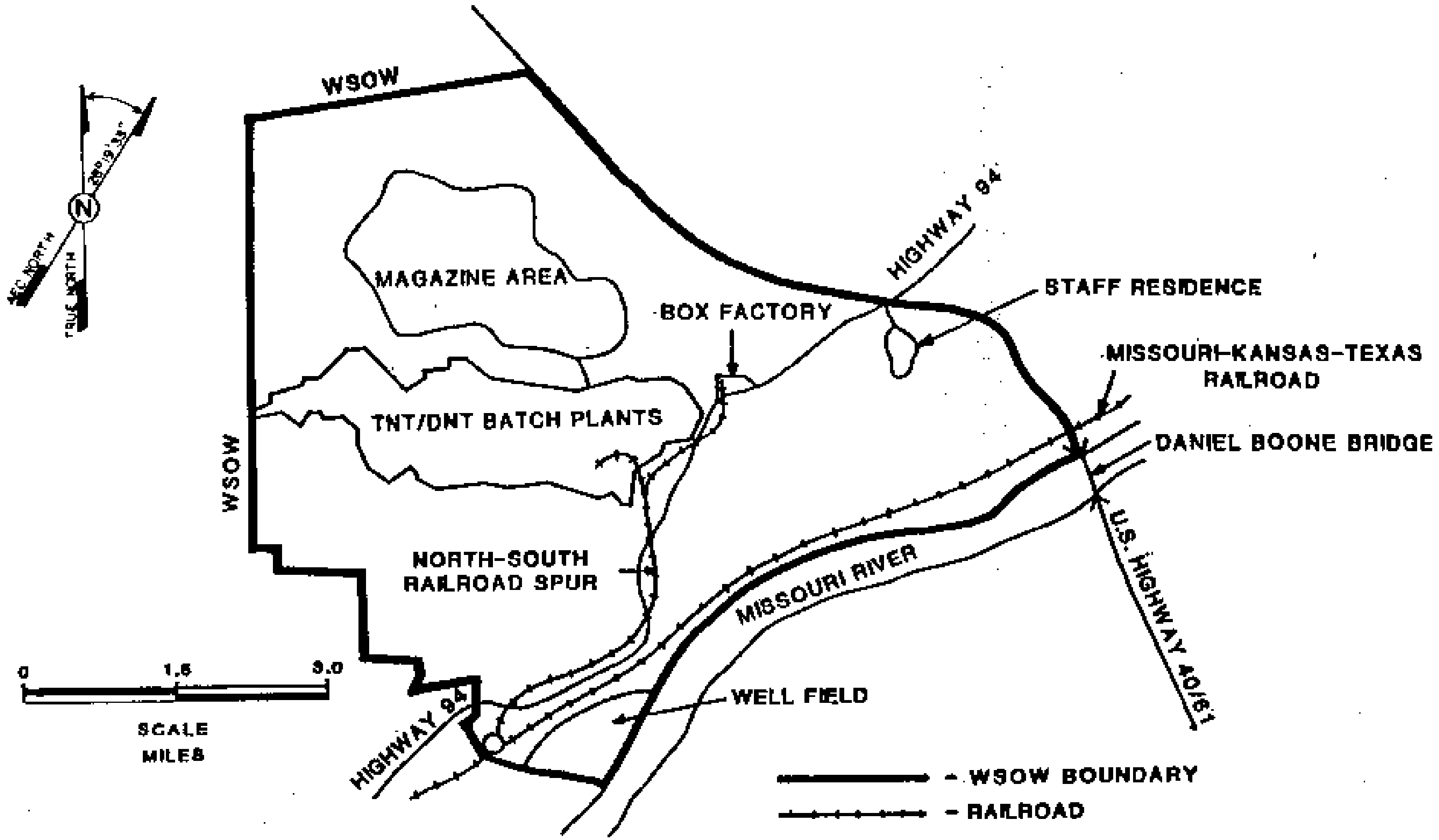


FIGURE D-1

Original WSOW Layout
(1941-1946)

SOURCE: MKF and JEG, 1988

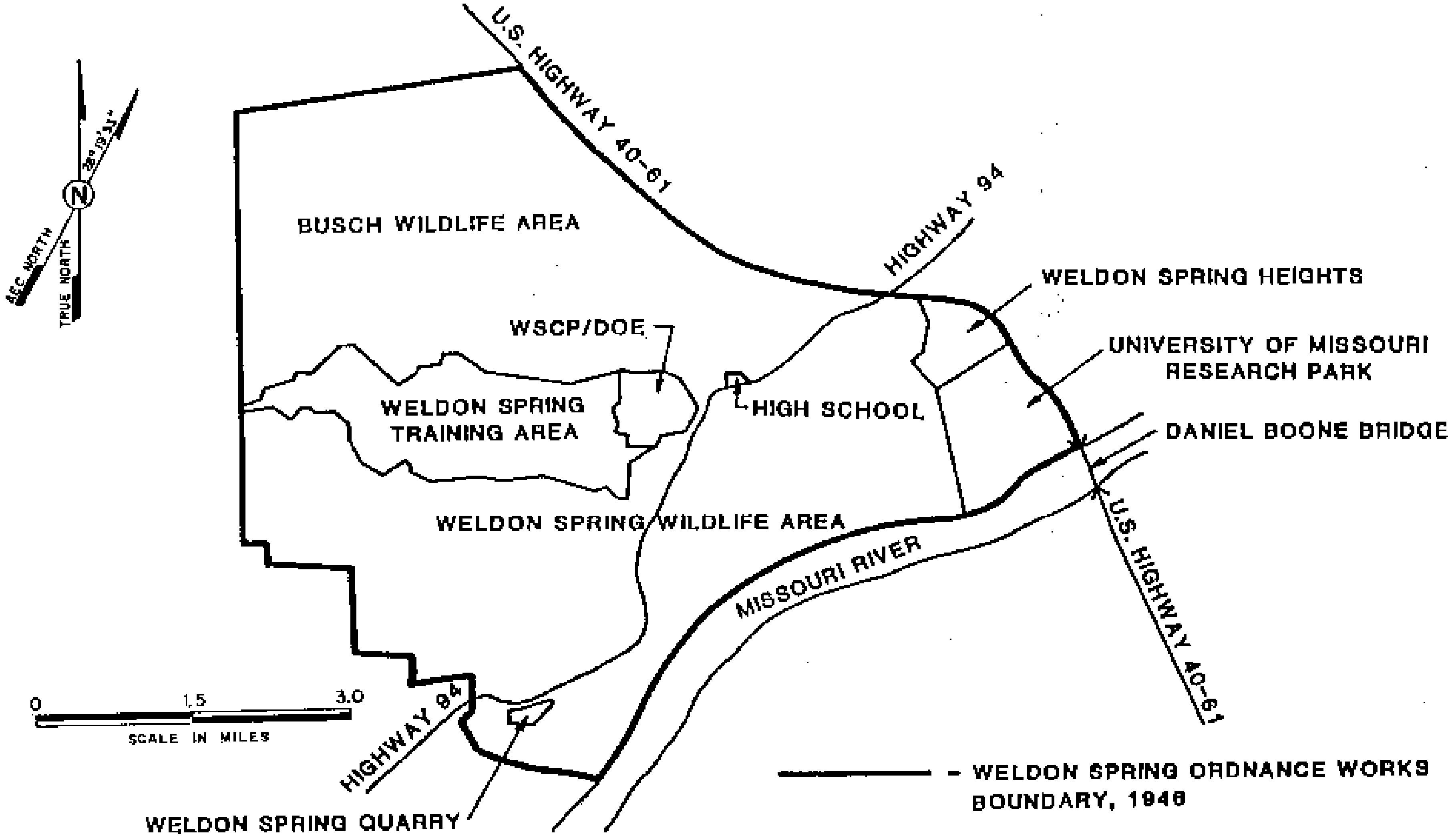
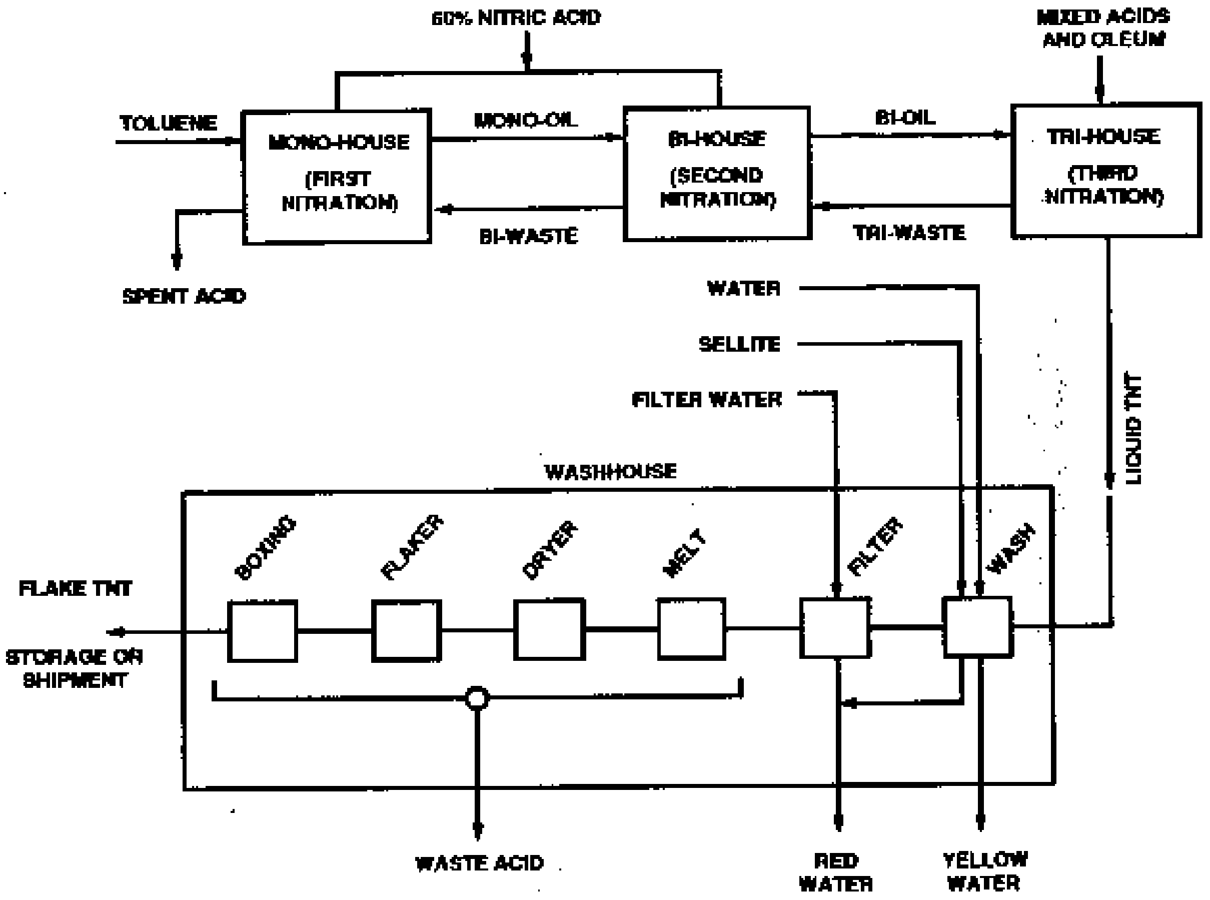


FIGURE D - 2

Current Disposition of WSOW Property

SOURCE: MKF and JEG 1988



WSOW Schematic flow diagram
with Waste Streams

FIGURE D-3

REPORT NO.: DOE/OR/21548-074		EXHIBIT NO.: SOURCE: MKF and JEG, 1989 k	
ORIGINATOR: JCP	DRAWN BY: JHB	DATE: 10/91	

TABLE D-1 Weldon Spring Ordnance Works Process Building Designation

Building	Plant Function
T-1	Toluene Storage
T-3	Acid Unloading
T-4	Acid Unloading
T-5	Acid Unloading
T-6	Acid Unloading
T-7	Mono Nitrating House
T-8	Acid Recovery House
T-9	Trinitrating House
T-10	Acid Storage
T-11	Valve House
T-12	Bi-Fortifier House
T-13	Wash Houses
T-16	Settling House
T-17	Sellite Storage
T-18	Wet Powder Holdover
T-19	Grainer House
T-20	Motor House
T-22	Settling Tanks
T-23	Dry Holdover
T-24	Pack House
T-25	Motor House
T-26	Rubbish Sheds
T-32	Settling Tanks
T-33	Transfer House
T-35	Pelleting
T-36	Box Service
T-37	Box Conveyor
T-38	Strapping House

Source: MKF and JEG 1988

the individual building numbers. Table D-2 lists the chemicals used in TNT and DNT production at the ordnance works. The nitration reactions are carried out in three consecutive batch units referred to as "Mono," "Bi," and "Tri" Houses. The feed chemicals to the Mono House (T-7) are toluene and waste acid from the Bi House (T-12), fortified with 60% nitric acid (HNO_3).

After reaction, the waste acid was transferred to a storage tank for recovery, and the partially nitrated toluene was pumped to the Bi House. At the Bi House, further nitration was effected with waste acid from the Tri House (T-9), fortified with 60% HNO_3. The result was a mixture of all possible dinitrated isomers, "Bi Oil." After settling and separation, the Bi Oil was pumped to the Tri House where the feed acid consisted of a mixture of 98% nitric acid and oleum. The nitrated product from this third nitration stage operation was crude TNT containing a-TNT (2,4,6-trinitrotoluene), the desired product, and unsymmetrical TNT isomers, which were impurities. The crude TNT was fed to the Wash House (T-13) for purification.

The purification of crude TNT involves crystallization in water, free acid neutralization with soda ash and dissolution and removal of undesirable nitrated products by treatment with a solution of sodium sulfite (sellite). The wastewater from the sellite purification stage was transferred to the red water treatment plant for disposal by evaporation-concentration and concentrate incineration.

The TNT slurry was transferred to a filter tank where it was washed and filtered on a screen leaving layers of TNT crystals. The crystals were reslurried with water and pumped to a melt tank where TNT was melted and most of the water was removed by evaporation. The molten product was run into hot air dryers for the removal of residual water. The water-free product was solidified on a water-cooled flaker drum or stainless steel belt, and the resultant film was removed in the form of small flakes by scraping the drum or belt with a beryllium blade. The flaked TNT was boxed and sent to a packing house for transfer to a storage or loading area.

Four waste streams are shown in Figure D-3: spent acid, waste acid, red water, and yellow water. The spent acid was not discharged; the nitric acid was distilled off and reused and the residual sulfuric acid was sold for commercial use. The waste acid (spillage, floor drainage, etc.) was neutralized with lime or soda ash and discharged to the chemical sewer for treatment and discharge to wastewater lagoons or surface drainages. The yellow water, essentially a dilute nitrator, and the red water were destroyed as previously described.

DNT, a closely related explosive, can be manufactured in a TNT plant and was produced at the ordnance works. No DNT was produced in production lines 1, 2, 3, and 4. Plate 1 shows the location of the process and waste lines as they existed on what is now the chemical plant and raffinate pits area. Of the 18 production lines which existed during the peak production period, only lines 1 through 4 were located in the vicinity of the chemical plant and raffinate pits.

TABLE D-2 Chemicals Used in TNT and DNT Production at the Weldon Spring Ordnance Works

Chemicals	Use(s)
Ammonia	Nitric acid production
Caustic Soda	Acidic wastewater neutralization
Chlorine	Water treatment
Coal	Burned for power generation
Fuel Oil	Sulfuric acid concentration and wastewater treatment
Oleum	TNT lines
Salt	Power generation
Soda Ash	Sellite production
Sulfur	Sellite production
Toluene	TNT lines

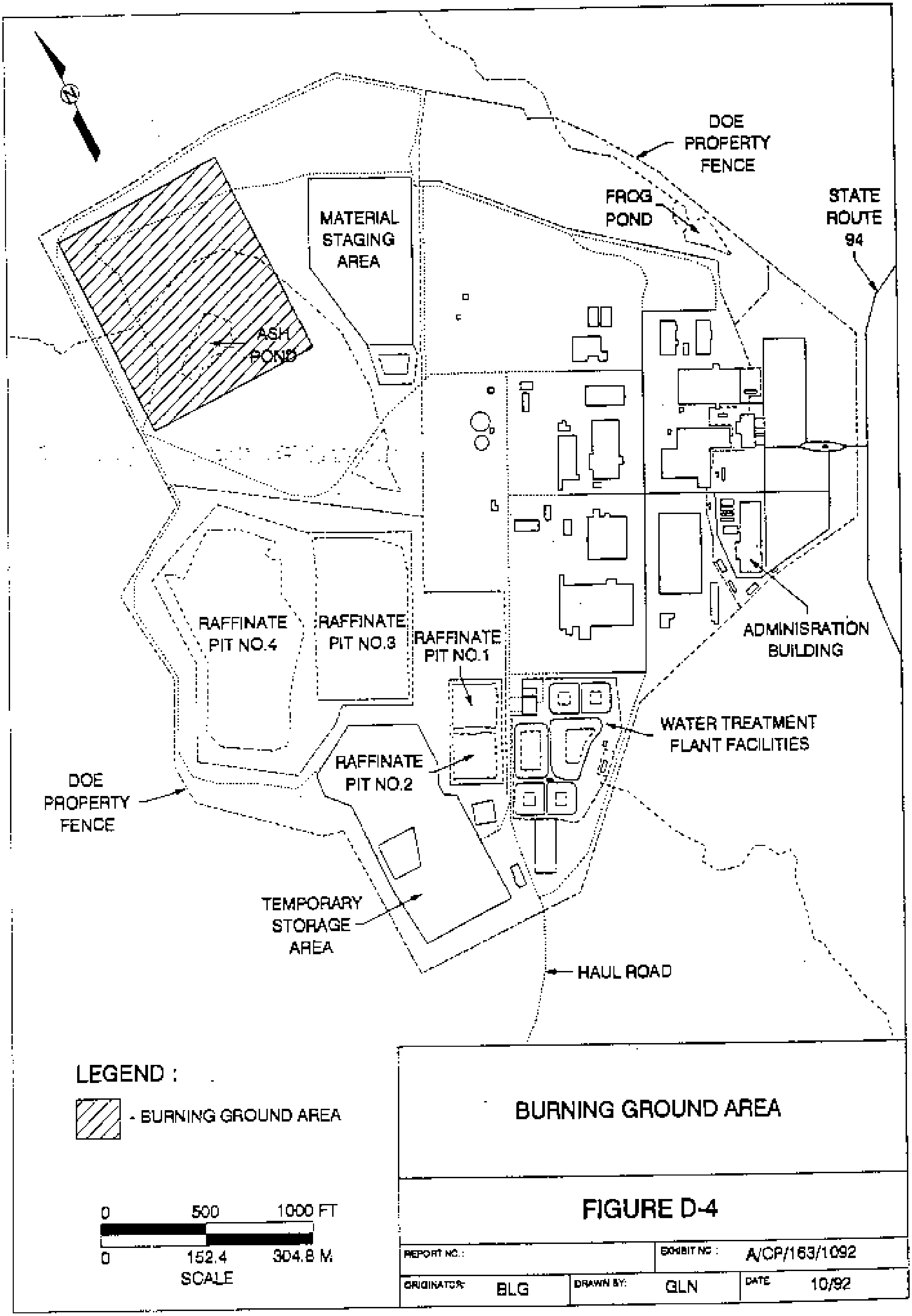
At peak operation, the ordnance works required 181,680 to 189,250 m^3 (48 to 50 million gallons) of water per day. In addition to the great quantities of water used for washing and mixing the chemicals, the process of manufacturing TNT and DNT also requires large quantities of nitric and sulfuric acids and a chemical solution called sellite (sodium sulfite). Leaks and spills of wastewater generated at the ordnance works caused the surface waters to become polluted with TNT and DNT. Prior to construction of the wastewater treatment plants in 1943, wastewater was discharged into seven lagoons for temporary storage. In December 1943, the Department of the Army (DA) drained and earth-filled four lagoons. The remaining three lagoons were drained but not filled.

Water and wastewater lines served each batch plant. Separate wastewater lines were used for chemical waste and for sewage. The chemical wastewater lines carried red and yellow wastewater from each batch plant to various locations where the lines terminated. An estimated 20,117 linear meters (66,000 linear feet) of wooden wastewater lines were laid at the ordnance works. The pipelines were generally made of cypress wood section, 3 m (10 ft) or less in length, constructed similarly to barrels with metal bands for support. Due to the state of emergency and apparent low priority placed on wastewater treatment, details on wastewater management practices are sketchy. Early in the operation of the ordnance works, wastewaters were discharged directly from production lines or pumped into lagoons. The direct discharge and leakage from the lagoons caused contamination of area streams and springs. After stream and spring contamination was noted, wastewaters were pumped directly to the Missouri River (Fishel and Williams 1944). At some point, wastewater evaporation and incineration plants were constructed and placed into operation (Greely and Hansen 1942); however, it is not clear whether this treatment practice ever totally replaced Missouri River disposal.

The wastewater treatment plants were used to evaporate the wastewater into a sludge. The sludge was then hauled to open burning grounds for incineration. Eight burning grounds were used at the ordnance works. Seven of these areas are located off the chemical plant site. One area, number five of the original eight, is thought to be located within the chemical plant area and is shown in Figure D-4.

Based on a comprehensive historical review, it was discovered that, during decontamination in 1944, residues remaining after burning nitroaromatic-contaminated material were scraped into piles, and attempts were made to reburn these piles. The burning process was not very successful, so the residues were dumped, presumably in the Weldon Spring quarry (Hannon 1944). Figure 3.1-2 indicates the location of a demolition storage area for nitroaromatic-contaminated rubble and a burning ground for nitroaromatic-contaminated material. Figure D-4 also indictes the location of the burning ground.

As described in Sections 3.2.1 and 5.2.1 the PMC conducted four soil sampling programs at the site. Nitroaromatic contamination was detected in 15 samples ranging in concentration from 0.48 to 307 $\mu g/g$. The final phase of sampling included biases for known locations of



BURNING GROUND AREA

FIGURE D-4

REPORT NO.:		EXHIBIT NO :	A/CP/163/1092
ORIGINATOR: BLG	DRAWN BY: GLN	DATE	10/92

ordnance works activities, uranium feed materials activities, and a random sampling program. No nitroaromatic compounds were detected in the uranium feed materials-biased and random samples. With the exception of the abandoned waste pond northeast of Frog Pond, no gross contamination was discovered during the soils sampling program.

In January 1944, the ordnance works ceased operations for approximately six months. The DA then reactivated and operated the facility until the end of World War II. Under the ordnance works reactivation program, equipment in line no. 18 was dismantled for use in other lines. Lines no. 2 and no. 3 were reassembled but were never placed in operation.

D.2 Weldon Spring Chemical Plant Operations

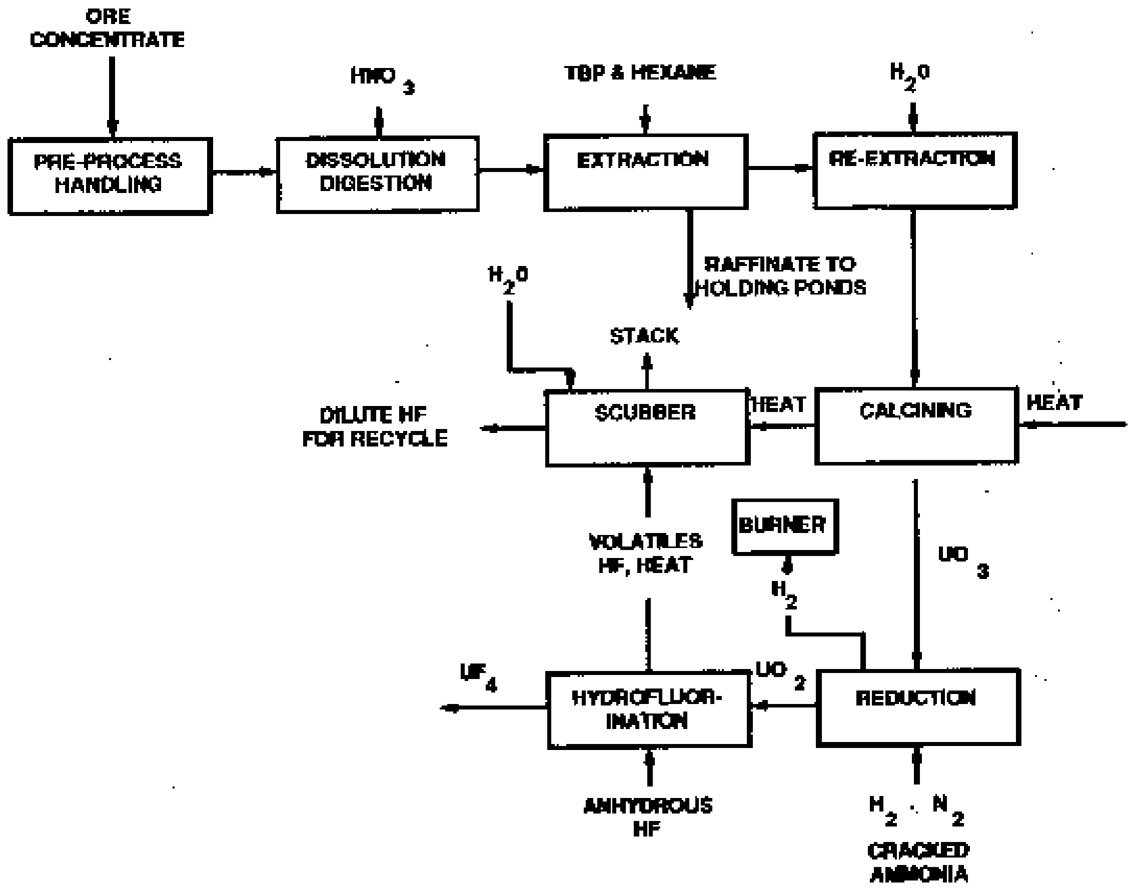
The primary fuction of the chemical plant was to convert uranium concentrate to uranium trioxide (UO_3), uranium tetrafluoride (UF_4), and nranium metal. The raw material received at the plant was yellowcake (uranium concentrate). A schematic diagram of a wet solvent extraction method nsed for UF_4 production is presented in Figure D-5. Before entering the refinery, the ore concentrate underwent a sampling and preparation process in the sampling plant (building 101).

Ore concentrate (about 6% to 70% uranium content) arrived at the sampling building in drums. The drums were opened, the concentrate was sampled using one of the two sampling methods (auger or mechanical sampling), and the drums were emptied into hoppers at the top of the building. From there, the material was emptied into portable hoppers for transfer to the refinery. Yellowcake dust was collected in three large dust collectors, each with its own stack. Some yellowcake was repackaged in drums and shipped out. The remainder was loaded into hoppers and moved to building 103 for digestion. The dust collection system was periodically vacuum cleaned, and the collected dust was reprocessed. Uranium dust washed off the drums, equipment, and floors was also reprocessed.

Building 103 was the first building of the refinery plant. Concentrate was brought in hoppers to the top of the building. Yellowcake dust generated while emptying the hoppers was collected in a dust collector with one stack. The concentrate was heated and digested with nitric acid to produce a solution of uranyl nitrate. The digested material was passed to building 105 in liquid form.

Pure uranyl nitrate solution was extracted in building 105. In this part of the plant, the material remained in liquid form. Impurities generated in the purification process were bled off in the raffinate, and the raffinate was pumped to the pits. This raffinate contained a conglomerate of radiouuclides, including thorium and radium in small concentrations.

Uranyl nitrate solution was pumped back to building 103 for the denitration process during which UO_3 was produced in powder form. This particular operation generated a large



TYPICAL UF_4
PRODUCTION WET SOLVENT
EXTRACTION-FLUORINATION
BLOCK DIAGRAM

FIGURE D-5

REPORT NO.: DOE/OR/21548-074		EXHIBIT NO.: SOURCE: MESHKOV 1988	
ORIGINATOR: JCP	DRAWN BY: JHB	DATE: 10/91	

FFW3068-10/91

amount of dust. The denitration process was performed using in about 20 steel pots located at the south end of the building. The pots were enclosed in vacuum hoods with separate exhaust systems that removed UO_3 powder from the pots and delivered it to separate dust collectors.

Uranium trioxide was placed in hoppers and transferred from building 103 to the top of building 201, the green salt (UF_4) plant. The UO_3 was then emptied into a reduction reactor where it was reduced to uranium dioxide (UO_2) using hydrogen gas. The entire operation was performed in a sealed system, and only a small amount of dust was generated inside the building. The reduction process offgas contained excess hydrogen gas, which was burned. An exhaust hood vented the combustion products to a dust collector. To cool the exhaust which contained UO_2, ambient air was vented to the collectors. For this phase of the operation, there was one dust collector for the six banks of reduction furnaces.

The next process was hydrofluorination, which transformed UO_2 to UF_4 (green salt). The excess hydrogen fluoride (HF) gas from the hydrofluorination process was filtered through carbon filters to recover unreacted uranium, which was recycled to the black oxide (U_3O_8) process. The discharge from the UF_4 reactor system was transferred to a mechanical system where it was crushed, blended, and sized. On the roof of building 201, there were two additional dust collectors to collect UF_4 dust. Uranium tetrafluoride was also converted into U_3O_8 in this building. There may have been a small dust collector for this process.

Green salt from building 201 was placed in hoppers and transferred to the metals plant, building 301. Magnesium was used to convert UF_4 to uranium metal in a multistep process. A green salt and magnesium mixture was placed in individual steel shells at the filling machine and transferred to the furnaces. The process generated green salt dust. Uranium tetrafluoride and magnesium fluoride (MgF), with 1% to 2% of residual uranium in various forms, were discharged from several dust collectors at the ground level on the south side of the building. In building 301 uranium metal chips were burned in a rotary kiln (calciner) and converted to U_3O_8. The dust generated by this operation was collected in one standard dust collector.

Two other buildings on site, pilot plants 403 and 404, produced discharges into the air. There were two to four dust collectors for these two buildings, and the discharges were of the same type as at the main plant (Meshkov 1986).

References Cited

Meshkov, N., et al., 1986. Weldon Spring Historical Dose Estimate. ANL/EES-TM-308; Argonne National Laboratory. July.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988. Waste Assessment Raffinate Pit Sampling Plan Weldon Spring Site. DOE/OR/21548-010. May.

MKF and JEG, see MK-Ferguson Company and Jacobs Engineering Group Inc.

Fishel, V.C. and C.C. Williams, 1944. The Contamination of Ground and Surface Waters by Liquid Wastes from the Weldon Spring Ordnance Works, Missouri. USGS.

Greely and Hansen Engineers, 1942. Report on Economic and Safe Disposal of TNT Waste Waters at Weldon Spring Ordnance Works. Report to the U.S. Army, Office of the District Engineer. July.

Hannon, E.S., 1944. Decontamination Report. From Ordnance Department WSOW Historic Report for Partial Periods.

APPENDIX E

CHRONOLOGY OF EVENTS AT THE WELDON SPRING SITE

APPENDIX E

CHRONOLOGY OF EVENTS AT THE WELDON SPRING SITE

This appendix provides a chronological listing of major historical events at the Weldon Spring site from the time the Department of the Army (DA) initially acquired the land in 1941 to the site's status as of September 1990.

Apr. 1941:	The DA, under a state of emergency, acquired 6,974 ha (17,232 ac) of land in western St. Charles County, Missouri for production of explosives for use in World War II.
Nov. 1941 through Jan. 1944:	Atlas Powder Company operated a trinitrotoluene (TNT) and dinitrotoluene (DNT) explosives production plant for the DA. The plants were known as the Weldon Spring ordnance works and were located on the 6,974 ha (17,232 ac) acquired by the DA in 1941.
Nov. 1941 through Dec. 1943	Wastewater was discharged into seven lagoons for temporary storage. In December 1943, the DA drained and earth-filled four of these lagoons. The remaining three were drained but not filled. During 1943, wastewater treatment plants were constructed and used to evaporate the wastewater into a sludge. The sludge was then hauled to open burning grounds for incineration.
Jan. 1944:	The ordnance works ceased operations for approximately six months before being reactivated by the DA. The DA continued to operate the ordnance works until the end of World War II.
Apr. 1946:	The Ordnance Review Board (ORB) declared the ordnance works surplus property.
Sep. 1946:	ORB transferred the ordnance works to the War Assets Administration (WAA) which had been organized to dispose of surplus U.S. government property.
Oct. 1946:	Atlas Powder Company initiated the first effort to decontaminate the facility. However, in the fall of 1946 several fatalities were caused by using improperly decontaminated equipment. As a result, the ORB recommended that any processing equipment in direct contact with TNT, DNT, or their intermediates be considered as hazardously contaminated. In addition, the ORB recommended removal of all contaminated earth around processing buildings, catch tanks, and similar areas. In 1946, following these recommendations, the Kansas City District of the Army Corps of Engineers removed 2,685 m^3 (3,512 yd^3) of earth and burned,

	in place, 51,250 kg (113,005 lb) of hand-picked TNT, 36,000 kg (80,000 lb) of TNT, and other residues. The site where the Corps deposited this earth is unknown. In addition, many buildings were burned or otherwise destroyed.
Dec. 1946:	The Kansas City District Corps of Engineers published a report at the conclusion of the 1946 decontamination effort titled "Survey Covering Salvageable Equipment and Buildings in TNT Area at Weldon Spring Ordnance Works."
Jan. 1947 through Dec. 1949:	As a result of WAA's efforts to dispose of surplus government property, much of the original ordnance works was conveyed to public entities. The University of Missouri received 3,205 ha (7,920 ac) for agricultural use. The Missouri Department of Conservation (MDOC) subsequently purchased 2,910 ha (7,200 ac) and created the Weldon Springs Wildlife Area (MKF and JEG 1987). The MDOC received an additional 2,810 ha (6,944 ac) of the original ordnance worksproperty and MDOC created the Busch Wildlife Area. St. Charles County Public Schools received 15.4 ha (37.90 ac), where Francis Howell High School was constructed.
Dur. 1950:	The General Services Administration (GSA) (successors to WAA) took custodial control of the remaining 835 ha (2,063 ac) of the ordnance works. The CSA also renovated some buildings and equipment.
Jun. 1954:	The GSA transferred the remaining 835 ha (2,063 ac) of ordnance works land to the DA as part of the National Industrial Plant Reserve.
Dur. 1955:	As a result of the Atomic Energy Commission's (AEC) interest in using the area for the Weldon Spring uranium feed materials plant, the DA agreed to transfer 83 ha (205 ac) to the AEC. Prior to the transfer, the land was partially decontaminated. After decontamination, the DA officially transferred the land to the AEC on August 6, 1956, with the stipulation that the land would revert back to the DA when the AEC operations ceased.
Jun. 1957:	Mallinckrodt Chemical Works (MCW), as contractors to the AEC, began operations at the feed materials plant. Uranium metal was produced by processing uranium ore. The original plant consisted of numerous buildings and two waste (raffinate) pits (MKF and JEG 1988).
Dur. 1958:	A third raffinate pit was constructed for the deposition of radioactive process waste from the feed materials plant (MKF and JEG 1988). The AEC also acquired an abandoned quarry for use as a low-level radioactive waste disposal site. The quarry was acquired from the DA which had

	used it for disposal of TNT-contaminated materials (Berkeley Geosciences Associates 1984).
Jun. 1959:	After the DA transferred 83 ha (205 ac) to the AEC, the remaining land, 752 ha (1860 ac), was designated as the Weldon Spring U.S. Army Reserve Training Area.
Jan. 1960 through Dec. 1963:	Wastes from dismantling the Mallinckrodt Chemical Works Destrehan Street uranium processing plant in St. Louis were deposited in the quarry.
Jan. 1963 through Dec. 1965:	Disposal in the quarry of several thousand barrels of low-level radioactive waste containing uranium and thorium from U.S. Army Granite City Arsenal, Granite City, Illinois, was begun. Shortly thereafter, a local company purchased the entire quantity of waste for rare-earths mineral recovery. Further dumping was suspended, and the purchaser removed as much dumped material as practical.
Jul. 1964:	Land was acquired, and the fourth raffinate pit was constructed on additional land that was transferred to the AEC by the DA (MKF and JEG, 1988).
Jan. 1965 through Dec. 1966:	Thorium oxide was processed at the feed materials plant, and the wastes were deposited in raffinate pit 4.
Jan. 1965 through Dec. 1966:	Thorium residues were brought to the quarry by railroad from the U.S. defense contractor's plants in the Cincinnati, Ohio, area. The material is thought to have consisted of several hundred drums, constituting about 425 m^3 (556 yd^3). During 1966, the DA disposed of TNT-contaminated stone and earth. This waste physically covered the thorium residues from the Cincinnati area.
Dec. 1966:	The AEC closed the feed materials plant after deciding it was obsolete. Shut-down procedures included cleaning all points of material accumulation and removing as much of the pure uranium compounds as possible from the production equipment. Cleanup wastes were dumped in raffinate pit 4 (Kleeschulte and Emmett 1986).

Jan. 1967:	The AEC transferred 83 ha (205 ac) of the feed materials plant back to the DA after the DA decided to use parts of the plant for production of a herbicide known as "agent orange." The AEC kept control of building 438 and a 20.5-ha (50.6-ac) tract that included the four raffinate pits (Kleeschulte and Emmett 1986).
Aug. 1967:	The Kansas City District Corps of Engineers contracted Thompson-Stearns-Roger Corporation (TSR) to design and construct a herbicide production facility, to be known as the Weldon Spring chemical plant, on the 83 ha (205 ac) of land transferred from the AEC back to the DA.
Jan. 1968:	TSR took occupancy of the chemical plant and began decontamination and removal of equipment from the former feed materials plant operations.
Jan. 1968 through Dec. 1969	Several buildings at the chemical plant were decontaminated, and 4,250 m^3 (5,560 yd^3) of wastes, contaminated with thorium and uranium, were placed on the main quarry floor and dumped over the northeast rim. (MKE 1989).
Feb. 1969:	Estimated costs for completing the chemical plant project had risen from \$10.5 million to more than \$30 million. Additionally, military demands for "agent orange" were reduced. The project was consequently cancelled, and no herbicide production occurred (Kleeschulte and Emmett 1986). Following project cancellation, the chemical plant remained under DA control, while the AEC administered the raffinate pits (MKF and JEG 1988).
Jul. 1970:	As a result of cancellation of the herbicide production project, the DA declared the property to be excess.
Aug. 1972:	St. Charles County purchased the well field that previously supplied water to the ordnance works. At the time, the well field consisted of 13 large-capacity wells in a 140-ha (344-ac) tract (Kleeschulte and Emmett 1986).
Aug. 1975:	The DA conducted a preliminary assessment of the environmental conditions at the chemical plant. Its findings indicated the plant could not be released for unrestricted use without decontaminating the land and buildings. However, insufficient data were available to decide what action was necessary to return the area to unrestricted use status. A recommendation was made that additional data be collected (Kleeschulte and Emmett 1986).

AEC contracted National Lead Company of Ohio (NLO) to perform environmental monitoring at and to maintain the raffinate pits and quarry (ORNL 1988).

Jan. 1977 through Dec. 1979: Ryckman, Edgerly, Tomlinson and Associates (RETA) studied the site for the DA Phase I and Phase III Installation Restoration Assessment.

Oct. 1981: Bechtel National, Inc. (BNI), under contract to the DOE (successor to the AEC), assumed management and maintenance responsibility for the Weldon Spring raffinate pits and quarry from NLO (ORNL 1988).

1984: The DA repaired several buildings at the chemical plant, decontaminated some floors, walls and ceilings, and isolated some contaminated equipment.

Nov. 1984: DOE was directed by the Office of Management and Budget to assume custody of and accountability for the chemical plant from the DA (ORNL 1988).

Feb. 1985: DOE proposed designating the control and decontamination of the chemical plant and raffinate pits as a major project (MKF and JEG 1988).

May 1985: Designation of the chemical plant and raffinate pits as a major project was effected by DOE Order 4240.1E (MKF and JEG 1988).

Oct. 1985: The DA transferred custody and accountability for the chemical plant to the DOE (ORNL 1988).

Feb. 1986: The Project Management Contractor (PMC), MK-Ferguson Company and Jacobs Engineering Group, for the Weldon Spring Site Remedial Action Project (WSSRAP) was selected (MKF and JEG 1988).

Jul. 1986: A DOE project office was established on the site (MKF and JEG 1988).

Oct. 1986: The PMC assumed control of the site, and initiated the remedial investigation and site characterization work (MKF and JEG 1988). Remedial investigation activities by the PMC included chemical and radiological characterization of chemical plant buildings, chemical and radiological soil characterization, chemical and radiological characterization of raffinate pit water and sludge, hydrogeologic investigations, geophysical and geotechnical investigations, and a bio-uptake study.

The PMC also initiated planning for a series of interim response actions (IRAs). A complete list of the IRAs to be executed at the site is described in Table 1.2-2.

July 1987: The EPA included the quarry on the NPL.

March 1989: The NPL designation was expanded to include the raffinate pit and chemical plant areas.

Sept. 1990: The RI/FS-EA process for the quarry bulk waste was completed and resulted in a Record of Decision for management of this material.

References Cited

Berkeley Geosciences Associates, 1984. Characterization and Assessment for the Weldon Spring Quarry Low-Level Radioactive Waste Storage Site. DOE/OR-853 (DE85005424). September.

Kleeschulte, M.J. and Emmett, L.F, 1986. Compilation and Preliminary Interpretation of Hydrologic Data for the Weldon Spring Radioactive Waste Disposal Sites. U.S. Geological Survey.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1987. Plan for Sampling and Analysis of Lake and Steam Sediments Influenced by the WSCP Drainage. DOE/OR/21548-006. November.

MK-Ferguson Company and Jacobs Engineering Group Inc., 1988. Weldon Spring Site Remedial Action Project Chemical Soil Investigation Sampling Plan for the Weldon Spring Chemical Plant/Raffinate Pits. DOE/OR/21548-013. May.

MKE, see Morrison-Knudsen Engineers, Inc.

MKF and JEG, see MK-Ferguson Company and Jacobs Engineering Group Inc.

Morrison-Knudsen Engineers, Inc., 1989. Draft Remedial Investigations Quarry Bulk Wastes. Revision A. DOE/OR/21548-066. February.

Oak Ridge National Laboratory, 1988. Work Plan for the Remedial Investigation/Feasibility Study - Environmental Impact Statement for the Weldon Spring Site. DOE/OR/21548-033. August.

ORNL, see Oak Ridge National Laboratory.

APPENDIX F

RADIOLOGICAL ANALYSES RESULTS FOR SITE SOIL SAMPLES

APPENDIX F
RADIOLOGICAL ANALYSES RESULTS FOR SITE SOIL SAMPLES

This appendix presents the analyses results of soil samples collected for the radiological characterization of the Weldon Spring chemical plant. The sample location number, coordinate location, sampling interval, sample number, and analyses results are presented in Table F-1. The sample locations are posted on Plate 2. Several sample locations were omitted from Plate 2 because of their close proximity to other sample locations. Table 5.2-3 lists the locations not included on Plate 2.

Soil samples were collected by UNC Geotech and the Project Management Contractor (PMC) as described in Section 3.2.2. Sample numbers with the prefix "UNC" indicate samples which were collected by UNC Geotech but were analyzed by the PMC. The prefix "WSC" identifies those samples which were collected and analyzed by the PMC. Samples collected and analyzed by UNC Geotech are identified by the prefixes "MNB," "MNC," "MNE," "MHN," and "MML."

Sample locations are numbered from 101 through 775. The coordinates of sample locations 691, 708, 726, and 730 are the same as the coordinates of locations 500, 505, 502, and 501, respectively. The analytical results for samples collected at locations 691, 708, 726, and 730 are therefore not included in Table F-1. Background uranium-238, radium-226, and radium-228 concentrations were not subtracted from the sample results reported in Table F-1. A dashed line in the table indicates that the sample was not analyzed for that particular radionuclide. The "<" (less than) symbol identifies where analytical results are less than the lower limit of detection.

In November 1988, a low bias was discovered in all uranium-238 analyses performed by the PMC on soil samples collected from vicinity properties and on site. The PMC reanalyzed all of the samples affected by the low bias, and the results are included in Table F-1.

TABLE F-1 Weldon Spring Radionuclide Data

Region 0

Outside of Fenced Site Perimeter

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
236	101275.0	49600.0	0.00	1.00	MNE752	<0.30	---	---	---
236	101275.0	49600.0	1.00	2.00	MNE753	0.30	---	---	---
369	98100.0	51095.0	0.00	1.00	MNB057	---	---	---	0.40
369	98100.0	51095.0	1.00	2.00	MNB058	---	---	---	0.60
369	98100.0	51095.0	2.00	3.00	MNB059	---	---	---	1.20
369	98100.0	51095.0	3.00	4.00	MNB060	---	---	---	1.40
369	98100.0	51095.0	4.00	5.00	MNB061	---	---	---	1.20
369	98100.0	51095.0	5.00	6.00	MNB062	---	---	---	1.80
433	101340.0	49680.0	0.00	1.00	MNE758	2.00	---	---	---
433	101340.0	49680.0	1.00	2.00	MNE759	<0.30	---	---	---
433	101340.0	49680.0	2.00	3.00	MNE760	<0.30	---	---	---
433	101340.0	49680.0	3.00	4.00	MNE761	<0.30	---	---	---
433	101340.0	49680.0	5.00	6.00	MNE763	<0.30	---	---	---
604	98100.0	51100.0	0.00	1.00	UNC339	<1.20	<0.20	<0.20	---
604	98100.0	51100.0	1.00	2.00	UNC340	<1.20	<0.30	<0.10	---
604	98100.0	51100.0	2.00	3.00	UNC341	<2.50	1.00	0.70	---
604	98100.0	51100.0	3.00	4.00	UNC342	<2.40	0.70	0.80	---
604	98100.0	51100.0	4.00	5.00	UNC343	<2.40	1.10	<0.50	---
604	98100.0	51100.0	5.00	6.00	UNC344	<2.30	0.90	<0.60	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 1

North Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
242	101400.0	52400.0	0.00	1.00	MNB972	302.20	---	---	---
242	101400.0	52400.0	1.00	2.00	MNB973	6.30	---	---	---
242	101400.0	52400.0	2.00	3.00	MNB974	24.80	---	---	---
242	101400.0	52400.0	3.00	4.00	MNB975	3.00	---	---	---
242	101400.0	52400.0	4.00	5.00	MNB976	43.00	---	---	---
243	101400.0	52200.0	0.00	1.00	MNB977	1380.30	---	---	---
243	101400.0	52200.0	1.00	2.00	MNB978	93.00	---	---	---
243	101400.0	52200.0	2.00	3.00	MHN819	86.20	---	---	---
243	101400.0	52200.0	2.00	3.00	MNB979	69.50	---	---	---
243	101400.0	52200.0	3.00	4.00	MNB980	10.30	---	---	---
243	101400.0	52200.0	4.00	5.00	MNB981	11.90	---	---	---
243	101400.0	52200.0	5.00	6.00	MNB982	4.00	---	---	---
245	101598.0	52010.0	0.00	1.00	MNB993	1.70	---	---	---
245	101598.0	52010.0	1.00	2.00	MNB994	0.70	---	---	---
245	101598.0	52010.0	2.00	3.00	MNB995	0.70	---	---	---
245	101598.0	52010.0	3.00	4.00	MNB996	0.70	---	---	---
245	101598.0	52010.0	4.00	5.00	MNB997	0.70	---	---	---
431	101450.0	52050.0	0.00	1.00	MML419	5.30	---	---	---
431	101450.0	52050.0	1.00	2.00	MML420	0.30	---	---	---
431	101450.0	52050.0	2.00	3.00	MML421	0.70	---	---	---
431	101450.0	52050.0	3.00	4.00	MML422	0.30	---	---	---
501	101400.0	52400.0	0.00	1.00	WSC269	327.40	1.50	<0.70	1.70
501	101400.0	52400.0	1.00	2.00	WSC270	126.30	1.40	<1.40	---
501	101400.0	52400.0	2.00	3.00	WSC271	36.90	1.80	<1.60	---
501	101400.0	52400.0	3.00	4.00	WSC272	<1.90	1.30	<1.20	---
501	101400.0	52400.0	4.00	5.00	WSC273	<2.10	1.60	1.20	---
501	101400.0	52400.0	5.00	6.00	WSC274	<2.00	1.40	1.00	---
501	101400.0	52400.0	6.00	7.00	WSC275	<1.60	1.30	<1.30	---
501	101400.0	52400.0	7.00	8.00	WSC276	<1.80	1.10	<1.40	---
501	101400.0	52400.0	8.00	9.00	WSC277	<1.70	1.20	1.20	---
501	101400.0	52400.0	9.00	10.00	WSC278	<1.70	0.90	1.30	---
731	101400.0	52300.0	0.00	0.50	MNC020	96.70	3.60	1.80	---
732	101400.0	52200.0	0.00	1.00	MNB977	---	---	1.40	9.50
734	101500.0	52200.0	0.00	0.50	MNC072	158.90	2.30	1.50	---
735	101500.0	52100.0	0.00	0.50	MNC021	281.00	1.60	1.50	---
735	101500.0	52100.0	0.50	1.00	MNC022	125.80	1.40	1.30	---
740	101600.0	51900.0	0.00	0.50	MNC074	---	3.00	1.50	---
740	101600.0	51900.0	0.00	0.50	UNC400	4.10	3.00	1.50	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 1

North Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
745	101700.0	51900.0	0.00	0.50	MNC073	---	5.60	1.60	---
745	101700.0	51900.0	0.00	0.50	UNC399	1.10	6.90	1.60	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 2
North Central Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
145	101000.0	51300.0	0.00	1.00	MNB725	2.60	---	---	---
145	101000.0	51300.0	1.00	2.00	MNB726	1.00	---	---	---
145	101000.0	51300.0	2.00	3.00	MNB727	1.00	---	---	---
145	101000.0	51300.0	3.00	4.00	MNB728	0.70	---	---	---
145	101000.0	51300.0	4.00	5.00	MHN809	<0.30	---	---	---
145	101000.0	51300.0	4.00	5.00	MNB729	0.70	---	---	---
146	101000.0	51200.0	0.00	1.00	MNB715	1.30	---	---	---
146	101000.0	51200.0	1.00	2.00	MNB716	1.00	---	---	---
146	101000.0	51200.0	2.00	3.00	MNB717	0.70	---	---	---
146	101000.0	51200.0	3.00	4.00	MNB718	0.70	---	---	---
146	101000.0	51200.0	4.00	5.00	MHN808	<0.30	---	---	---
146	101000.0	51200.0	4.00	5.00	MNB719	0.70	---	---	---
147	101000.0	51100.0	0.00	1.00	MNB730	2.60	---	---	---
147	101000.0	51100.0	1.00	2.00	MNB731	1.00	---	---	---
147	101000.0	51100.0	2.00	3.00	MNB732	1.00	---	---	---
147	101000.0	51100.0	3.00	4.00	MNB733	0.70	---	---	---
147	101000.0	51100.0	4.00	5.00	MNB734	0.70	---	---	---
246	101500.0	51700.0	0.00	1.00	MNC452	3.60	---	---	---
246	101500.0	51700.0	1.00	2.00	MNC453	0.70	---	---	---
246	101500.0	51700.0	2.00	3.00	MHN825	<0.30	---	---	---
246	101500.0	51700.0	2.00	3.00	MNC454	1.00	---	---	---
246	101500.0	51700.0	3.00	4.00	MNC455	1.00	---	---	---
246	101500.0	51700.0	4.00	5.00	MNC456	0.70	---	---	---
246	101500.0	51700.0	5.00	6.00	MNC457	0.70	---	---	---
247	101800.0	51700.0	0.00	1.00	MNB988	1.70	---	---	---
247	101800.0	51700.0	1.00	2.00	MHN820	<0.30	---	---	---
247	101800.0	51700.0	1.00	2.00	MNB989	0.70	---	---	---
247	101800.0	51700.0	2.00	3.00	MNB990	1.00	---	---	---
247	101800.0	51700.0	3.00	4.00	MNB991	0.70	---	---	---
247	101800.0	51700.0	4.00	5.00	MNB992	0.70	---	---	---
248	101200.0	51400.0	0.00	1.00	MNC440	3.30	---	---	---
248	101200.0	51400.0	1.00	2.00	MNC441	1.00	---	---	---
248	101200.0	51400.0	2.00	3.00	MNC442	1.00	---	---	---
248	101200.0	51400.0	3.00	4.00	MNC443	0.70	---	---	---
248	101200.0	51400.0	4.00	5.00	MHN824	<0.30	---	---	---
248	101200.0	51400.0	4.00	5.00	MNC444	0.70	---	---	---
248	101200.0	51400.0	5.00	6.00	MNC445	0.70	---	---	---
252	101400.0	51100.0	0.00	1.00	MNC458	3.00	---	---	---
252	101400.0	51100.0	1.00	2.00	MNC459	0.70	---	---	---
252	101400.0	51100.0	2.00	3.00	MNC460	0.70	---	---	---
252	101400.0	51100.0	3.00	4.00	MNC461	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 2

North Central Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
252	101400.0	51100.0	4.00	5.00	MNC462	0.70	---	---	---
255	101920.0	51400.0	0.00	1.00	MNB998	1.30	---	---	---
255	101920.0	51400.0	1.00	2.00	MHN821	<0.30	---	---	---
255	101920.0	51400.0	1.00	2.00	MNB999	0.70	---	---	---
255	101920.0	51400.0	2.00	3.00	MNC126	0.70	---	---	---
255	101920.0	51400.0	3.00	4.00	MNC127	0.70	---	---	---
255	101920.0	51400.0	4.00	5.00	MNC128	0.70	---	---	---
719	101200.0	51100.0	0.00	0.50	MNC071	6.30	1.70	1.30	---
736	101500.0	51100.0	0.00	0.50	MNC070	4.60	1.30	1.30	---
741	101600.0	51600.0	0.00	0.50	MHN724	2.60	1.10	1.00	---
741	101600.0	51600.0	0.00	0.50	MNC049	2.80	1.40	1.80	---
741	101600.0	51600.0	0.50	1.00	MNC050	0.70	1.70	1.40	---
746	101700.0	51400.0	0.00	0.50	MNC023	5.00	1.50	0.90	---
749	101900.0	51400.0	0.00	0.50	MNC024	2.60	1.10	1.10	0.00

TABLE F-1 Weldon Spring Radionuclide Data (Continued).

Region 3

Frog Pond Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
230	101056.0	49587.0	0.00	1.00	MNE713	87.40	---	---	---
230	101056.0	49587.0	1.00	2.00	MNE714	280.40	---	---	---
230	101056.0	49587.0	2.00	3.00	MNE715	92.00	---	---	---
230	101056.0	49587.0	3.00	4.00	MNE716	26.80	---	---	---
230	101056.0	49587.0	4.50	5.00	MML449	6.00	---	---	---
230	101056.0	49587.0	5.00	5.50	MML450	7.60	---	---	---
231	100999.0	49610.0	0.00	1.00	MNC487	1.70	---	---	---
231	100999.0	49610.0	1.00	2.00	MNC488	1.00	---	---	---
231	100999.0	49610.0	2.00	3.00	MNC489	0.70	---	---	---
231	100999.0	49610.0	3.00	4.00	MNC490	0.70	---	---	---
231	100999.0	49610.0	4.00	5.00	MNC491	0.70	---	---	---
231	100999.0	49610.0	5.00	6.00	MNC492	0.70	---	---	---
231	100999.0	49610.0	6.00	7.00	MNC493	0.70	---	---	---
231	100999.0	49610.0	7.00	8.00	MHN827	<0.30	---	---	---
231	100999.0	49610.0	7.00	8.00	MNC494	0.70	---	---	---
231	100999.0	49610.0	8.00	9.00	MNC495	0.70	---	---	---
231	100999.0	49610.0	9.00	10.00	MNC496	0.70	---	---	---
233	101098.0	49621.0	0.00	1.00	MNC526	3.30	---	---	---
233	101098.0	49621.0	1.00	2.00	MNC527	1.70	---	---	---
233	101098.0	49621.0	2.00	3.00	MNC528	0.70	---	---	---
233	101098.0	49621.0	3.00	4.00	MNC529	0.30	---	---	---
233	101098.0	49621.0	4.00	5.00	MHN828	<0.30	---	---	---
233	101098.0	49621.0	4.00	5.00	MNC530	0.30	---	---	---
233	101098.0	49621.0	5.00	6.00	MNC531	0.30	---	---	---
233	101098.0	49621.0	6.00	7.00	MNC532	0.30	---	---	---
233	101098.0	49621.0	7.00	8.00	MNC533	<0.30	---	---	---
233	101098.0	49621.0	8.00	9.00	MNC534	<0.30	---	---	---
233	101098.0	49621.0	9.00	10.00	MNC535	<0.30	---	---	---
234	101098.0	49586.0	0.00	1.00	MNE709	119.80	---	---	---
234	101098.0	49586.0	1.00	2.00	MNE710	127.10	---	---	---
234	101098.0	49586.0	2.00	3.00	MNE711	130.40	---	---	---
234	101098.0	49586.0	3.00	4.00	MNE712	20.50	---	---	---
234	101098.0	49586.0	4.00	5.00	MML451	3.60	---	---	---
237	101293.0	49834.0	0.00	1.00	MNE717	1.70	---	---	---
237	101293.0	49834.0	1.00	1.50	MNE718	0.30	---	---	---
238	101253.0	49636.0	0.00	1.00	MNE721	24.20	---	---	---
238	101253.0	49636.0	1.00	2.00	MNE722	6.30	---	---	---
238	101253.0	49636.0	2.00	3.00	MNE723	2.30	---	---	---
238	101253.0	49636.0	3.00	4.00	MNE724	1.70	---	---	---
238	101253.0	49636.0	4.00	5.00	MNE725	0.70	---	---	---
239	101319.0	49760.0	0.00	1.00	MNE719	12.60	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 3

Frog Pond Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
239	101319.0	49760.0	1.00	1.50	MNE720	3.30	---	---	---
254	101294.0	50298.0	0.00	1.00	MNC572	4.30	---	---	---
254	101294.0	50298.0	1.00	2.00	MNC573	0.30	---	---	---
254	101294.0	50298.0	2.00	3.00	MNC574	0.30	---	---	---
254	101294.0	50298.0	3.00	4.00	MNC575	<0.30	---	---	---
254	101294.0	50298.0	4.00	5.00	MHN862	<0.30	---	---	---
254	101294.0	50298.0	4.00	5.00	MNC576	<0.30	---	---	---
254	101294.0	50298.0	5.00	6.00	MNC577	<0.30	---	---	---
256	101802.0	50911.0	0.00	1.00	MNC566	3.30	---	---	---
256	101802.0	50911.0	1.00	2.00	MNC567	0.70	---	---	---
256	101802.0	50911.0	2.00	3.00	MNC568	0.30	---	---	---
256	101802.0	50911.0	3.00	4.00	MNC569	0.30	---	---	---
256	101802.0	50911.0	4.00	5.00	MHN832	<0.30	---	---	---
256	101802.0	50911.0	4.00	5.00	MNC570	<0.30	---	---	---
256	101802.0	50911.0	5.00	6.00	MNC571	0.30	---	---	---
717	101100.0	49600.0	0.00	0.50	MNC120	25.20	0.90	0.90	---
721	101200.0	50000.0	0.00	0.50	MNC123	24.20	1.90	1.20	---
727	101300.0	50100.0	0.00	0.50	MNC039	7.90	1.00	1.50	---
727	101300.0	50100.0	0.50	1.00	MNC040	2.00	1.20	1.10	---
728	101300.0	50000.0	0.00	0.50	MNC124	6.60	1.50	1.70	---
729	101300.0	49700.0	0.00	0.50	MNC121	4.60	1.00	1.10	---
733	101400.0	49900.0	0.00	0.50	MHN854	6.00	0.90	1.50	---
733	101400.0	49900.0	0.00	0.50	MNC122	5.30	1.40	1.20	---
737	101500.0	50500.0	0.00	0.50	MNC027	8.30	1.20	1.30	---
738	101500.0	50200.0	0.00	0.50	MNC068	6.60	1.40	1.80	---
739	101500.0	50000.0	0.00	0.50	MHN855	9.60	1.40	1.20	---
739	101500.0	50000.0	0.00	0.50	MNE701	8.30	1.50	0.90	---
742	101600.0	50900.0	0.00	0.50	MNC035	2.60	1.30	1.60	---
742	101600.0	50900.0	0.50	1.00	MNC036	1.00	1.50	1.40	---
743	101600.0	50700.0	0.00	0.50	MNC067	6.30	1.20	1.90	---
744	101650.0	50330.0	0.00	0.50	MNE702	12.60	1.10	1.20	---
747	101700.0	60500.0	0.00	0.50	MNC037	24.20	0.90	0.60	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 3

Frog Pond Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
747	101700.0	50600.0	0.50	1.00	MNC038	23.50	0.60	0.70	---
748	101710.0	50365.0	0.00	0.50	MML460	13.90	---	---	---
748	101710.0	50365.0	0.50	1.00	MML461	7.30	---	---	---
748	101710.0	50365.0	1.00	1.50	MML462	4.30	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
102	100200.0	52100.0	0.00	1.00	MNB858	0.70	---	---	---
102	100200.0	52100.0	1.00	2.00	MHN815	<0.30	---	---	---
102	100200.0	52100.0	1.00	2.00	MNB859	0.30	---	---	---
102	100200.0	52100.0	2.00	3.00	MNB860	0.30	---	---	---
102	100200.0	52100.0	3.00	4.00	MNB861	0.30	---	---	---
102	100200.0	52100.0	4.00	5.00	MNB862	0.70	---	---	---
103	100200.0	51100.0	0.00	1.00	MNB556	5.30	---	---	---
103	100200.0	51100.0	1.00	2.00	MNB557	1.00	---	---	---
103	100200.0	51100.0	2.00	3.00	MHN794	<0.30	---	---	---
103	100200.0	51100.0	2.00	3.00	MNB558	1.00	---	---	---
103	100200.0	51100.0	3.00	4.00	MNB559	1.00	---	---	---
103	100200.0	51100.0	4.00	5.00	MNB560	0.70	---	---	---
105	100300.0	51300.0	0.00	1.00	MNB598	2.00	---	---	---
105	100300.0	51300.0	1.00	2.00	MNB599	1.00	---	---	---
105	100300.0	51300.0	2.00	3.00	MNB600	1.30	---	---	---
105	100300.0	51300.0	3.00	4.00	MHN797	<0.30	---	---	---
105	100300.0	51300.0	3.00	4.00	MNB601	0.70	---	---	---
105	100300.0	51300.0	4.00	5.00	MNB602	0.70	---	---	---
106	100300.0	51100.0	0.00	1.00	MNB561	0.70	---	---	---
106	100300.0	51100.0	1.00	2.00	MNB562	1.30	---	---	---
106	100300.0	51100.0	2.00	3.00	MNB563	0.70	---	---	---
106	100300.0	51100.0	3.00	4.00	MNB564	0.70	---	---	---
106	100300.0	51100.0	4.00	5.00	MNB565	0.70	---	---	---
108	100400.0	51500.0	0.00	1.00	MNB889	42.00	---	---	---
108	100400.0	51500.0	1.00	2.00	MNB890	5.30	---	---	---
108	100400.0	51500.0	2.00	3.00	MNB891	1.00	---	---	---
108	100400.0	51500.0	3.00	4.00	MNB892	0.70	---	---	---
108	100400.0	51500.0	4.00	5.00	MNB893	1.30	---	---	---
109	100401.0	51379.0	0.00	1.00	MNB613	15.60	---	---	---
109	100401.0	51379.0	1.00	2.00	MNB614	6.30	---	---	---
109	100401.0	51379.0	2.00	3.00	MNB615	1.30	---	---	---
109	100401.0	51379.0	3.00	4.00	MNB616	1.00	---	---	---
109	100401.0	51379.0	4.00	5.00	MHN798	<0.30	---	---	---
109	100401.0	51379.0	4.00	5.00	MNB617	0.70	---	---	---
110	100400.0	51300.0	0.00	1.00	MNB603	11.60	---	---	---
110	100400.0	51300.0	1.00	2.00	MNB604	2.30	---	---	---
110	100400.0	51300.0	2.00	3.00	MNB605	1.30	---	---	---
110	100400.0	51300.0	3.00	4.00	MNB606	1.00	---	---	---
110	100400.0	51300.0	4.00	5.00	MNB607	0.70	---	---	---
111	100400.0	51200.0	0.00	1.00	MNB581	6.00	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
111	100400.0	51200.0	1.00	2.00	MNB582	1.70	---	---	---
111	100400.0	51200.0	2.00	3.00	MNB583	1.30	---	---	---
111	100400.0	51200.0	3.00	4.00	MNB584	1.30	---	---	---
111	100400.0	51200.0	4.00	5.00	MNB585	1.30	---	---	---
112	100400.0	51100.0	0.00	1.00	MNB566	1.70	---	---	---
112	100400.0	51100.0	1.00	2.00	MHN795	<0.30	---	---	---
112	100400.0	51100.0	1.00	2.00	MNB567	0.70	---	---	---
112	100400.0	51100.0	2.00	3.00	MNB568	0.70	---	---	---
112	100400.0	51100.0	3.00	4.00	MNB569	0.30	---	---	---
112	100400.0	51100.0	4.00	5.00	MNB570	0.70	---	---	---
113	100500.0	52200.0	0.00	1.00	MNC129	1.70	---	---	---
113	100500.0	52200.0	1.00	2.00	MNC130	0.70	---	---	---
113	100500.0	52200.0	2.00	3.00	MNC131	1.00	---	---	---
113	100500.0	52200.0	3.00	4.00	MNC132	0.70	---	---	---
113	100500.0	52200.0	4.00	5.00	MNC133	0.70	---	---	---
113	100500.0	52200.0	5.00	6.00	MNC134	0.70	---	---	---
113	100500.0	52200.0	6.00	7.00	MNC135	0.70	---	---	---
113	100500.0	52200.0	7.00	8.00	MNC136	0.70	---	---	---
114	100521.0	51502.0	0.00	1.00	MNB628	8.30	---	---	---
114	100521.0	51502.0	1.00	2.00	MNB629	1.30	---	---	---
114	100521.0	51502.0	2.00	3.00	MNB630	1.00	---	---	---
114	100521.0	51502.0	3.00	4.00	MNB631	1.00	---	---	---
114	100521.0	51502.0	4.00	5.00	MNB632	1.00	---	---	---
114	100521.0	51502.0	5.00	6.00	MNB633	1.00	---	---	---
114	100521.0	51502.0	6.00	7.00	MNB634	1.00	---	---	---
115	100500.0	51400.0	0.00	1.00	MNB618	13.60	---	---	---
115	100500.0	51400.0	1.00	2.00	MNB619	1.00	---	---	---
115	100500.0	51400.0	2.00	3.00	MNB620	1.70	---	---	---
115	100500.0	51400.0	3.00	4.00	MNB621	1.00	---	---	---
115	100500.0	51400.0	4.00	5.00	MNB622	1.00	---	---	---
116	100500.0	51300.0	0.00	1.00	MNB608	---	---	---	1.90
116	100500.0	51300.0	1.00	2.00	MNB609	---	---	---	1.50
116	100500.0	51300.0	2.00	3.00	MNB610	---	---	---	1.00
116	100500.0	51300.0	3.00	4.00	MNB611	---	---	---	1.20
116	100500.0	51300.0	4.00	5.00	MNB612	---	---	---	1.10
117	100500.0	51200.0	0.00	1.00	MNB576	4.00	---	---	---
117	100500.0	51200.0	1.00	2.00	MNB577	1.30	---	---	---
117	100500.0	51200.0	2.00	3.00	MNB578	1.30	---	---	---
117	100500.0	51200.0	3.00	4.00	MNB579	1.30	---	---	---
117	100500.0	51200.0	4.00	5.00	MNB580	1.30	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
118	100500.0	51100.0	0.00	1.00	MNB571	1.00	---	---	---
118	100500.0	51100.0	1.00	2.00	MNB572	0.70	---	---	---
118	100500.0	51100.0	2.00	3.00	MNB573	0.70	---	---	---
118	100500.0	51100.0	3.00	4.00	MHN796	<0.30	---	---	---
118	100500.0	51100.0	3.00	4.00	MNB574	0.70	---	---	---
118	100500.0	51100.0	4.00	5.00	MNB575	0.70	---	---	---
119	100597.0	52280.0	0.00	1.00	MHN817	2.00	---	---	---
119	100597.0	52280.0	0.00	1.00	MNB959	0.60	---	---	---
119	100597.0	52280.0	1.00	2.00	MNB960	0.70	---	---	---
119	100597.0	52280.0	2.00	3.00	MNB961	1.00	---	---	---
119	100597.0	52280.0	3.00	4.00	MNB962	0.30	---	---	---
119	100597.0	52280.0	4.00	5.00	MNB963	0.70	---	---	---
120	100600.0	51500.0	1.00	2.00	MNB624	3.30	---	---	---
120	100600.0	51500.0	2.00	3.00	MNB625	0.70	---	---	---
120	100600.0	51500.0	3.00	4.00	MHN799	<0.30	---	---	---
120	100600.0	51500.0	3.00	4.00	MNB626	0.70	---	---	---
120	100600.0	51500.0	4.00	5.00	MNB627	1.00	---	---	---
121	100600.0	51409.0	0.00	1.00	MNB645	5.30	---	---	---
121	100600.0	51409.0	1.00	2.00	MNB646	1.00	---	---	---
121	100600.0	51409.0	2.00	3.00	MNB647	1.00	---	---	---
121	100600.0	51409.0	3.00	4.00	MNB648	1.00	---	---	---
121	100600.0	51409.0	4.00	5.00	MNB649	1.00	---	---	---
122	100600.0	51300.0	0.00	1.00	MNB660	3.60	---	---	---
122	100600.0	51300.0	1.00	2.00	MNB661	1.00	---	---	---
122	100600.0	51300.0	2.00	3.00	MNB662	1.70	---	---	---
122	100600.0	51300.0	3.00	4.00	MNB663	0.70	---	---	---
122	100600.0	51300.0	4.00	5.00	MNB664	0.70	---	---	---
123	100600.0	51200.0	0.00	1.00	MNB675	8.30	---	---	---
123	100600.0	51200.0	1.00	2.00	MNB676	13.90	---	---	---
123	100600.0	51200.0	2.00	3.00	MNB677	9.30	---	---	---
123	100600.0	51200.0	3.00	4.00	MNB678	3.60	---	---	---
123	100600.0	51200.0	4.00	5.00	MHN804	0.70	---	---	---
123	100600.0	51200.0	4.00	5.00	MNB679	1.70	---	---	---
124	100600.0	51100.0	0.00	1.00	MNB680	6.60	---	---	---
124	100600.0	51100.0	1.00	2.00	MNB681	3.30	---	---	---
124	100600.0	51100.0	2.00	3.00	MNB682	1.30	---	---	---
124	100600.0	51100.0	3.00	4.00	MNB683	0.70	---	---	---
124	100600.0	51100.0	4.00	5.00	MNB684	0.70	---	---	---
126	100715.0	52400.0	0.00	1.00	MNC418	1.70	---	---	---
126	100715.0	52400.0	1.00	2.00	MHN822	<0.30	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
126	100715.0	52400.0	1.00	2.00	MNC419	0.70	---	---	---
126	100715.0	52400.0	2.00	3.00	MNC420	0.70	---	---	---
126	100715.0	52400.0	3.00	4.00	MNC421	0.30	---	---	---
126	100715.0	52400.0	4.00	5.00	MNC422	0.70	---	---	---
126	100715.0	52400.0	5.00	6.00	MNC423	0.70	---	---	---
127	100700.0	51500.0	0.00	1.00	MNB655	2.30	---	---	---
127	100700.0	51500.0	1.00	2.00	MHN802	<0.30	---	---	---
127	100700.0	51500.0	1.00	2.00	MNB656	1.00	---	---	---
127	100700.0	51500.0	2.00	3.00	MNB657	0.70	---	---	---
127	100700.0	51500.0	3.00	4.00	MNB658	0.70	---	---	---
127	100700.0	51500.0	4.00	5.00	MNB659	0.70	---	---	---
128	100700.0	51400.0	0.00	1.00	MNB650	4.00	---	---	---
128	100700.0	51400.0	1.00	2.00	MNB651	1.00	---	---	---
128	100700.0	51400.0	2.00	3.00	MNB652	1.00	---	---	---
128	100700.0	51400.0	3.00	4.00	MNB653	0.70	---	---	---
128	100700.0	51400.0	4.00	5.00	MNB654	1.00	---	---	---
129	100700.0	51300.0	0.00	1.00	MNB665	1.00	---	---	---
129	100700.0	51300.0	1.00	2.00	MNB666	0.70	---	---	---
129	100700.0	51300.0	2.00	3.00	MNB667	0.70	---	---	---
129	100700.0	51300.0	3.00	4.00	MNB668	0.30	---	---	---
129	100700.0	51300.0	4.00	5.00	MHN803	<0.30	---	---	---
129	100700.0	51300.0	4.00	5.00	MNB669	0.30	---	---	---
130	100700.0	51192.0	0.00	1.00	MNB670	3.30	---	---	---
130	100700.0	51192.0	1.00	2.00	MNB671	1.30	---	---	---
130	100700.0	51192.0	2.00	3.00	MNB672	1.00	---	---	---
130	100700.0	51192.0	3.00	4.00	MNB673	1.00	---	---	---
130	100700.0	51192.0	4.00	5.00	MNB674	0.70	---	---	---
131	100700.0	51100.0	0.00	1.00	MNB685	3.30	---	---	---
131	100700.0	51100.0	1.00	2.00	MNB686	1.00	---	---	---
131	100700.0	51100.0	2.00	3.00	MNB687	0.70	---	---	---
131	100700.0	51100.0	3.00	4.00	MNB688	0.70	---	---	---
131	100700.0	51100.0	4.00	5.00	MHN805	<0.30	---	---	---
131	100700.0	51100.0	4.00	5.00	MNB689	0.70	---	---	---
132	100824.0	52202.0	0.00	1.00	MNB964	1.00	---	---	---
132	100824.0	52202.0	1.00	2.00	MNB965	0.30	---	---	---
132	100824.0	52202.0	2.00	3.00	MNB966	0.70	---	---	---
132	100824.0	52202.0	3.00	4.00	MNB967	0.30	---	---	---
132	100824.0	52202.0	4.00	5.00	MNB968	0.70	---	---	---
132	100824.0	52202.0	5.00	6.00	MHN818	0.30	---	---	---
132	100824.0	52202.0	5.00	6.00	MNB969	1.00	---	---	---
132	100824.0	52202.0	6.00	7.00	MNB970	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
132	100824.0	52202.0	7.00	8.00	MNB971	0.70	---	---	---
133	100800.0	51500.0	0.00	1.00	MNB752	5.00	---	---	---
133	100800.0	51500.0	1.00	2.00	MNB753	1.00	---	---	---
133	100800.0	51500.0	2.00	3.00	MNB754	1.00	---	---	---
133	100800.0	51500.0	3.00	4.00	MNB755	0.70	---	---	---
133	100800.0	51500.0	4.00	5.00	MNB756	0.70	---	---	---
134	100800.0	51400.0	0.00	1.00	MNC434	7.00	---	---	---
134	100800.0	51400.0	1.00	2.00	MNC435	5.30	---	---	---
134	100800.0	51400.0	2.00	3.00	MNC436	4.00	---	---	---
134	100800.0	51400.0	4.00	5.00	MNC438	1.00	---	---	---
134	100800.0	51400.0	5.00	6.00	MHN823	<0.30	---	---	---
134	100800.0	51400.0	5.00	6.00	MNC439	0.70	---	---	---
135	100800.0	51300.0	0.00	1.00	MNB700	2.30	---	---	---
135	100800.0	51300.0	1.00	2.00	MNB701	1.00	---	---	---
135	100800.0	51300.0	2.00	3.00	MNB702	1.00	---	---	---
135	100800.0	51300.0	3.00	4.00	MNB703	1.00	---	---	---
135	100800.0	51300.0	4.00	5.00	MNB704	1.00	---	---	---
136	100800.0	51200.0	0.00	1.00	MNB695	5.00	---	---	---
136	100800.0	51200.0	1.00	2.00	MNB696	1.00	---	---	---
136	100800.0	51200.0	2.00	3.00	MNB697	1.00	---	---	---
136	100800.0	51200.0	3.00	4.00	MNB698	1.30	---	---	---
136	100800.0	51200.0	4.00	5.00	MHN806	<0.30	---	---	---
136	100800.0	51200.0	4.00	5.00	MNB699	1.00	---	---	---
137	100800.0	51100.0	0.00	1.00	MNB690	3.60	---	---	---
137	100800.0	51100.0	1.00	2.00	MNB691	1.00	---	---	---
137	100800.0	51100.0	2.00	3.00	MNB692	1.70	---	---	---
137	100800.0	51100.0	3.00	4.00	MNB693	1.00	---	---	---
137	100800.0	51100.0	4.00	5.00	MNB694	1.00	---	---	---
138	100888.0	51975.0	0.00	1.00	MNB777	8.60	---	---	---
138	100888.0	51975.0	1.00	2.00	MNB778	0.70	---	---	---
138	100888.0	51975.0	2.00	3.00	MHN814	<0.30	---	---	---
138	100888.0	51975.0	2.00	3.00	MNB779	0.70	---	---	---
138	100888.0	51975.0	3.00	4.00	MNB780	0.30	---	---	---
138	100888.0	51975.0	4.00	5.00	MNB781	0.30	---	---	---
139	100898.0	51534.0	0.00	1.00	MNB747	4.00	---	---	---
139	100898.0	51534.0	1.00	2.00	MNB748	1.00	---	---	---
139	100898.0	51534.0	2.00	3.00	MHN811	<0.30	---	---	---
139	100898.0	51534.0	2.00	3.00	MNB749	0.70	---	---	---
139	100898.0	51534.0	3.00	4.00	MNB750	2.00	---	---	---
139	100898.0	51534.0	4.00	5.00	MNB751	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
140	100900.0	51400.0	0.00	1.00	MNB735	4.30	---	---	---
140	100900.0	51400.0	1.00	2.00	MNB736	1.30	---	---	---
140	100900.0	51400.0	2.00	3.00	MNB737	1.70	---	---	---
140	100900.0	51400.0	3.00	4.00	MNB738	1.30	---	---	---
140	100900.0	51400.0	4.00	5.00	MHN810	<0.30	---	---	---
140	100900.0	51400.0	4.00	5.00	MNB739	1.30	---	---	---
141	100886.0	51301.0	0.00	1.00	MNB705	6.30	---	---	---
141	100886.0	51301.0	1.00	2.00	MNB706	2.30	---	---	---
141	100886.0	51301.0	2.00	3.00	MNB707	1.70	---	---	---
141	100886.0	51301.0	3.00	4.00	MNB708	0.70	---	---	---
141	100886.0	51301.0	4.00	5.00	MHN807	<0.30	---	---	---
141	100886.0	51301.0	4.00	5.00	MNB709	1.00	---	---	---
142	100900.0	51200.0	0.00	1.00	MNB720	4.30	---	---	---
142	100900.0	51200.0	1.00	2.00	MNB721	1.00	---	---	---
142	100900.0	51200.0	2.00	3.00	MNB722	1.00	---	---	---
142	100900.0	51200.0	3.00	4.00	MNB723	0.70	---	---	---
142	100900.0	51200.0	4.00	5.00	MNB724	0.70	---	---	---
143	100898.0	51104.0	0.00	1.00	MNB710	2.00	---	---	---
143	100898.0	51104.0	1.00	2.00	MNB711	1.30	---	---	---
143	100898.0	51104.0	2.00	3.00	MNB712	1.00	---	---	---
143	100898.0	51104.0	3.00	4.00	MNB713	1.00	---	---	---
143	100898.0	51104.0	4.00	5.00	MNB714	1.00	---	---	---
144	100995.0	51503.0	0.00	1.00	MNB740	2.60	---	---	---
144	100995.0	51503.0	1.00	2.00	MNB741	1.30	---	---	---
144	100995.0	51503.0	2.00	3.00	MNB742	1.00	---	---	---
144	100995.0	51503.0	3.00	4.00	MNB743	0.70	---	---	---
144	100995.0	51503.0	4.00	5.00	MNB744	0.70	---	---	---
144	100995.0	51503.0	5.00	6.00	MNB745	1.00	---	---	---
144	100995.0	51503.0	6.00	7.00	MNB746	1.00	---	---	---
149	101100.0	51900.0	0.00	1.00	MHN861	1.30	---	---	---
149	101100.0	51900.0	0.00	1.00	MNB772	2.00	---	---	---
149	101100.0	51900.0	1.00	2.00	MNB773	0.70	---	---	---
149	101100.0	51900.0	2.00	3.00	MNB774	0.70	---	---	---
149	101100.0	51900.0	3.00	4.00	MNB775	0.70	---	---	---
149	101100.0	51900.0	4.00	5.00	MNB776	0.70	---	---	---
150	101100.0	51800.0	0.00	1.00	MNB767	3.00	---	---	---
150	101100.0	51800.0	1.00	2.00	MNB768	0.70	---	---	---
150	101100.0	51800.0	2.00	3.00	MHN813	<0.30	---	---	---
150	101100.0	51800.0	2.00	3.00	MNB769	0.70	---	---	---
150	101100.0	51800.0	3.00	4.00	MNB770	0.70	---	---	---
150	101100.0	51800.0	4.00	5.00	MNB771	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
151	101100.0	51700.0	0.00	1.00	MNB762	2.00	---	---	---
151	101100.0	51700.0	1.00	2.00	MNB763	0.70	---	---	---
151	101100.0	51700.0	2.00	3.00	MNB764	0.70	---	---	---
151	101100.0	51700.0	3.00	4.00	MNB765	1.00	---	---	---
151	101100.0	51700.0	4.00	5.00	MNB766	0.70	---	---	---
152	101104.0	51601.0	0.00	1.00	MNB757	2.30	---	---	---
152	101104.0	51601.0	1.00	2.00	MNB758	0.70	---	---	---
152	101104.0	51601.0	2.00	3.00	MHN812	<0.30	---	---	---
152	101104.0	51601.0	2.00	3.00	MNB759	1.00	---	---	---
152	101104.0	51601.0	3.00	4.00	MNB760	1.00	---	---	---
152	101104.0	51601.0	4.00	5.00	MNB761	1.00	---	---	---
244	101400.0	52000.0	0.00	1.00	MNB983	3.60	---	---	---
244	101400.0	52000.0	1.00	2.00	MNB984	1.30	---	---	---
244	101400.0	52000.0	2.00	3.00	MNB985	1.30	---	---	---
244	101400.0	52000.0	3.00	4.00	MNB986	1.00	---	---	---
244	101400.0	52000.0	4.00	5.00	MNB987	0.70	---	---	---
250	101299.0	52088.0	0.00	1.00	MNC554	1.30	---	---	---
250	101299.0	52088.0	1.00	2.00	MNC555	0.70	---	---	---
250	101299.0	52088.0	2.00	3.00	MNC556	0.70	---	---	---
250	101299.0	52088.0	3.00	4.00	MNC557	0.30	---	---	---
250	101299.0	52088.0	4.00	5.00	MNC558	0.30	---	---	---
250	101299.0	52088.0	5.00	6.00	MNC559	0.30	---	---	---
251	101400.0	51800.0	2.00	3.00	MNC448	1.00	---	---	---
251	101400.0	51800.0	3.00	4.00	MNC449	1.00	---	---	---
251	101400.0	51800.0	4.00	5.00	MNC450	0.70	---	---	---
251	101400.0	51800.0	5.00	6.00	MNC451	0.70	---	---	---
313	99937.0	51476.0	0.00	1.00	MNC760	3.00	---	---	3.90
313	99937.0	51476.0	1.00	2.00	MNC761	0.30	---	---	1.50
313	99937.0	51476.0	15.00	16.00	MNC775	<0.30	---	---	0.90
313	99937.0	51476.0	16.00	17.00	MNC776	<0.30	---	---	0.40
313	99937.0	51476.0	17.00	18.00	MNC777	<0.30	---	---	0.70
314	99927.0	51403.0	0.00	1.00	MHN858	4.60	---	---	2.50
314	99927.0	51403.0	0.00	1.00	MNC738	4.60	---	---	2.50
314	99927.0	51403.0	1.00	2.00	MNC739	2.30	---	---	1.60
314	99927.0	51403.0	19.00	20.00	MNC757	<0.30	---	---	0.80
314	99927.0	51403.0	20.00	21.00	MNC758	<0.30	---	---	0.70
315	99925.0	51300.0	0.00	1.00	MNC714	8.30	---	---	3.60
315	99925.0	51300.0	21.00	22.00	MNC735	<0.30	---	---	0.60
315	99925.0	51300.0	22.00	23.00	MNC736	<0.30	---	---	0.70

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4
Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
316	99923.0	51197.0	0.00	1.00	MHN857	3.00	---	---	3.90
316	99923.0	51197.0	0.00	1.00	MNC666	3.00	---	---	3.60
316	99923.0	51197.0	1.00	2.00	MNC667	1.00	---	---	0.90
316	99923.0	51197.0	12.00	13.00	MNC678	<0.30	---	---	1.10
316	99923.0	51197.0	13.00	14.00	MNC679	<0.30	---	---	1.70
317	99919.0	51102.0	0.00	1.00	MNC692	2.60	---	---	3.50
317	99919.0	51102.0	1.00	2.00	MNC693	2.30	---	---	2.30
317	99919.0	51102.0	16.00	17.00	MNC708	<0.30	---	---	1.20
317	99919.0	51102.0	20.00	21.00	MNC712	<0.30	---	---	0.70
321	99957.0	51601.0	0.00	1.00	MNC778	---	---	---	2.20
321	99957.0	51601.0	1.00	2.00	MNC779	---	---	---	1.10
321	99957.0	51601.0	21.00	22.00	MNC799	<0.30	---	---	0.30
322	99993.0	51705.0	0.00	1.00	MHN773	0.30	---	---	1.40
322	99993.0	51705.0	0.00	1.00	MNC856	---	---	---	2.30
322	99993.0	51705.0	1.00	2.00	MNC857	---	---	---	1.20
322	99993.0	51705.0	16.00	17.00	MHN774	0.70	---	---	1.00
322	99993.0	51705.0	17.00	18.00	MNC873	<0.30	---	---	0.30
322	99993.0	51705.0	19.00	20.00	MNC875	<0.70	---	---	0.20
325	100006.0	51499.0	0.00	1.00	MHN866	1.30	---	---	---
325	100006.0	51499.0	0.00	1.00	MNC802	1.30	---	---	---
325	100006.0	51499.0	1.00	2.00	MNC803	0.30	---	---	---
325	100006.0	51499.0	15.00	16.00	MNC817	<0.30	---	---	---
325	100006.0	51499.0	16.00	17.00	MNC818	<0.30	---	---	---
325	100006.0	51499.0	17.00	17.50	MNC819	<0.30	---	---	---
326	100000.0	51400.0	0.00	1.00	MNC820	4.60	---	---	---
326	100000.0	51400.0	1.00	2.00	MNC821	0.70	---	---	---
326	100000.0	51400.0	15.00	15.50	MNC835	<0.30	---	---	0.60
326	100000.0	51400.0	16.00	17.00	MNC836	---	---	---	0.30
326	100000.0	51400.0	17.00	18.00	MNC837	<0.30	---	---	---
327	100000.0	51300.0	0.00	1.00	MHN785	---	---	---	2.00
327	100000.0	51300.0	0.00	1.00	MNB924	---	---	---	2.20
327	100000.0	51300.0	1.00	2.00	MNB925	---	---	---	2.20
328	99984.0	51201.0	0.00	1.00	MNB929	---	---	---	2.90
328	99984.0	51201.0	1.00	2.00	MNB930	---	---	---	2.00
328	99984.0	51201.0	2.00	3.00	MNB931	---	---	---	1.20
328	99984.0	51201.0	3.00	4.00	MNB932	---	---	---	1.20
328	99984.0	51201.0	4.00	5.00	MNB933	---	---	---	1.30
328	99984.0	51201.0	5.00	6.00	MNB934	---	---	---	1.00
328	99984.0	51201.0	6.00	7.00	MNB935	---	---	---	1.50
328	99984.0	51201.0	7.00	8.00	MNB936	---	---	---	1.00

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
328	99984.0	51201.0	8.00	9.00	MNB937	---	---	---	1.10
328	99984.0	51201.0	9.00	10.00	MNB938	---	---	---	1.10
329	99984.0	51201.0	10.00	11.00	MNB939	---	---	---	1.10
328	99984.0	51201.0	11.00	12.00	MNB940	---	---	---	1.20
328	99984.0	51201.0	12.00	13.00	MNB941	---	---	---	1.80
328	99984.0	51201.0	13.00	14.00	MHN786	---	---	---	0.70
328	99984.0	51201.0	13.00	14.00	MNB942	---	---	---	1.70
330	100000.0	51100.0	0.00	1.00	MNB954	---	---	---	2.00
330	100000.0	51100.0	1.00	2.00	MNB955	---	---	---	1.60
334	100036.0	51799.0	0.00	1.00	MNC876	4.00	---	---	2.40
334	100036.0	51799.0	1.00	2.00	MNC877	0.30	---	---	1.20
334	100036.0	51799.0	15.00	16.00	MNC891	<0.30	---	---	0.30
334	100036.0	51799.0	17.00	18.00	MNC893	<0.30	---	---	0.20
336	100100.0	51800.0	0.00	1.00	MNB848	3.80	---	---	---
336	100100.0	51800.0	1.00	2.00	MNB849	0.70	---	---	---
336	100100.0	51800.0	2.00	3.00	MNB850	0.70	---	---	---
336	100100.0	51800.0	3.00	4.00	MNB851	0.30	---	---	---
336	100100.0	51800.0	4.00	5.00	MNB852	0.30	---	---	---
337	100100.0	51600.0	0.00	1.00	MNB863	3.60	---	---	1.70
337	100100.0	51600.0	1.00	2.00	MNB864	1.00	---	---	1.30
337	100100.0	51600.0	2.00	3.00	MNB865	1.00	---	---	1.20
337	100100.0	51600.0	3.00	4.00	MNB866	0.70	---	---	1.00
337	100100.0	51600.0	4.00	5.00	MNB867	0.70	---	---	1.10
338	100100.0	51500.0	0.00	1.00	MNB909	---	---	---	1.40
338	100100.0	51500.0	1.00	2.00	MNB910	---	---	---	1.20
338	100100.0	51500.0	2.00	3.00	MNB911	---	---	---	1.20
338	100100.0	51500.0	3.00	4.00	MNB912	---	---	---	1.40
338	100100.0	51500.0	4.00	5.00	MNB913	---	---	---	1.10
339	100200.0	51800.0	0.00	1.00	MNB824	15.20	---	---	4.90
339	100200.0	51800.0	1.00	2.00	MNB825	26.10	---	---	2.80
339	100200.0	51800.0	2.00	3.00	MNB826	1.00	---	---	1.60
339	100200.0	51800.0	3.00	4.00	MNB827	1.00	---	---	1.20
339	100200.0	51800.0	4.00	5.00	MNB928	0.70	---	---	0.90
340	100200.0	51704.0	0.00	1.00	MNB836	---	---	---	4.10
340	100200.0	51704.0	1.00	2.00	MHN715	---	---	---	2.50
340	100200.0	51704.0	1.00	2.00	MNB837	---	---	---	1.50
340	100200.0	51704.0	2.00	3.00	MNB838	---	---	---	1.60
340	100200.0	51704.0	3.00	4.00	MNB839	---	---	---	1.10
340	100200.0	51704.0	4.00	5.00	MNB840	---	---	---	1.30
340	100200.0	51704.0	5.00	6.00	MNB841	---	---	---	1.00

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
340	100200.0	51704.0	6.00	7.00	MNB842	---	---	---	1.90
341	100193.0	51600.0	0.00	1.00	MNB868	37.40	---	---	2.60
341	100193.0	51600.0	1.00	2.00	MNB869	14.90	---	---	1.50
341	100133.0	51600.0	2.00	3.00	MNB870	3.00	---	---	1.20
341	100193.0	51600.0	3.00	4.00	MNB871	1.00	---	---	1.10
341	100193.0	51600.0	4.00	5.00	MNB872	1.30	---	---	1.40
341	100193.0	51600.0	5.00	6.00	MNB873	0.70	---	---	1.00
342	100200.0	51500.0	0.00	1.00	MNB879	---	---	---	1.60
342	100200.0	51500.0	1.00	2.00	MNB880	---	---	---	1.10
342	100200.0	51500.0	2.00	3.00	MNB881	---	---	---	1.10
342	100200.0	51500.0	3.00	4.00	MNB882	---	---	---	1.20
342	100200.0	51500.0	4.00	5.00	MNB883	---	---	---	0.80
343	100200.0	51400.0	0.00	1.00	MNB899	5.30	---	---	1.50
343	100200.0	51400.0	1.00	2.00	MNB900	1.00	---	---	1.30
343	100200.0	51400.0	2.00	3.00	MNB901	1.00	---	---	1.40
343	100200.0	51400.0	3.00	4.00	MNB902	0.70	---	---	1.50
343	100200.0	51400.0	4.00	5.00	MNB903	0.70	---	---	1.40
344	100300.0	52000.0	0.00	1.00	MNB802	---	---	---	1.50
344	100300.0	52000.0	1.00	2.00	MNB803	---	---	---	1.60
344	100300.0	52000.0	2.00	3.00	MNB804	---	---	---	1.40
344	100300.0	52000.0	3.00	4.00	MNB805	---	---	---	1.20
344	100300.0	52000.0	4.00	5.00	MNB806	---	---	---	0.90
345	100300.0	51900.0	0.00	1.00	MNC386	9.30	---	---	1.70
345	100300.0	51900.0	1.00	2.00	MNC387	6.00	---	---	1.10
345	100300.0	51900.0	2.00	3.00	MNC388	1.30	---	---	1.00
345	100300.0	51900.0	3.00	4.00	MHN769	0.30	---	---	1.10
345	100300.0	51900.0	3.00	4.00	MNC389	0.70	---	---	1.30
345	100300.0	51900.0	4.00	5.00	MNC390	0.70	---	---	1.10
345	100300.0	51900.0	5.00	6.00	MNC391	1.00	---	---	0.90
345	100300.0	51900.0	6.00	7.00	MNC392	0.70	---	---	0.90
345	100300.0	51900.0	7.00	8.00	MNC393	1.00	---	---	0.70
345	100300.0	51900.0	8.00	9.00	MNC394	0.70	---	---	0.60
345	100300.0	51900.0	9.00	10.00	MNC395	0.70	---	---	0.60
345	100300.0	51900.0	10.00	11.00	MHN770	0.30	---	---	0.90
345	100300.0	51900.0	10.00	11.00	MNC396	0.30	---	---	0.70
345	100300.0	51900.0	11.00	12.00	MNC397	0.30	---	---	0.40
345	100300.0	51900.0	12.00	13.00	MNC398	0.30	---	---	0.30
345	100300.0	51900.0	13.00	14.00	MNC399	0.30	---	---	0.60
345	100300.0	51900.0	14.00	15.00	MNC400	0.30	---	---	0.50
345	100300.0	51900.0	15.00	16.00	MNC401	0.30	---	---	0.60
345	100300.0	51900.0	16.00	17.00	MNC402	<0.30	---	---	0.30
345	100300.0	51900.0	17.00	17.50	MNC403	<0.30	---	---	0.50

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
345	100300.0	51900.0	19.00	20.00	MNC404	<0.30	---	---	0.40
346	100300.0	51800.0	0.00	1.00	MNB817	---	---	---	17.60
346	100300.0	51800.0	1.00	2.00	MNB818	---	---	---	5.60
346	100300.0	51800.0	2.00	3.00	MNB819	---	---	---	4.30
346	100300.0	51800.0	3.00	4.00	MNB820	---	---	---	1.70
346	100300.0	51800.0	4.00	5.00	MNB821	---	---	---	2.00
346	100300.0	51800.0	5.00	6.00	MNB822	---	---	---	1.10
346	100300.0	51800.0	6.00	7.00	MNB823	---	---	---	0.80
347	100300.0	51700.0	0.00	1.00	MNB829	989.70	---	---	18.00
347	100300.0	51700.0	1.00	2.00	MNB830	2105.00	---	---	33.00
347	100300.0	51700.0	2.00	3.00	MNB831	850.70	---	---	14.00
347	100300.0	51700.0	3.00	4.00	MNB832	39.10	---	---	1.20
347	100300.0	51700.0	4.00	5.00	MNB833	6.30	---	---	1.30
347	100300.0	51700.0	5.00	6.00	MNB834	2.60	---	---	2.60
347	100300.0	51700.0	6.00	7.00	MHN720	1.30	---	---	1.00
347	100300.0	51700.0	6.00	7.00	MNB835	1.00	---	---	0.90
348	100323.0	51507.0	0.00	1.00	MNB874	---	---	---	11.40
348	100323.0	51507.0	1.00	2.00	MNB875	---	---	---	6.40
348	100323.0	51507.0	2.00	3.00	MNB876	---	---	---	0.90
348	100323.0	51507.0	3.00	4.00	MHN783	---	---	---	0.90
348	100323.0	51507.0	3.00	4.00	MNB877	---	---	---	0.80
348	100323.0	51507.0	4.00	5.00	MNB878	---	---	---	1.20
349	100300.0	51500.0	0.00	1.00	MNB884	32.40	---	---	97.20
349	100300.0	51500.0	1.00	2.00	MNB885	7.60	---	---	2.70
349	100300.0	51500.0	2.00	3.00	MNB886	1.30	---	---	2.10
349	100300.0	51500.0	3.00	4.00	MNB887	0.70	---	---	1.50
349	100300.0	51500.0	4.00	5.00	MNB888	0.30	---	---	0.80
350	100300.0	51400.0	0.00	1.00	MNB894	---	---	---	1.00
350	100300.0	51400.0	1.00	2.00	MNB895	---	---	---	123.00
350	100300.0	51400.0	2.00	3.00	MNB896	---	---	---	6.00
350	100300.0	51400.0	3.00	4.00	MNB897	---	---	---	2.50
350	100300.0	51400.0	4.00	5.00	MHN784	---	---	---	1.70
350	100300.0	51400.0	4.00	5.00	MNB898	---	---	---	2.40
351	100310.0	52100.0	0.00	1.00	MNB787	2.00	---	---	2.50
351	100310.0	52100.0	1.00	2.00	MNB788	1.00	---	---	1.20
351	100310.0	52100.0	2.00	3.00	MNB789	0.70	---	---	1.30
351	100310.0	52100.0	3.00	4.00	MHN718	0.70	---	---	1.50
351	100310.0	52100.0	3.00	4.00	MNB790	0.30	---	---	0.90
351	100310.0	52100.0	4.00	5.00	MNB791	<0.30	---	---	1.30
352	100400.0	52200.0	0.00	1.00	MNB797	---	---	---	1.60

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
352	100400.0	52200.0	1.00	2.00	MNB798	---	---	---	1.30
352	100400.0	52200.0	2.00	3.00	MNB799	---	---	---	0.90
352	100400.0	52200.0	3.00	4.00	MHN713	---	---	---	0.90
352	100400.0	52200.0	3.00	4.00	MNB800	---	---	---	1.00
352	100400.0	52200.0	4.00	5.00	MNB801	---	---	---	1.20
353	100400.0	52100.0	0.00	1.00	MNB792	9.30	---	---	6.30
353	100400.0	52100.0	1.00	2.00	MNB793	2.60	---	---	1.20
353	100400.0	52100.0	2.00	3.00	MNB794	0.70	---	---	1.70
353	100400.0	52100.0	3.00	4.00	MNB795	0.30	---	---	1.40
353	100400.0	52100.0	4.00	5.00	MNB796	0.30	---	---	1.30
354	100400.0	52000.0	0.00	1.00	MNC371	---	---	---	3.90
354	100400.0	52000.0	1.00	2.00	MNC372	---	---	---	1.70
354	100400.0	52000.0	2.00	3.00	MNC373	---	---	---	1.00
354	100400.0	52000.0	3.00	4.00	MHN788	---	---	---	1.20
354	100400.0	52000.0	3.00	4.00	MNC374	---	---	---	1.20
354	100400.0	52000.0	4.00	5.00	MNC375	---	---	---	1.40
354	100400.0	52000.0	5.00	6.00	MNC376	---	---	---	0.90
354	100400.0	52000.0	6.00	7.00	MNC377	---	---	---	0.60
354	100400.0	52000.0	7.00	8.00	MNC378	---	---	---	0.70
354	100400.0	52000.0	8.00	9.00	MNC379	---	---	---	0.90
354	100400.0	52000.0	9.00	10.00	MNC380	---	---	---	0.70
354	100400.0	52000.0	10.00	11.00	MNC381	---	---	---	0.40
354	100400.0	52000.0	13.00	14.00	MNC384	---	---	---	0.30
354	100400.0	52000.0	14.00	15.00	MNC385	---	---	---	0.30
355	100400.0	51900.0	0.00	1.00	MNB807	4.60	---	---	1.30
355	100400.0	51900.0	1.00	2.00	MNB808	3.30	---	---	1.60
355	100400.0	51900.0	2.00	3.00	MHN719	<0.30	---	---	1.20
355	100400.0	51900.0	2.00	3.00	MNB809	1.30	---	---	1.40
355	100400.0	51900.0	3.00	4.00	MNB810	1.00	---	---	1.00
355	100400.0	51900.0	4.00	5.00	MNB811	1.70	---	---	1.80
356	100384.0	51812.0	0.00	1.00	MNB812	---	---	---	6.80
356	100384.0	51812.0	1.00	2.00	MNB813	---	---	---	1.50
356	100384.0	51812.0	2.00	3.00	MNB814	---	---	---	1.70
356	100384.0	51812.0	3.00	4.00	MHN714	---	---	---	1.20
356	100384.0	51812.0	3.00	4.00	MNB815	---	---	---	0.70
356	100384.0	51812.0	4.00	5.00	MNB816	---	---	---	0.40
357	100600.0	52100.0	0.00	1.00	MML394	4.00	---	---	1.20
357	100600.0	52100.0	1.00	2.00	MML395	0.30	---	---	1.40
357	100600.0	52100.0	2.00	3.00	MML396	0.30	---	---	1.10
357	100600.0	52100.0	3.00	4.00	MML397	0.30	---	---	1.20
357	100600.0	52100.0	4.00	5.00	MHN874	0.70	---	---	1.50
357	100600.0	52100.0	4.00	5.00	MML398	0.30	---	---	1.00

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
357	100600.0	52100.0	5.00	6.00	MML399	0.30	---	---	1.00
357	100600.0	52100.0	6.00	7.00	MML400	0.30	---	---	1.20
357	100600.0	52100.0	7.00	8.00	MML401	0.30	---	---	1.40
357	100600.0	52100.0	8.00	9.00	MML402	0.30	---	---	1.80
357	100600.0	52100.0	9.00	10.00	MML403	<0.30	---	---	0.90
357	100600.0	52100.0	10.00	11.00	MML404	<0.30	---	---	0.80
358	100776.0	51865.0	0.00	1.00	MML405	2.30	---	---	1.40
358	100776.0	51865.0	1.00	2.00	MHN875	0.30	---	---	1.10
358	100776.0	51865.0	1.00	2.00	MML406	0.30	---	---	1.40
358	100776.0	51865.0	2.00	3.00	MML407	<0.30	---	---	1.30
358	100776.0	51865.0	3.00	4.00	MML408	<0.30	---	---	1.40
358	100776.0	51865.0	4.00	5.00	MML409	<0.30	---	---	1.30
358	100776.0	51865.0	5.00	6.00	MML410	<0.30	---	---	0.80
358	100776.0	51865.0	6.00	7.00	MML411	<0.30	---	---	0.80
358	100776.0	51865.0	7.00	8.00	MML412	<0.30	---	---	0.50
359	100500.0	51600.0	0.00	1.00	MNC424	6.00	---	---	4.00
359	100500.0	51600.0	1.00	2.00	MNC425	7.00	---	---	4.80
359	100500.0	51600.0	2.00	3.00	MNC426	0.70	---	---	1.30
359	100500.0	51600.0	3.00	4.00	MNC427	0.70	---	---	1.30
359	100500.0	51600.0	4.00	5.00	MNC428	0.70	---	---	1.20
359	100500.0	51600.0	5.00	6.00	MNC429	0.70	---	---	1.10
359	100500.0	51600.0	6.00	7.00	MNC430	0.70	---	---	0.80
359	100500.0	51600.0	7.00	8.00	MNC431	0.70	---	---	0.70
359	100500.0	51600.0	8.00	8.92	MNC432	<0.30	---	---	0.50
360	100100.0	51700.0	0.00	1.00	MNB843	4.60	---	---	1.10
360	100100.0	51700.0	1.00	2.00	MNB844	1.30	---	---	1.60
360	100100.0	51700.0	2.00	3.00	MNB845	1.00	---	---	1.50
360	100100.0	51700.0	3.00	4.00	MNB846	0.30	---	---	1.80
360	100100.0	51700.0	4.00	5.00	MNB847	0.30	---	---	1.00
361	100100.0	51400.0	0.00	1.00	MNB904	3.60	---	---	2.40
361	100100.0	51400.0	1.00	2.00	MNB905	3.30	---	---	1.10
361	100100.0	51400.0	2.00	3.00	MNB906	0.70	---	---	1.20
361	100100.0	51400.0	3.00	4.00	MNB907	0.70	---	---	1.10
361	100100.0	51400.0	4.00	5.00	MNB908	1.00	---	---	1.20
362	100100.0	51300.0	0.00	1.00	MNB914	4.60	---	---	1.70
362	100100.0	51300.0	1.00	2.00	MNB915	0.70	---	---	1.80
362	100100.0	51300.0	2.00	3.00	MNB916	0.70	---	---	1.10
362	100100.0	51300.0	3.00	4.00	MNB917	0.70	---	---	1.10
362	100100.0	51300.0	4.00	5.00	MNB918	0.70	---	---	2.70
363	100100.0	51200.0	0.00	1.00	MNB919	4.30	---	---	2.00
363	100100.0	51200.0	1.00	2.00	MNB920	3.60	---	---	1.50

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
363	100100.0	51200.0	2.00	3.00	MNB921	2.60	---	---	1.20
363	100100.0	51200.0	3.00	4.00	MNB922	1.00	---	---	1.40
363	100100.0	51200.0	4.00	5.00	MNB923	1.30	---	---	1.30
364	100100.0	51100.0	0.00	1.00	MNB551	0.70	---	---	1.50
364	100100.0	51100.0	1.00	2.00	MNB552	<0.30	---	---	0.80
364	100100.0	51100.0	2.00	3.00	MNB553	0.70	---	---	1.10
364	100100.0	51100.0	3.00	4.00	MNB554	1.30	---	---	1.10
364	100100.0	51100.0	4.00	5.00	MNB555	0.30	---	---	0.80
365	100200.0	51900.0	0.00	1.00	MNB853	9.90	---	---	3.10
365	100200.0	51900.0	1.00	2.00	MNB854	1.70	---	---	1.20
365	100200.0	51900.0	2.00	3.00	MNB855	0.70	---	---	1.10
365	100200.0	51900.0	3.00	4.00	MNB856	1.00	---	---	1.00
365	100200.0	51900.0	4.00	5.00	MNB857	0.70	---	---	1.30
366	100200.0	51300.0	0.00	1.00	MNC405	3.60	---	---	2.40
366	100200.0	51300.0	1.00	2.00	MNC406	4.00	---	---	1.50
366	100200.0	51300.0	2.00	3.00	MNC407	3.30	---	---	1.70
366	100200.0	51300.0	3.00	4.00	MNC408	3.30	---	---	1.40
366	100200.0	51300.0	4.00	5.00	MNC409	1.00	---	---	1.50
366	100200.0	51300.0	5.00	6.00	MNC410	1.00	---	---	1.40
366	100200.0	51300.0	6.00	7.00	MHN771	0.70	---	---	1.10
366	100200.0	51300.0	6.00	7.00	MNC411	0.70	---	---	1.40
366	100200.0	51300.0	7.00	8.00	MNC412	1.00	---	---	1.00
367	100200.0	51200.0	0.00	1.00	MHN717	2.30	---	---	1.50
367	100200.0	51200.0	0.00	1.00	MNB591	2.30	---	---	1.30
367	100200.0	51200.0	1.00	2.00	MNB592	1.30	---	---	0.90
367	100200.0	51200.0	2.00	3.00	MNB593	1.00	---	---	1.00
367	100200.0	51200.0	3.00	4.00	MNB594	1.00	---	---	0.80
367	100200.0	51200.0	4.00	5.00	MNB595	1.70	---	---	0.90
367	100200.0	51200.0	5.00	6.00	MNB596	1.70	---	---	0.80
367	100200.0	51200.0	6.00	7.00	MNB597	1.00	---	---	0.30
368	100300.0	51200.0	0.00	1.00	MNB586	1.30	---	---	1.40
368	100300.0	51200.0	1.00	2.00	MNB587	0.70	---	---	1.40
368	100300.0	51200.0	2.00	3.00	MNB588	0.70	---	---	1.00
368	100300.0	51200.0	3.00	4.00	MNB589	3.30	---	---	0.70
368	100300.0	51200.0	4.00	5.00	MNB590	0.30	---	---	0.50
414	100820.0	52545.0	3.00	4.00	MML413	43.00	---	---	1.00
414	100820.0	52545.0	4.00	5.00	MML414	42.40	---	---	0.70
414	100820.0	52545.0	5.00	6.00	MML415	0.70	---	---	0.80
414	100820.0	52545.0	6.00	6.25	MML416	<0.30	---	---	0.70
414	100820.0	52545.0	8.00	8.25	MHN876	<0.30	---	---	0.40
414	100820.0	52545.0	8.00	8.25	MML417	1.00	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
415	100684.0	51600.0	0.00	1.00	MNB640	5.60	---	---	---
415	100684.0	51600.0	1.00	2.00	MNB641	2.00	---	---	---
415	100684.0	51600.0	2.00	3.00	MNB642	1.00	---	---	---
415	100684.0	51600.0	3.00	4.00	MHN801	<0.30	---	---	---
415	100684.0	51600.0	3.00	4.00	MNB643	0.70	---	---	---
415	100684.0	51600.0	4.00	5.00	MNB644	0.70	---	---	---
416	100600.0	51600.0	0.00	1.00	MNB635	8.30	---	---	---
416	100600.0	51600.0	1.00	2.00	MHN800	1.30	---	---	---
416	100600.0	51600.0	1.00	2.00	MNB636	2.30	---	---	---
416	100600.0	51600.0	2.00	3.00	MNB637	1.00	---	---	---
416	100600.0	51600.0	3.00	4.00	MNB638	1.00	---	---	---
416	100600.0	51600.0	4.00	5.00	MNB639	0.70	---	---	---
417	100600.0	52000.0	0.00	0.50	MNC075	122.50	---	---	---
417	100600.0	52000.0	0.50	1.00	MNC077	109.20	---	---	---
417	100600.0	52000.0	1.00	1.50	MNC095	39.40	---	---	---
418	100600.0	51900.0	0.00	0.50	MNC078	125.80	---	---	---
418	100600.0	51900.0	0.50	1.00	MNC079	76.10	---	---	---
418	100600.0	51900.0	1.00	2.00	MNC096	37.40	---	---	---
419	100500.0	51800.0	0.00	0.50	MNC081	142.30	---	---	---
419	100500.0	51800.0	0.50	1.00	MHN727	43.00	---	---	---
419	100500.0	51800.0	0.50	1.00	MNC082	55.90	---	---	---
419	100500.0	51800.0	1.00	2.00	MNC097	42.40	---	---	---
419	100500.0	51800.0	2.00	3.00	MNC098	149.00	---	---	---
420	100600.0	51800.0	0.00	0.50	MNC083	14.20	---	---	---
420	100600.0	51600.0	0.50	1.00	MNC084	7.60	---	---	---
420	100600.0	51600.0	1.00	2.00	MNC099	28.50	---	---	---
420	100600.0	51800.0	2.00	3.00	MNC100	39.10	---	---	---
420	100600.0	51800.0	3.00	4.00	MNC101	11.90	---	---	---
421	100900.0	51900.0	0.00	1.00	MNB782	1.30	---	---	---
421	100900.0	51900.0	1.00	2.00	MNB783	0.70	---	---	---
421	100900.0	51900.0	2.00	3.00	MNB784	0.70	---	---	---
421	100900.0	51900.0	3.00	4.00	MNB785	0.30	---	---	---
421	100900.0	51900.0	4.00	5.00	MNB786	0.30	---	---	---
426	100799.0	52535.0	0.00	1.00	MNE727	109.90	---	---	---
426	100799.0	52535.0	1.00	1.50	MNE728	78.40	---	---	---
428	101100.0	52400.0	0.00	1.00	MNC560	4.60	---	---	---
428	101100.0	52400.0	1.00	2.00	MNC561	0.30	---	---	---
428	101100.0	52400.0	2.00	3.00	MNC562	<0.30	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
428	101100.0	52400.0	3.00	4.00	MNC563	0.30	---	---	---
428	101100.0	52400.0	4.00	5.00	MHN831	<0.30	---	---	---
428	101100.0	52400.0	4.00	5.00	MNC564	0.30	---	---	---
428	101100.0	52400.0	5.00	6.00	MNC565	0.30	---	---	---
500	100550.0	51900.0	0.00	1.00	WSC279	118.20	5.80	2.90	---
500	100550.0	51900.0	1.00	2.00	WSC280	60.10	7.10	2.10	---
500	100550.0	51900.0	4.00	5.00	WSC283	20.50	1.80	1.60	---
500	100550.0	51900.0	5.00	6.00	WSC284	11.10	1.40	1.30	---
500	100550.0	51900.0	6.00	7.00	WSC285	6.30	1.80	1.40	---
500	100550.0	51900.0	7.00	8.00	WSC286	4.30	1.10	1.30	---
500	100550.0	51900.0	8.00	9.00	WSC287	<1.80	1.00	1.20	---
500	100550.0	51900.0	9.00	10.00	WSC288	<1.80	0.80	0.90	---
505	100890.0	51665.0	0.00	1.00	WSC262	<1.60	1.00	1.30	---
505	100890.0	51665.0	1.00	2.00	WSC263	<2.00	1.50	1.40	---
505	100890.0	51665.0	2.00	3.00	WSC264	<1.80	1.30	1.30	---
505	100890.0	51665.0	3.00	4.00	WSC265	<2.00	1.10	1.40	---
505	100890.0	51665.0	4.00	5.00	WSC266	<2.00	0.90	1.60	---
505	100890.0	51665.0	5.00	6.00	WSC267	<1.90	1.00	1.80	---
505	100890.0	51665.0	6.00	6.50	WSC268	<2.00	1.00	1.40	---
673	100200.0	52000.0	0.00	0.50	MNC033	0.70	1.30	1.20	---
674	100200.0	51704.0	0.00	1.00	UNC424	167.80	2.90	1.80	---
674	100200.0	51704.0	1.00	2.00	UNC422	101.10	1.60	1.40	---
675	100200.0	51500.0	0.00	1.00	UNC423	6.40	1.30	1.50	---
675	100200.0	51500.0	1.00	2.00	UNC415	1.90	1.20	0.70	---
678	100300.0	51400.0	2.00	3.00	UNC421	14.30	1.90	1.90	---
678	100300.0	51400.0	3.00	4.00	UNC417	10.60	1.40	1.60	---
680	100384.0	51812.0	0.00	1.00	UNC414	81.50	3.90	2.60	---
680	100384.0	51812.0	1.00	2.00	UNC413	65.40	1.30	1.20	---
681	100400.0	52000.0	0.00	1.00	UNC418	10.60	2.30	1.20	---
686	100500.0	51900.0	0.00	0.50	MNC080	48.70	3.40	2.50	---
687	100500.0	51800.0	0.00	0.50	WSC382	147.00	3.60	5.10	16.80
687	100500.0	51800.0	0.50	1.50	WSC383	89.10	1.20	1.50	2.20
688	100500.0	51700.0	0.00	0.50	MNC087	7.90	4.20	1.90	---
692	100600.0	51700.0	0.00	0.50	MNC089	---	3.90	2.10	---
692	100600.0	51700.0	0.50	1.00	MNC089	6.30	4.50	1.60	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 4

Ash Pond and South Dump Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
693	100600.0	51600.0	0.00	0.50	MNC091	---	5.60	2.40	---
693	100600.0	51600.0	0.00	0.50	UNC403	7.10	6.50	1.80	---
693	100600.0	51600.0	0.50	1.00	MNC092	6.60	6.40	1.90	---
698	100600.0	51700.0	0.00	0.50	UNC402	12.30	5.00	1.60	---
699	100700.0	51800.0	0.00	0.50	MNC085	---	4.40	1.80	---
699	100700.0	51800.0	0.00	0.50	UNC401	2.80	6.20	2.10	---
699	100700.0	51800.0	0.50	1.00	MNC086	5.00	4.60	2.10	---
700	100700.0	51700.0	0.00	0.50	MNC090	3.00	2.10	1.50	---
701	100700.0	51600.0	0.00	0.50	MNC093	4.00	4.40	1.30	---
701	100700.0	51600.0	0.50	1.00	MHN728	3.00	3.80	1.80	---
701	100700.0	51600.0	0.50	1.00	MNC094	4.30	4.10	1.80	---
703	100800.0	52400.0	0.00	0.50	MNC034	2.00	1.10	1.50	---
704	100800.0	51100.0	0.00	0.50	MNC025	3.00	1.30	1.10	---
711	101000.0	51415.0	0.00	0.50	MNC125	2.60	1.00	0.40	---
711	101000.0	51415.0	0.00	0.50	UNC404	3.00	0.60	0.50	---
718	101180.0	51900.0	0.00	0.50	MNC119	6.60	1.30	1.40	---
722	101260.0	52200.0	0.00	0.50	MNC118	2.00	0.80	0.90	—
723	101300.0	51700.0	0.00	0.50	MNC076	2.60	1.20	1.80	---
764	100300.0	51120.0	0.00	0.50	WSC406	148.60	3.70	154.70	---
765	100320.0	51100.0	0.00	0.50	WSC407	21.50	1.40	20.80	—
766	100300.0	51150.0	0.00	0.50	WSC408	67.80	2.30	50.10	---
772	100243.0	51760.0	0.00	2.00	WSC455	351.80	3.30	1.00	—
772	100243.0	51760.0	2.00	3.00	WSC456	914.60	1.40	<0.40	---
773	100315.0	51780.0	0.00	1.00	WSC457	166.80	0.80	0.60	---
774	100430.0	51770.0	0.00	1.00	WSC458	84.40	1.30	0.90	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 5

Northwest Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
101	100100.0	51000.0	0.00	1.00	MNB546	5.60	---	---	---
101	100100.0	51000.0	1.00	2.00	MHN793	0.30	---	---	---
101	100100.0	51000.0	1.00	2.00	MNB547	0.70	---	---	---
101	100100.0	51000.0	2.00	3.00	MNB548	1.00	---	---	---
101	100100.0	51000.0	3.00	4.00	MNB549	0.70	---	---	---
101	100100.0	51000.0	4.00	5.00	MNB550	0.70	---	---	---
104	100200.0	51000.0	0.00	1.00	MNB536	6.00	---	---	---
104	100200.0	51000.0	1.00	2.00	MNB537	7.60	---	---	---
104	100200.0	51000.0	2.00	3.00	MNB538	1.30	---	---	---
104	100200.0	51000.0	3.00	4.00	MNB539	0.30	---	---	---
104	100200.0	51000.0	4.00	5.00	MNB540	0.70	---	---	---
107	100300.0	51000.0	0.00	1.00	MNB531	4.60	---	---	---
107	100300.0	51000.0	1.00	2.00	MNB532	2.60	---	---	---
107	100300.0	51000.0	2.00	3.00	MNB533	3.00	---	---	---
107	100300.0	51000.0	3.00	4.00	MNB534	7.90	---	---	---
107	100300.0	51000.0	4.00	5.00	MNB535	4.00	---	---	---
125	100600.0	50700.0	0.00	1.00	MNC413	10.30	---	---	---
125	100600.0	50700.0	1.00	2.00	MNC414	18.50	---	---	---
125	100600.0	50700.0	2.00	3.00	MNC415	11.30	---	---	---
125	100600.0	50700.0	3.00	4.00	MNC416	1.70	---	---	---
125	100600.0	50700.0	4.00	5.00	MNC417	2.00	---	---	---
148	101000.0	50100.0	0.00	1.00	MNE784	0.30	---	---	---
148	101000.0	50100.0	1.00	2.00	MNE785	<0.30	---	---	---
155	100243.0	50172.0	0.00	1.00	MNC215	92.00	---	---	1.10
155	100243.0	50172.0	1.00	2.00	MNC216	71.50	---	---	0.50
155	100243.0	50172.0	2.00	3.00	MNC217	9.30	---	---	0.90
155	100243.0	50172.0	3.00	4.00	MNC218	1.00	---	---	1.10
155	100243.0	50172.0	4.00	5.00	MHN766	1.00	---	---	1.00
155	100243.0	50172.0	4.00	5.00	MNC219	1.30	---	---	0.90
156	100456.0	50097.0	0.00	1.00	MNC623	8.60	---	---	2.20
156	100456.0	50097.0	1.00	2.00	MNC619	1.00	---	---	1.10
156	100456.0	50097.0	2.00	3.00	MNC620	1.00	---	---	1.30
156	100456.0	50097.0	3.00	4.00	MNC621	1.00	---	---	1.40
156	100456.0	50097.0	4.00	5.00	MNC622	1.00	---	---	1.20
158	100715.0	50229.0	0.00	1.00	MHN816	24.20	---	---	---
158	100715.0	50229.0	0.00	1.00	MNB949	23.80	---	---	---
158	100715.0	50229.0	1.00	2.00	MNB950	4.30	---	---	---
158	100715.0	50229.0	2.00	3.00	MNB951	0.70	---	---	---
158	100715.0	50229.0	3.00	4.00	MNB952	0.70	---	---	---
158	100715.0	50229.0	4.00	5.00	MNB953	0.30	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 5

Northwest Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
192	100095.0	50165.0	0.00	1.00	MNB283	0.70	---	---	---
192	100095.0	50165.0	1.00	2.00	MNB284	1.30	---	---	---
192	100095.0	50165.0	2.00	3.00	MHN746	<0.30	---	---	---
192	100095.0	50165.0	2.00	3.00	MNB285	0.70	---	---	---
192	100095.0	50165.0	3.00	4.00	MNB286	2.30	---	---	---
192	100095.0	50165.0	4.00	5.00	MNB287	10.30	---	---	---
193	100100.0	50800.0	0.00	1.00	MNC593	5.60	---	---	---
193	100100.0	50800.0	1.00	2.00	MNC594	0.70	---	---	---
193	100100.0	50800.0	2.00	3.00	MNC595	<0.30	---	---	---
194	100100.0	50500.0	0.00	1.00	MNB184	12.20	---	---	---
194	100100.0	50500.0	1.00	2.00	MNB185	3.00	---	---	---
194	100100.0	50500.0	2.00	3.00	MNB186	9.90	---	---	---
194	100100.0	50500.0	3.00	4.00	MHN736	20.20	---	---	---
194	100100.0	50500.0	3.00	4.00	MNB187	19.90	---	---	---
194	100100.0	50500.0	4.00	5.00	MNB188	2.00	---	---	---
195	100200.0	50500.0	0.00	1.00	MNB189	4.30	---	---	---
195	100200.0	50500.0	1.00	2.00	MNB190	1.30	---	---	---
195	100200.0	50500.0	2.00	3.00	MNB191	1.30	---	---	---
195	100200.0	50500.0	3.00	4.00	MNB192	0.70	---	---	---
195	100200.0	50500.0	4.00	5.00	MNB193	1.00	---	---	---
197	100113.0	50413.0	0.00	1.00	MHN880	2.60	---	---	---
197	100113.0	50413.0	0.00	1.00	MML344	2.30	---	---	---
197	100113.0	50413.0	1.00	2.00	MML345	<0.30	---	---	---
197	100113.0	50413.0	2.00	3.00	MML346	0.30	---	---	---
197	100113.0	50413.0	3.00	4.00	MML347	<0.30	---	---	---
197	100113.0	50413.0	4.00	5.00	MML348	<0.30	---	---	---
198	100230.0	50080.0	0.00	1.00	MNB288	9.90	---	---	---
198	100230.0	50080.0	1.00	2.00	MNB289	6.60	---	---	---
198	100230.0	50080.0	2.00	3.00	MNB290	1.70	---	---	---
198	100230.0	50080.0	3.00	4.00	MNB291	0.70	---	---	---
198	100230.0	50080.0	4.00	5.00	MHN747	0.30	---	---	---
198	100230.0	50080.0	4.00	5.00	MNB292	1.00	---	---	---
199	100275.0	50220.0	0.00	1.00	MNB278	2.60	---	---	---
199	100275.0	50220.0	1.00	2.00	MNB279	2.00	---	---	---
199	100275.0	50220.0	2.00	3.00	MNB280	3.30	---	---	---
199	100275.0	50220.0	3.00	4.00	MNB281	0.70	---	---	---
199	100275.0	50220.0	4.00	5.00	MNB282	0.70	---	---	---
200	100300.0	50500.0	0.00	1.00	MNB194	6.30	---	---	---
200	100300.0	50500.0	1.00	2.00	MNB195	1.70	---	---	---
200	100300.0	50500.0	2.00	3.00	MNB196	2.30	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 5

Northwest Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
200	100300.0	50500.0	3.00	4.00	MNB197	1.30	---	---	---
200	100300.0	50500.0	4.00	5.00	MNB198	1.30	---	---	---
201	100299.0	50365.0	1.00	2.00	MHN867	4.30	---	---	---
201	100299.0	50365.0	1.00	2.00	MNC959	4.30	---	---	---
201	100299.0	50365.0	2.00	3.00	MNC960	<0.30	---	---	---
201	100299.0	50365.0	3.00	4.00	MNC961	<0.30	---	---	---
201	100299.0	50365.0	4.00	5.00	MNC962	0.30	---	---	---
201	100299.0	50365.0	5.00	6.00	MNC963	<0.30	---	---	1.70
203	100395.0	50500.0	0.00	1.00	MNC548	9.60	---	---	---
203	100395.0	50500.0	1.00	2.00	MNC549	1.00	---	---	---
203	100395.0	50500.0	2.00	3.00	MHN830	<0.30	---	---	---
203	100395.0	50500.0	2.00	3.00	MNC550	<0.30	---	---	---
203	100395.0	50500.0	3.00	4.00	MNC551	<0.30	---	---	---
203	100395.0	50500.0	4.00	5.00	MNC552	<0.30	---	---	---
203	100395.0	50500.0	5.00	6.00	MNC553	<0.30	---	---	---
205	100359.0	50385.0	0.00	1.00	MNC982	23.50	---	---	0.80
205	100359.0	50385.0	1.00	2.00	MNC983	8.90	---	---	0.50
205	100359.0	50385.0	2.00	3.00	MNC984	0.30	---	---	1.20
205	100359.0	50385.0	3.00	4.00	MHN880	0.30	---	---	1.00
205	100359.0	50385.0	3.00	4.00	MNC985	0.30	---	---	0.70
205	100359.0	50385.0	4.00	5.00	MNC986	<0.30	---	---	0.80
206	100491.0	50255.0	0.00	1.00	MNB333	11.30	---	---	---
206	100491.0	50255.0	1.00	2.00	MNB334	9.90	---	---	---
206	100491.0	50255.0	2.00	3.00	MNB335	1.70	---	---	---
206	100491.0	50255.0	3.00	4.00	MNB336	1.00	---	---	---
206	100491.0	50255.0	4.00	5.00	MNB337	1.00	---	---	---
207	100499.0	50406.0	0.00	1.00	MML439	27.80	---	---	---
207	100499.0	50406.0	1.00	2.00	MHN881	13.60	---	---	---
207	100499.0	50406.0	1.00	2.00	MML440	13.20	---	---	---
207	100499.0	50406.0	2.00	3.00	MML441	2.00	---	---	---
207	100499.0	50406.0	3.00	4.00	MML442	<0.30	---	---	---
207	100499.0	50406.0	4.00	5.00	MML443	2.30	---	---	---
211	100530.0	50325.0	0.00	1.00	MNB328	7.90	---	---	---
211	100530.0	50325.0	1.00	2.00	MNB329	6.60	---	---	---
211	100530.0	50325.0	2.00	3.00	MNB330	6.60	---	---	---
211	100530.0	50325.0	3.00	4.00	MNB331	5.00	---	---	---
211	100530.0	50325.0	4.00	5.00	MNB332	1.30	---	---	---
212	100553.0	50056.0	0.00	1.00	MNB394	18.50	---	---	---
212	100553.0	50056.0	1.00	2.00	MNB395	2.00	---	---	---
212	100553.0	50056.0	2.00	3.00	MNB396	9.60	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 5

Northwest Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
212	100553.0	50056.0	3.00	4.00	MNB397	1.00	---	---	---
212	100553.0	50056.0	4.00	5.00	MNB398	5.30	---	---	---
213	100400.0	50100.0	0.00	1.00	MNB293	21.20	---	---	---
213	100400.0	50100.0	1.00	2.00	MNB294	21.50	---	---	---
213	100400.0	50100.0	2.00	3.00	MNB295	6.60	---	---	---
213	100400.0	50100.0	3.00	4.00	MNB296	278.00	---	---	---
213	100400.0	50100.0	4.00	5.00	MNB297	56.30	---	---	---
213	100400.0	50100.0	5.00	6.00	MNB298	420.40	---	---	---
213	100400.0	50100.0	6.00	7.00	MNB299	384.00	---	---	---
213	100400.0	50100.0	7.00	8.00	MNB300	175.40	---	---	---
213	100400.0	50100.0	8.00	9.00	MNB301	80.90	---	---	---
213	100400.0	50100.0	9.00	10.00	MNB302	142.30	---	---	---
213	100400.0	50100.0	10.00	11.00	MNB303	109.90	---	---	---
214	100600.0	50300.0	0.00	1.00	MNB323	2.30	---	---	---
214	100600.0	50300.0	1.00	2.00	MNB324	0.70	---	---	---
214	100600.0	50300.0	3.00	4.00	MHN750	<0.30	---	---	---
214	100600.0	50300.0	3.00	4.00	MNB325	1.00	---	---	---
214	100600.0	50300.0	4.00	5.00	MNB326	1.00	---	---	---
214	100600.0	50300.0	5.00	6.00	MNB327	5.00	---	---	---
217	100645.0	50215.0	0.00	1.00	MHN749	7.30	---	---	---
217	100645.0	50215.0	0.00	1.00	MNB318	7.90	---	---	---
217	100645.0	50215.0	1.00	2.00	MNB319	2.60	---	---	---
217	100645.0	50215.0	2.00	3.00	MNB320	1.00	---	---	---
217	100645.0	50215.0	3.00	4.00	MNB321	0.70	---	---	---
217	100645.0	50215.0	4.00	5.00	MNB322	1.00	---	---	---
220	100765.0	50215.0	0.00	1.00	MNB338	5.60	---	---	---
220	100765.0	50215.0	1.00	2.00	MNB339	3.30	---	---	---
220	100765.0	50215.0	2.00	3.00	MNB340	2.30	---	---	---
220	100765.0	50215.0	3.00	4.00	MHN751	0.70	---	---	---
220	100765.0	50215.0	3.00	4.00	MNB341	1.30	---	---	---
220	100765.0	50215.0	4.00	5.00	MNB342	1.00	---	---	---
224	100900.0	50600.0	0.00	1.00	MNE770	0.30	---	---	---
224	100900.0	50600.0	1.00	2.00	MNE771	<0.30	---	---	---
224	100900.0	50600.0	2.00	3.00	MNE772	<0.30	---	---	---
224	100900.0	50600.0	3.00	4.00	MNE773	<0.30	---	---	---
224	100900.0	50600.0	4.00	5.00	MNE774	<0.30	---	---	---
224	100900.0	50600.0	5.00	6.00	MNE775	<0.30	---	---	1.10
224	100900.0	50600.0	6.00	7.00	MNE776	<0.30	---	---	---
224	100900.0	50600.0	7.00	8.00	MNE777	<0.30	---	---	---
225	100900.0	50400.0	0.00	1.00	MNE764	7.30	---	---	---
225	100900.0	50400.0	1.00	2.00	MNE765	<0.30	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 5

Northwest Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
225	100900.0	50400.0	5.00	6.00	MHN871	<0.30	---	---	---
225	100900.0	50400.0	5.00	6.00	MNE769	<0.30	---	---	---
241	101100.0	49900.0	0.00	1.00	MNC987	2.60	---	---	---
241	101100.0	49900.0	1.00	2.00	MHN868	2.00	---	---	---
241	101100.0	49900.0	1.00	2.00	MNC988	1.70	---	---	---
241	101100.0	49900.0	5.00	6.00	MNC992	<0.30	---	---	---
249	101200.0	50900.0	0.00	1.00	MNE778	2.60	---	---	---
249	101200.0	50800.0	1.00	2.00	MNE779	<0.30	---	---	---
253	101200.0	50500.0	0.00	1.00	MHN869	8.30	---	---	---
253	101200.0	50500.0	0.00	1.00	MNE738	7.60	---	---	---
253	101200.0	50500.0	1.00	2.00	MNE739	2.30	---	---	---
253	101200.0	50500.0	2.00	3.00	MNE740	5.30	---	---	---
253	101200.0	50500.0	3.00	4.00	MNE741	12.60	---	---	---
253	101200.0	50500.0	4.00	5.00	MNE742	1.00	---	---	---
253	101200.0	50500.0	5.00	6.00	MNE743	<0.30	---	---	---
253	101200.0	50500.0	6.00	7.00	MNE744	<0.30	---	---	---
253	101200.0	50500.0	7.00	8.00	MNE745	<0.30	---	---	---
412	100419.0	50100.0	0.00	1.00	MNB306	380.70	---	---	---
412	100419.0	50100.0	1.00	2.00	MNB307	31.10	---	---	---
412	100419.0	50100.0	2.00	3.00	MNB308	7.30	---	---	---
412	100419.0	50100.0	3.00	4.00	MHN748	2.60	---	---	---
412	100419.0	50100.0	3.00	4.00	MNB309	3.30	---	---	---
412	100419.0	50100.0	4.00	5.00	MNB310	2.30	---	---	---
413	100396.0	50099.0	0.00	1.00	MNB311	4.00	---	---	---
413	100396.0	50099.0	1.00	2.00	MNB312	5.60	---	---	---
413	100396.0	50099.0	2.00	3.00	MNB313	1.30	---	---	---
413	100396.0	50099.0	3.00	4.00	MNB314	1.30	---	---	---
413	100396.0	50099.0	4.00	5.00	MNB315	1.30	---	---	---
413	100396.0	50099.0	5.00	6.00	MNB316	6.80	---	---	---
413	100396.0	50099.0	6.00	7.00	MNB317	1.30	---	---	---
502	101300.0	50550.0	0.00	1.00	WSC257	20.30	0.90	<0.50	1.50
502	101300.0	50550.0	1.00	2.00	WSC258	12.60	1.70	1.60	---
502	101300.0	50550.0	2.00	3.00	WSC259	6.00	1.30	1.40	---
502	101300.0	50550.0	3.00	4.00	WSC260	<1.70	1.60	1.50	---
502	101300.0	50550.0	4.00	5.00	WSC261	<1.90	1.20	1.40	---
670	100100.0	50000.0	0.00	0.50	MHN725	142.70	3.90	0.40	---
670	100100.0	50000.0	0.00	0.50	MNC059	185.40	4.80	0.50	---
670	100100.0	50000.0	0.00	0.50	UNC397	201.90	3.10	0.80	---
670	100100.0	50000.0	0.50	1.00	MNC060	162.20	6.20	0.60	---
670	100100.0	50000.0	0.50	1.00	UNC398	174.10	3.60	0.80	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 5

Northwest Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
676	100200.0	50900.0	0.00	0.50	MHN723	6.00	0.80	0.20	—
676	100200.0	50900.0	0.00	0.50	MNC031	8.30	0.70	0.30	—
676	100200.0	50900.0	0.00	0.50	UNC395	10.80	0.90	0.50	—
677	100200.0	50700.0	0.00	0.50	MNC104	6.30	1.40	1.00	---
677	100200.0	50700.0	0.50	1.00	MNC105	2.00	1.10	1.20	---
682	100400.0	50700.0	0.00	0.50	MNC061	33.40	1.50	1.00	---
683	100400.0	50400.0	0.00	0.50	MNC010	6.60	1.30	8.40	---
683	100400.0	50400.0	0.50	1.00	MNC011	28.10	0.70	25.30	---
683	100400.0	50400.0	0.50	1.00	UNC393	46.20	1.50	26.90	---
684	100400.0	50100.0	0.00	0.50	MNC054	13.60	1.60	4.70	---
684	100400.0	50100.0	0.50	1.00	MNC055	37.10	3.10	3.10	---
689	100500.0	50400.0	0.00	0.50	MNC008	6.30	0.70	1.90	---
689	100500.0	50400.0	0.50	1.00	MNC009	4.30	0.40	4.20	---
690	100500.0	50000.0	0.00	0.50	MNC056	70.20	4.60	5.10	---
690	100500.0	50000.0	0.50	1.00	MNC057	198.60	22.30	1.50	---
694	100600.0	51000.0	0.00	0.50	MNC032	4.30	1.90	1.70	---
695	100600.0	50700.0	0.00	0.50	MNC102	7.00	1.30	1.20	---
695	100600.0	50700.0	0.50	1.00	MNC103	7.30	1.00	1.00	---
702	100700.0	50600.0	0.00	0.50	MNC058	---	5.10	2.20	---
702	100700.0	50600.0	0.00	0.50	UNC396	10.90	5.50	2.80	---
705	100800.0	50400.0	0.00	0.50	MNC007	131.10	0.70	5.30	---
712	101000.0	50300.0	0.00	0.50	MNC018	11.60	1.60	1.40	---
714	101100.0	50600.0	0.00	0.50	MNC043	6.60	1.10	1.70	---
714	101100.0	50600.0	0.50	1.00	MNC044	1.70	1.00	1.30	---
715	101100.0	50300.0	0.00	0.50	MNC041	8.30	4.30	1.90	---
715	101100.0	50300.0	0.50	1.00	MNC042	5.60	2.70	1.80	---
716	101100.0	50000.0	0.00	0.50	MNC029	12.90	3.20	2.10	---
720	101200.0	50700.0	0.00	0.50	MNC069	4.00	1.60	0.90	---
724	101300.0	51000.0	0.00	0.50	MNC047	3.60	1.20	1.80	---
724	101300.0	51000.0	0.50	1.00	MNC048	1.00	1.40	1.80	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 5

Northwest Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
725	101300.0	50600.0	0.00	0.50	MNC045	26.10	1.40	1.50	---
725	101300.0	50600.0	0.50	1.00	MNC046	1.30	1.40	1.20	---
771	100420.0	50220.0	0.00	0.50	WSC454	192.90	66.40	107.40	---
775	100860.0	50910.0	0.00	0.50	WSC423	461.10	1.20	1.70	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 6

Northeast Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
157	100550.0	49619.0	0.00	1.00	MNB031	1.00	---	---	---
157	100550.0	49619.0	1.00	1.50	MNB032	0.30	---	---	---
157	100550.0	49619.0	1.50	2.50	MNB033	0.70	---	---	---
157	100550.0	49619.0	2.50	3.50	MNB034	0.70	---	---	---
157	100550.0	49619.0	3.50	4.50	MNB035	0.70	---	---	---
157	100550.0	49619.0	4.50	5.50	MNB036	0.70	---	---	---
159	100795.0	49682.0	0.67	1.00	MHN865	12.60	---	---	---
159	100795.0	49682.0	0.67	1.00	MNC651	12.20	---	---	---
159	100795.0	49682.0	1.00	2.00	MNC652	4.00	---	---	---
159	100795.0	49682.0	2.00	3.00	MNC653	0.70	---	---	---
159	100795.0	49682.0	3.00	4.00	MNC654	0.70	---	---	---
159	100795.0	49682.0	4.00	5.00	MNC650	2.30	---	---	---
159	100795.0	49682.0	4.00	5.00	MNC655	<0.30	---	---	---
160	100775.0	49869.0	0.00	1.00	MNB944	14.20	---	---	1.20
160	100775.0	49869.0	1.00	2.00	MNB943	31.40	---	---	1.00
160	100775.0	49869.0	2.00	3.00	MNB945	1.30	---	---	1.00
160	100775.0	49869.0	3.00	4.00	MNB946	1.00	---	---	1.40
160	100775.0	49869.0	3.00	4.00	MNB947	1.00	---	---	0.70
160	100775.0	49869.0	4.00	5.00	MNB948	0.70	---	---	1.10
196	100300.0	49900.0	0.00	1.00	MNB434	14.60	---	---	---
196	100300.0	49900.0	1.00	2.00	MHN758	3.30	---	---	---
196	100300.0	49900.0	1.00	2.00	MNB435	4.60	---	---	---
196	100300.0	49900.0	2.00	3.00	MNB436	3.30	---	---	---
196	100300.0	49900.0	3.00	4.00	MNB437	2.30	---	---	---
196	100300.0	49900.0	4.00	5.00	MNB438	1.30	---	---	---
202	100340.0	49650.0	0.00	1.00	MNB399	5.30	---	---	---
202	100340.0	49650.0	1.00	2.00	MNB400	2.00	---	---	---
202	100340.0	49650.0	2.00	3.00	MNB426	1.30	---	---	---
202	100340.0	49650.0	3.00	4.00	MNB427	1.30	---	---	---
202	100340.0	49650.0	4.00	5.00	MHN757	0.70	---	---	---
202	100340.0	49650.0	4.00	5.00	MNB428	1.70	---	---	---
204	100420.0	49580.0	0.00	1.00	MNB429	3.30	---	---	---
204	100420.0	49580.0	1.00	2.00	MNB430	1.30	---	---	---
204	100420.0	49580.0	2.00	3.00	MNB431	1.00	---	---	---
204	100420.0	49580.0	3.00	4.00	MNB432	1.30	---	---	---
204	100420.0	49580.0	4.00	5.00	MNB433	1.30	---	---	---
208	100500.0	49900.0	0.00	1.00	MNB348	11.60	---	---	---
208	100500.0	49900.0	1.00	2.00	MNB349	3.00	---	---	---
209	100500.0	49900.0	2.00	3.00	MNB350	1.70	---	---	---
208	100500.0	49900.0	3.00	4.00	MNB351	0.70	---	---	---
208	100500.0	49900.0	4.00	5.00	MNB352	1.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 6

Northeast Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
209	100500.0	49819.0	0.00	1.00	MNB353	6.00	---	---	---
209	100500.0	49819.0	1.00	2.00	MNB354	1.00	---	---	---
209	100500.0	49819.0	2.00	3.00	MNB355	1.00	---	---	---
209	100500.0	49819.0	3.00	4.00	MNB356	0.70	---	---	---
209	100500.0	49819.0	4.00	5.00	MNB357	1.00	---	---	---
210	100500.0	49500.0	0.00	1.00	MNB387	3.60	---	---	---
210	100500.0	49500.0	1.00	2.00	MNB388	0.70	---	---	---
210	100500.0	49500.0	2.00	3.00	MNB389	1.70	---	---	---
210	100500.0	49500.0	3.00	4.00	MNB390	0.70	---	---	---
210	100500.0	49500.0	4.00	5.00	MNB391	0.70	---	---	---
210	100500.0	49500.0	5.00	6.00	MNB392	0.70	---	---	---
210	100500.0	49500.0	6.00	7.00	MHN756	0.30	---	---	---
210	100500.0	49500.0	6.00	7.00	MNB393	1.00	---	---	---
215	100635.0	49850.0	0.00	1.00	MNB367	20.20	---	---	---
215	100635.0	49850.0	1.00	2.00	MNB368	2.00	---	---	---
215	100635.0	49850.0	2.00	3.00	MNB369	1.30	---	---	---
215	100635.0	49850.0	3.00	4.00	MHN754	0.30	---	---	---
215	100635.0	49850.0	3.00	4.00	MNB370	1.30	---	---	---
215	100635.0	49850.0	4.00	5.00	MNB371	0.70	---	---	---
216	100628.0	49700.0	0.00	1.00	MNB372	16.90	---	---	---
216	100628.0	49700.0	1.00	2.00	MNB373	2.00	---	---	---
216	100628.0	49700.0	2.00	3.00	MNB374	1.00	---	---	---
216	100628.0	49700.0	3.00	4.00	MNB375	1.00	---	---	---
216	100628.0	49700.0	4.00	5.00	MNB376	1.30	---	---	---
218	100715.0	49650.0	0.25	1.00	MNB377	16.50	---	---	---
218	100715.0	49650.0	1.00	2.00	MNB378	2.00	---	---	---
218	100715.0	49850.0	2.00	3.00	MNB379	2.00	---	---	---
218	100715.0	49850.0	3.00	4.00	MNB380	1.00	---	---	---
218	100715.0	49650.0	4.00	5.00	MHN755	0.30	---	---	---
218	100715.0	49650.0	4.00	5.00	MNB381	1.30	---	---	---
219	100750.0	49955.0	0.00	1.00	MNB358	66.90	---	---	---
219	100750.0	49955.0	1.00	2.00	MHN752	2.30	---	---	---
219	100750.0	49955.0	1.00	2.00	MNB359	3.30	---	---	---
219	100750.0	49955.0	2.00	3.00	MNB360	1.30	---	---	---
219	100750.0	49955.0	3.00	4.00	MNB361	0.70	---	---	---
219	100750.0	49955.0	4.00	5.00	MNB362	1.00	---	---	---
219	100750.0	49955.0	5.00	6.00	MNB363	1.30	---	---	---
219	100750.0	49955.0	6.00	7.00	MNB364	0.70	---	---	---
219	100750.0	49955.0	7.00	8.00	MNB365	1.70	---	---	---
219	100750.0	49955.0	8.00	9.00	MHN753	<0.30	---	---	---
219	100750.0	49955.0	8.00	9.00	MNB366	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 6

Northeast Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
221	100804.0	49740.0	0.00	1.00	MNB382	1.70	---	---	---
221	100804.0	49740.0	1.00	2.00	MNB383	2.30	---	---	---
221	100804.0	49740.0	2.00	3.00	MNB384	1.30	---	---	---
221	100804.0	49740.0	3.00	4.00	MNB385	1.00	---	---	---
221	100804.0	49740.0	4.00	5.00	MNB386	1.00	---	---	---
222	100800.0	49805.0	0.00	1.00	MNB343	2.00	---	---	---
222	100800.0	49805.0	1.00	2.00	MNB344	2.60	---	---	---
222	100800.0	49805.0	2.00	3.00	MNB345	2.30	---	---	---
222	100800.0	49805.0	3.00	4.00	MNB346	1.30	---	---	---
222	100800.0	49805.0	4.00	5.00	MNB347	0.70	---	---	---
223	100800.0	49600.0	0.00	1.00	MNC463	6.00	---	---	---
223	100800.0	49600.0	1.00	2.00	MHN825	23.80	---	---	---
223	100800.0	49600.0	1.00	2.00	MNC464	26.10	---	---	---
223	100800.0	49600.0	2.00	3.00	MNC465	2.00	---	---	---
223	100800.0	49600.0	3.00	4.00	MNC466	1.00	---	---	---
223	100800.0	49600.0	4.00	5.00	MNC467	2.00	---	---	---
223	100800.0	49600.0	5.00	6.00	MNC468	1.00	---	---	---
223	100800.0	49600.0	6.00	7.00	MNC469	0.70	---	---	---
223	100800.0	49600.0	7.00	8.00	MNC470	0.70	---	---	---
223	100800.0	49600.0	8.00	9.00	MNC471	0.70	---	---	---
223	100800.0	49600.0	9.00	10.00	MNC472	0.70	---	---	---
232	101100.0	49700.0	0.00	1.00	MNC993	4.00	---	---	---
232	101100.0	49700.0	1.00	2.00	MNC994	3.60	---	---	---
240	101000.0	49700.0	0.00	1.00	MNE732	3.30	---	---	---
240	101000.0	49700.0	1.00	2.00	MNE733	<0.30	---	---	---
424	100715.0	49844.0	0.00	0.17	MNC624	42.40	---	---	8.50
424	100715.0	49844.0	0.17	1.00	MNC625	15.90	---	---	1.50
424	100715.0	49844.0	1.00	2.00	MHN772	<0.30	---	---	1.40
424	100715.0	49844.0	1.00	2.00	MNC626	83.40	---	---	1.60
424	100715.0	49844.0	2.00	3.00	MNC627	17.50	---	---	1.10
424	100715.0	49844.0	3.00	4.00	MNC628	4.60	---	---	1.20
679	100335.0	49700.0	0.00	0.50	MNC014	54.90	1.30	2.10	---
696	100600.0	49900.0	0.00	0.50	MNC015	26.10	1.30	2.70	---
697	100600.0	49800.0	0.00	0.50	MNC016	13.20	1.50	2.30	---
706	100800.0	49910.0	0.00	0.50	MHN721	8.90	3.60	5.80	---
706	100800.0	49910.0	0.00	0.50	MNC006	8.90	2.10	6.50	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 6

Northeast Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
707	100800.0	49500.0	0.00	0.50	MNC026	23.80	1.00	1.50	—
709	100900.0	49800.0	0.00	0.50	MNC028	44.70	1.40	1.70	---
709	100900.0	49800.0	0.50	1.00	MNC117	3.60	1.20	1.50	---
713	101000.0	49800.0	0.00	0.50	MHN722	9.30	1.50	0.90	---
713	101000.0	49800.0	0.00	0.50	MNC019	12.20	2.20	1.80	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 7

Administration Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
226	99800.0	49500.0	0.00	1.00	MNC964	<0.30	---	---	---
226	99800.0	49500.0	1.00	2.00	MNC965	0.30	---	---	---
226	99800.0	49500.0	2.00	3.00	MNC966	<0.30	---	---	---
226	99800.0	49500.0	3.00	4.00	MNC967	<0.30	---	---	---
226	99800.0	49500.0	4.00	5.00	MNC968	<0.30	---	---	---
227	99900.0	49300.0	0.00	1.00	MNC970	<0.30	---	---	---
227	99900.0	49300.0	1.00	2.00	MNC971	<0.30	---	---	---
228	100400.0	49200.0	0.00	1.00	MNC542	0.30	---	---	---
228	100400.0	49200.0	1.00	2.00	MNC543	0.30	---	---	---
228	100400.0	49200.0	2.00	3.00	MNC544	<0.30	---	---	---
228	100400.0	49200.0	3.00	4.00	MNC545	<0.30	---	---	---
228	100400.0	49200.0	4.00	5.00	MNC546	<0.30	---	---	---
228	100400.0	49200.0	5.00	6.00	MNC547	<0.30	---	---	---
229	100600.0	49300.0	0.00	1.00	MNC976	<0.30	---	---	---
229	100600.0	49300.0	1.00	2.00	MNC977	<0.30	---	---	---
427	100733.0	49319.0	0.00	1.00	MNC536	2.00	---	---	---
427	100733.0	49319.0	1.00	2.00	MNC537	0.70	---	---	---
427	100733.0	49319.0	2.00	3.00	MNC538	0.30	---	---	---
427	100733.0	49319.0	3.00	4.00	MNC539	0.70	---	---	---
427	100733.0	49319.0	4.00	5.00	MHN829	<0.30	---	---	---
427	100733.0	49319.0	4.00	5.00	MNC540	0.70	---	---	---
427	100733.0	49319.0	5.00	6.00	MNC541	0.30	---	---	---
432	100500.0	49100.0	0.00	1.00	MNE746	2.00	---	---	---
432	100500.0	49100.0	1.00	2.00	MHN870	<0.30	---	---	---
432	100500.0	49100.0	1.00	2.00	MNE747	<0.30	---	---	---
671	100100.0	49300.0	0.00	0.50	MHN726	6.00	1.30	1.40	---
671	100100.0	49300.0	0.00	0.50	MNC066	7.30	1.50	1.60	---
672	100100.0	49000.0	0.00	0.50	MNC063	2.00	0.90	0.60	---
685	100400.0	49100.0	0.00	0.50	MNC064	4.00	1.20	1.20	---
710	100900.0	49300.0	0.00	0.50	MNC065	2.30	1.10	1.00	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued).

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
269	98762.0	51576.0	0.00	1.00	MNC640	---	---	---	1.30
269	98762.0	51576.0	1.00	2.00	MNC641	---	---	---	1.20
270	98775.0	51700.0	0.00	1.00	MNE976	0.70	---	---	0.30
270	98775.0	51700.0	30.00	31.00	MHN872	<0.30	---	---	1.20
270	98775.0	51700.0	30.00	31.00	MML232	<0.30	---	---	0.60
271	98784.0	51799.0	0.00	1.00	MML234	0.70	---	---	1.20
271	98784.0	51799.0	8.00	9.00	MML242	<0.30	---	---	1.00
274	98801.0	52026.0	0.00	1.00	MNE916	---	---	---	1.00
274	98801.0	52026.0	8.00	9.00	MNE924	---	---	---	1.00
275	98828.0	51494.0	0.00	1.00	MML252	0.70	---	---	1.20
275	98828.0	51494.0	1.00	2.00	MML253	0.30	---	---	1.10
275	98828.0	51494.0	2.00	3.00	MML254	0.30	---	---	0.60
275	98828.0	51494.0	3.00	4.00	MML255	<0.30	---	---	0.90
275	98828.0	51494.0	4.00	5.00	MML256	<0.30	---	---	1.20
275	98828.0	51494.0	5.00	6.00	MHN879	<0.30	---	---	---
275	98828.0	51494.0	5.00	6.00	MML257	0.30	---	---	---
275	98828.0	51494.0	6.00	7.00	MML258	0.30	---	---	---
275	98828.0	51494.0	7.00	8.00	MML259	<0.30	---	---	---
275	98828.0	51494.0	29.00	30.00	MML281	---	---	---	0.70
276	98896.0	52117.0	21.00	22.00	MHN878	---	---	---	0.70
276	98896.0	52117.0	21.00	22.00	MNE947	---	---	---	0.80
279	98951.0	51412.0	0.00	1.00	MNC630	---	---	---	1.30
279	98951.0	51412.0	1.00	2.00	MNC631	---	---	---	1.10
280	98999.0	52124.0	1.00	2.00	MNE907	---	---	---	1.70
280	98999.0	52124.0	8.00	9.00	MNE914	---	---	---	0.80
283	99088.0	51331.0	0.00	1.00	MNC355	---	---	---	2.00
283	99088.0	51331.0	1.00	2.00	MNC356	---	---	---	1.40
284	99065.0	51100.0	0.00	1.00	MNC320	---	---	---	1.00
284	99065.0	51100.0	1.00	2.00	MNC321	---	---	---	1.30
285	99075.0	51200.0	0.00	1.00	MNC325	---	---	---	1.00
285	99075.0	51200.0	1.00	2.00	MNC326	---	---	---	0.90
286	99083.0	52129.0	2.00	3.00	MNE885	---	---	---	1.50
286	99083.0	52129.0	21.00	21.83	MNE904	---	---	---	0.80
289	98778.0	51899.0	0.00	1.00	MNE950	0.70	---	---	0.70
289	98778.0	51899.0	23.00	24.00	MNE973	<0.30	---	---	0.40

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
291	99193.0	52131.0	5.00	6.00	MNC939	---	---	---	1.10
291	99193.0	52131.0	9.00	10.00	MNC943	---	---	---	0.80
291	99193.0	52131.0	12.00	13.00	MHN777	0.70	---	---	1.10
291	99193.0	52131.0	23.00	23.83	MNC957	<0.30	---	---	0.60
297	99288.0	52168.0	2.00	3.00	MHN877	---	---	---	2.50
297	99288.0	52168.0	2.00	3.00	MNE611	---	---	---	2.60
297	99288.0	52168.0	3.00	4.00	MNE612	---	---	---	3.10
302	99384.0	52197.0	2.00	3.00	MNE875	---	---	---	1.50
302	99384.0	52197.0	7.00	8.00	MNE880	---	---	---	0.70
304	99476.0	52239.0	0.00	1.00	MNE849	---	---	---	1.40
304	99476.0	52239.0	19.00	20.00	MNE869	---	---	---	0.80
306	99561.0	52290.0	0.00	1.00	MNE839	---	---	---	1.20
306	99561.0	52290.0	1.00	2.00	MNE840	---	---	---	1.40
308	99663.0	52317.0	0.00	1.00	MNE815	---	---	---	0.90
308	99663.0	52317.0	17.00	18.00	MNE832	<0.30	---	---	0.60
311	99772.0	52270.0	0.00	1.00	MNE805	---	---	---	1.10
311	99772.0	52270.0	3.00	4.00	MNE808	---	---	---	1.50
320	99853.0	52193.0	0.00	1.00	MNC914	---	---	---	0.90
320	99853.0	52193.0	1.00	2.00	MHN776	<0.30	---	---	0.80
320	99853.0	52193.0	1.00	2.00	MNC915	---	---	---	1.20
320	99853.0	52193.0	14.00	15.00	MNC928	<0.30	---	---	0.40
320	99853.0	52193.0	19.00	20.00	MNC933	<0.30	---	---	0.80
332	99970.0	52102.0	0.00	1.00	MNC838	---	---	---	2.10
332	99970.0	52102.0	1.00	2.00	MHN856	---	---	---	1.50
332	99970.0	52102.0	1.00	2.00	MNC839	---	---	---	1.20
332	99970.0	52102.0	17.00	18.00	MNC853	<0.30	---	---	0.30
332	99970.0	52102.0	18.00	19.00	MHN859	<0.30	---	---	0.30
332	99970.0	52102.0	18.00	19.00	MNC854	<0.30	---	---	0.30
332	99970.0	52102.0	19.00	20.00	MNC855	<0.30	---	---	0.30
333	100063.0	51896.0	0.00	1.00	MNC894	---	---	---	1.60
333	100063.0	51896.0	1.00	2.00	MNC895	---	---	---	1.10
333	100063.0	51896.0	6.00	7.00	MHN775	0.70	---	---	1.60
335	100090.0	52115.0	0.00	1.00	MHN782	---	---	---	1.00
335	100090.0	52115.0	0.00	1.00	MNC365	---	---	---	1.10
335	100090.0	52115.0	1.00	2.00	MNC366	---	---	---	1.10
369	98100.0	51095.0	0.00	1.00	MNB057	---	---	---	0.40

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
369	98100.0	51095.0	1.00	2.00	MNB058	---	---	---	0.60
369	98100.0	51095.0	2.00	3.00	MNB059	---	---	---	1.20
369	98100.0	51095.0	3.00	4.00	MNB060	---	---	---	1.40
369	98100.0	51095.0	4.00	5.00	MNB061	---	---	---	1.20
369	98100.0	51095.0	5.00	6.00	MNB062	---	---	---	1.90
370	98000.0	50900.0	0.00	1.00	MNB037	---	---	---	2.40
370	98000.0	50900.0	1.00	2.00	MNB038	---	---	---	1.30
370	98000.0	50900.0	2.00	3.00	MNB039	---	---	---	1.50
370	98000.0	50900.0	3.00	4.00	MNB040	---	---	---	1.20
370	98000.0	50900.0	4.00	5.00	MNB041	---	---	---	1.30
371	98100.0	50900.0	0.00	1.00	MNB047	---	---	---	0.90
371	98100.0	50900.0	1.00	2.00	MNB048	---	---	---	1.70
371	98100.0	50900.0	2.00	3.00	MNB049	---	---	---	0.80
371	98100.0	50900.0	3.00	4.00	MNB050	---	---	---	1.40
371	98100.0	50900.0	4.00	5.00	MNB051	---	---	---	1.30
372	98100.0	50800.0	0.00	1.00	MNB042	---	---	---	1.80
372	98100.0	50800.0	1.00	2.00	MNB043	---	---	---	1.20
372	98100.0	50800.0	2.00	3.00	MNB044	---	---	---	1.30
372	98100.0	50800.0	3.00	4.00	MNB045	---	---	---	1.10
372	98100.0	50800.0	4.00	5.00	MHN701	---	---	---	1.10
372	98100.0	50800.0	4.00	5.00	MNB046	---	---	---	1.20
373	98200.0	51000.0	0.00	1.00	MNB052	---	---	---	1.70
373	98200.0	51000.0	1.00	2.00	MNB053	---	---	---	2.10
373	98200.0	51000.0	2.00	3.00	MNB054	---	---	---	1.10
373	98200.0	51000.0	3.00	4.00	MNB055	---	---	---	1.20
373	98200.0	51000.0	4.00	5.00	MHN702	---	---	---	1.10
373	98200.0	51000.0	4.00	5.00	MNB056	---	---	---	1.40
374	98300.0	51100.0	0.00	1.00	MNB063	---	---	---	1.10
374	98300.0	51100.0	1.00	2.00	MNB064	---	---	---	1.20
374	98300.0	51100.0	2.00	3.00	MNB065	---	---	---	1.20
374	98300.0	51100.0	3.00	4.00	MHN703	---	---	---	1.10
374	98300.0	51100.0	3.00	4.00	MNB066	---	---	---	1.20
374	98300.0	51100.0	4.00	5.00	MNB067	---	---	---	1.00
377	98400.0	51200.0	0.00	1.00	MNB068	---	---	---	1.10
377	98400.0	51200.0	1.00	2.00	MNB069	---	---	---	1.10
377	98400.0	51200.0	2.00	3.00	MNB070	---	---	---	1.20
377	98400.0	51200.0	3.00	4.00	MNB071	---	---	---	1.10
377	98400.0	51200.0	4.00	5.00	MNB072	---	---	---	1.30
379	98510.0	51300.0	0.00	1.00	MNB087	---	---	---	1.50
379	98510.0	51300.0	1.00	2.00	MNB088	---	---	---	1.60

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
379	98510.0	51300.0	2.00	3.00	MNB089	---	---	---	1.70
379	98510.0	51300.0	3.00	4.00	MNB090	---	---	---	1.40
379	98510.0	51300.0	4.00	5.00	MNB091	---	---	---	1.10
380	98500.0	51100.0	0.00	1.00	MNB073	---	---	---	0.90
380	98500.0	51100.0	1.00	2.00	MNB074	---	---	---	1.20
380	98500.0	51100.0	2.00	3.00	MNB075	---	---	---	1.10
380	98500.0	51100.0	3.00	4.00	MHN704	---	---	---	1.10
380	98500.0	51100.0	3.00	4.00	MNB076	---	---	---	1.50
380	98500.0	51100.0	4.00	5.00	MNB077	---	---	---	1.50
383	98800.0	51600.0	0.00	1.00	MNB092	---	---	---	0.70
383	98600.0	51600.0	1.00	2.00	MNB093	---	---	---	0.70
383	98600.0	51600.0	2.00	3.00	MNB094	---	---	---	1.20
383	98600.0	51600.0	3.00	4.00	MNB095	---	---	---	1.20
383	98600.0	51600.0	4.00	5.00	MHN706	---	---	---	1.10
383	98600.0	51600.0	4.00	5.00	MNB096	---	---	---	1.00
384	98600.0	50900.0	0.00	1.00	MNB102	---	---	---	1.10
384	98600.0	50900.0	1.00	2.00	MNB103	---	---	---	1.50
384	98600.0	50900.0	2.00	3.00	MNB104	---	---	---	1.60
384	98600.0	50900.0	3.00	4.00	MNB105	---	---	---	1.10
384	98600.0	50900.0	4.00	5.00	MHN707	---	---	---	1.30
384	98600.0	50900.0	4.00	5.00	MNB106	---	---	---	1.00
385	98700.0	52000.0	0.00	1.00	MNB097	---	---	---	1.00
385	98700.0	52000.0	1.00	2.00	MNB098	---	---	---	1.60
385	98700.0	52000.0	2.00	3.00	MNB099	---	---	---	1.10
385	98700.0	52000.0	3.00	4.00	MNB100	---	---	---	0.80
385	98700.0	52000.0	4.00	5.00	MNB101	---	---	---	1.50
386	98700.0	51200.0	0.00	1.00	MNB078	---	0.70	1.10	1.60
386	98700.0	51200.0	1.00	2.00	MNB079	---	0.60	0.80	1.10
386	98700.0	51200.0	2.00	3.00	MNB080	---	0.90	0.80	1.80
386	98700.0	51200.0	3.00	4.00	MNB081	---	0.70	0.80	1.20
396	98700.0	51200.0	4.00	5.00	MNB082	---	1.00	0.90	1.40
386	98700.0	51200.0	5.00	6.00	MNB083	---	1.00	1.00	1.30
386	98700.0	51200.0	6.00	7.00	MNB084	---	0.90	2.00	1.30
386	98700.0	51200.0	7.00	8.00	MNB085	---	1.00	1.20	1.10
386	98700.0	51200.0	9.00	10.00	MHN705	---	---	---	1.20
386	98700.0	51200.0	9.00	10.00	MNB086	---	0.90	0.70	0.90
600	98000.0	50950.0	0.00	0.50	WSC172	15.30	1.60	1.50	---
601	98000.0	50900.0	0.00	0.50	WSC159	22.40	1.60	1.70	---
601	98000.0	50900.0	0.00	1.00	UNC319	13.50	2.18	2.06	---
601	98000.0	50900.0	0.00	1.00	WSC169	5.70	1.70	1.30	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
601	98000.0	50900.0	1.00	2.00	UNC320	<2.39	1.89	1.42	---
601	98000.0	50900.0	2.00	3.00	UNC321	<2.51	1.83	1.28	---
601	98000.0	50900.0	3.00	4.00	UNC322	<1.98	2.03	1.90	---
601	98000.0	50900.0	4.00	5.00	UNC323	<1.95	2.21	1.89	---
602	98000.0	50800.0	0.00	0.50	WSC158	<2.30	1.70	1.30	---
603	98050.0	50775.0	0.00	0.50	WSC197	27.63	1.96	2.77	---
604	98100.0	51100.0	0.00	1.00	UNC339	<0.90	0.37	<0.18	---
604	98100.0	51100.0	1.00	2.00	UNC340	<1.12	<0.44	<0.14	---
604	98100.0	51100.0	2.00	3.00	UNC341	<1.77	1.71	1.61	---
604	98100.0	51100.0	3.00	4.00	UNC342	<2.16	1.37	1.41	---
604	98100.0	51100.0	4.00	5.00	UNC343	<4.33	1.43	1.40	---
604	98100.0	51100.0	5.00	6.00	UNC344	<2.15	1.35	1.22	---
605	98100.0	51000.0	0.00	0.50	WSC173	26.40	1.70	1.40	---
606	98100.0	50950.0	0.00	0.50	WSC207	231.70	3.80	2.60	---
607	98100.0	50900.0	0.00	0.50	WSC161	20.10	1.50	1.40	---
607	98100.0	50900.0	0.00	1.00	UNC329	16.46	1.82	1.98	---
607	98100.0	50900.0	1.00	2.00	UNC330	<1.83	1.53	1.43	---
607	98100.0	50900.0	2.00	3.00	UNC331	<5.19	1.71	1.62	---
607	98100.0	50900.0	3.00	4.00	UNC332	<2.11	1.17	1.41	---
607	98100.0	50900.0	4.00	5.00	UNC328	<2.01	2.51	1.75	---
607	98100.0	50900.0	4.00	5.00	UNC333	<4.47	1.26	1.44	---
609	98100.0	50800.0	0.00	0.50	WSC160	<2.30	2.00	1.60	---
608	98100.0	50800.0	0.00	1.00	UNC324	<2.26	2.32	2.30	---
608	98100.0	50800.0	1.00	2.00	UNC325	<7.23	1.76	1.51	---
608	98100.0	50800.0	2.00	3.00	UNC326	<2.16	2.32	2.23	---
608	98100.0	50800.0	3.00	4.00	UNC327	<3.04	1.59	1.56	---
609	98100.0	50750.0	0.00	0.50	WSC171	<1.60	1.40	<1.70	---
611	98150.0	51050.0	0.00	0.50	WSC175	20.90	1.50	2.10	---
612	98150.0	51000.0	0.00	0.50	WSC198	146.90	2.80	4.70	---
612	98150.0	51000.0	0.50	1.00	WSC199	41.00	1.80	1.60	---
612	98150.0	51000.0	1.00	1.50	WSC200	9.40	1.80	1.60	---
612	98150.0	51000.0	1.50	2.00	WSC201	<2.40	1.70	1.50	---
613	98150.0	50999.0	0.00	0.50	WSC208	171.20	6.80	5.10	---
614	98150.0	50800.0	0.00	0.50	WSC174	<1.60	1.40	<0.70	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
615	98200.0	51000.0	0.00	0.50	WSC164	49.40	1.70	1.40	---
615	98200.0	51000.0	0.00	1.00	WSC170	7.70	1.50	1.40	---
616	98200.0	50900.0	0.00	0.50	WSC163	10.00	1.60	1.50	---
616	98200.0	50900.0	0.00	1.00	UNC334	58.19	1.73	1.41	---
616	98200.0	50900.0	1.00	2.00	UNC335	1.55	1.20	1.56	---
616	98200.0	50900.0	2.00	3.00	UNC336	6.50	1.53	1.65	---
616	98200.0	50900.0	3.00	4.00	UNC337	<4.43	1.55	1.68	---
616	98200.0	50900.0	4.00	5.00	UNC338	9.90	2.22	1.63	---
617	98250.0	51155.0	0.00	0.50	WSC202	326.70	1.30	1.2	---
617	98250.0	51155.0	0.50	1.00	WSC203	129.00	1.50	1.70	---
617	98250.0	51155.0	1.00	1.50	WSC204	28.50	1.60	1.40	---
617	98250.0	51155.0	1.50	2.00	WSC205	4.90	1.70	1.60	---
617	98250.0	51155.0	2.00	2.50	WSC206	<1.80	1.60	1.30	---
618	98250.0	50850.0	0.00	0.50	WSC162	9.40	1.70	1.60	---
619	98300.0	51100.0	0.00	0.50	WSC168	3.90	1.30	0.80	---
619	98300.0	51100.0	0.00	1.00	UNC345	<1.40	1.29	1.34	---
619	98300.0	51100.0	1.00	2.00	UNC346	<2.25	1.83	1.43	---
619	98300.0	51100.0	2.00	3.00	UNC347	<1.68	1.41	1.41	---
619	98300.0	51100.0	3.00	4.00	UNC348	<2.09	1.76	1.44	---
619	98300.0	51100.0	4.00	5.00	UNC349	<1.42	1.56	1.31	---
620	98300.0	51000.0	0.00	0.50	WSC166	12.70	2.00	2.00	---
621	98300.0	50900.0	0.00	0.50	WSC165	4.80	1.50	1.30	---
623	98345.0	51152.0	0.00	0.50	WSC189	2259.30	2.00	<0.70	---
623	98345.0	51152.0	0.50	1.00	WSC190	302.90	1.30	<0.70	---
623	98345.0	51152.0	1.00	1.50	WSC191	122.00	1.70	1.70	---
623	98345.0	51152.0	1.50	2.00	WSC192	25.70	1.40	1.50	---
623	98345.0	51152.0	2.00	2.50	WSC193	9.60	1.70	1.40	---
623	98345.0	51152.0	2.50	3.00	WSC194	35.40	1.80	1.00	---
623	98345.0	51152.0	3.00	3.50	WSC195	69.90	1.20	1.30	---
623	98345.0	51152.0	3.50	4.00	WSC196	35.70	1.90	1.10	---
624	98370.0	51210.0	0.00	0.50	WSC186	61.10	1.90	2.10	---
624	98370.0	51210.0	0.50	1.00	WSC187	19.70	1.60	1.50	---
624	98370.0	51210.0	1.00	1.50	WSC188	8.50	1.80	1.60	---
625	98400.0	51200.0	0.00	0.50	WSC182	29.20	1.70	2.50	---
625	98400.0	51200.0	0.00	1.00	UNC350	19.75	1.54	1.30	---
625	98400.0	51200.0	1.00	2.00	UNC351	<1.87	1.31	1.48	---
625	98400.0	51200.0	2.00	3.00	UNC352	<6.45	1.42	1.32	---
625	98400.0	51200.0	3.00	4.00	UNC353	<1.68	1.71	1.28	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
625	98400.0	51200.0	4.00	5.00	UNC354	<8.02	1.71	1.22	---
626	98400.0	51150.0	0.00	0.50	WSC177	<1.60	1.20	0.80	---
627	98400.0	51100.0	0.00	0.50	WSC176	3.80	1.30	0.60	---
628	98400.0	51050.0	0.00	0.50	WSC183	5.10	1.70	0.80	---
629	98400.0	50900.0	0.00	0.50	WSC167	6.50	1.70	1.30	---
630	98450.0	51050.0	0.00	0.50	WSC180	7.70	1.50	1.50	---
632	98510.0	51300.0	0.00	1.00	UNC369	<1.46	1.42	0.71	---
632	98510.0	51300.0	1.00	2.00	UNC370	<1.99	<1.35	0.73	---
632	98510.0	51300.0	2.00	3.00	UNC371	<1.71	1.39	1.36	---
632	98510.0	51300.0	4.00	5.00	UNC373	<2.06	1.82	1.26	---
633	98500.0	51100.0	0.00	1.00	UNC355	2.39	<0.47	0.86	---
633	98500.0	51100.0	1.00	2.00	UNC356	<2.04	1.10	1.37	---
633	98500.0	51100.0	2.00	3.00	UNC357	<4.72	1.74	1.30	---
633	98500.0	51100.0	3.00	4.00	UNC358	<1.75	1.42	1.30	---
633	98500.0	51100.0	4.00	5.00	UNC359	<1.67	1.39	1.54	---
634	98600.0	51600.0	0.00	1.00	UNC374	5.08	1.65	1.32	---
634	98600.0	51600.0	1.00	2.00	UNC375	<2.17	1.64	1.54	---
634	98600.0	51600.0	2.00	3.00	UNC376	<4.46	1.48	1.33	---
634	98600.0	51600.0	3.00	4.00	UNC377	<2.49	1.76	1.83	---
634	98600.0	51600.0	4.00	5.00	UNC378	<1.63	1.54	1.59	---
635	98600.0	51025.0	0.00	0.50	WSC185	265.70	2.10	1.60	---
636	98650.0	51250.0	0.00	0.50	WSC184	<1.70	1.60	1.50	---
637	98650.0	51200.0	0.00	0.50	WSC178	<1.70	1.10	0.70	---
638	98650.0	51150.0	0.00	0.50	WSC179	4.20	1.40	1.30	---
639	98650.0	51100.0	0.00	0.50	WSC181	4.50	1.20	1.00	---
642	98700.0	51200.0	0.00	1.00	UNC360	<1.69	1.26	1.16	---
642	98700.0	51200.0	1.00	2.00	UNC361	<2.48	<1.09	1.14	---
642	98700.0	51200.0	2.00	3.00	UNC362	<2.37	1.97	1.46	---
642	98700.0	51200.0	3.00	4.00	UNC363	<1.49	1.30	1.31	---
642	98700.0	51200.0	4.00	5.00	UNC364	<2.77	1.58	1.39	---
642	98700.0	51200.0	5.00	6.00	UNC365	<1.64	1.76	1.46	---
642	98700.0	51200.0	6.00	7.00	UNC366	<4.50	1.64	2.46	---
642	98700.0	51200.0	7.00	8.00	UNC367	<1.66	1.39	1.49	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 8

West Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
642	98700.0	51200.0	8.00	9.00	UNC368	<2.06	1.27	1.37	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
161	99300.0	50584.0	0.00	1.00	MNB214	1.30	---	---	---
161	99300.0	50584.0	1.00	2.00	MNB215	0.70	---	---	---
161	99300.0	50584.0	2.00	3.00	MNB216	0.70	---	---	---
161	99300.0	50584.0	3.00	4.00	MNB217	0.70	---	---	---
161	99300.0	50584.0	4.00	5.00	MNB218	0.30	---	---	---
162	99400.0	50585.0	0.00	1.00	MNB209	1.30	---	---	---
162	99400.0	50585.0	1.00	2.00	MNB210	1.00	---	---	---
162	99400.0	50585.0	2.00	3.00	MHN738	0.30	---	---	---
162	99400.0	50585.0	2.00	3.00	MNB211	1.00	---	---	---
162	99400.0	50585.0	3.00	4.00	MNB212	1.30	---	---	---
162	99400.0	50585.0	4.00	5.00	MNB213	1.00	---	---	---
166	99503.0	50585.0	0.00	1.00	MNB204	2.00	---	---	---
166	99503.0	50585.0	1.00	2.00	MNB205	1.30	---	---	---
166	99503.0	50585.0	2.00	3.00	MNB206	1.70	---	---	---
166	99503.0	50585.0	3.00	4.00	MNB207	1.30	---	---	---
166	99503.0	50585.0	4.00	5.00	MNB208	1.00	---	---	---
179	99802.0	50593.0	0.00	1.00	MNB149	3.00	---	---	---
179	99802.0	50593.0	1.00	2.00	MNB150	1.30	---	---	---
179	99802.0	50593.0	2.00	3.00	MNB151	1.30	---	---	---
179	99802.0	50593.0	3.00	4.00	MHN732	0.30	---	---	---
179	99802.0	50593.0	3.00	4.00	MNB152	1.00	---	---	---
179	99802.0	50593.0	4.00	5.00	MNB153	1.30	---	---	---
188	100000.0	50800.0	0.00	1.00	MHN864	2.30	---	---	---
188	100000.0	50800.0	0.00	1.00	MNC613	2.00	---	---	---
188	100000.0	50800.0	1.00	2.00	MNC614	0.30	---	---	---
188	100000.0	50800.0	2.00	3.00	MNC615	<0.30	---	---	---
188	100000.0	50800.0	3.00	4.00	MNC616	<0.30	---	---	---
188	100000.0	50800.0	4.00	5.00	MNC617	0.30	---	---	---
188	100000.0	50800.0	5.00	6.00	MNC618	0.30	---	---	---
265	98690.0	50800.0	0.00	1.00	MNC340	---	---	---	2.60
265	98690.0	50800.0	1.00	2.00	MNC341	---	---	---	1.50
266	98690.0	50700.0	0.00	1.00	MNC335	---	---	---	1.50
266	98690.0	50700.0	1.00	2.00	MNC336	---	---	---	1.00
267	98714.0	50837.0	0.00	1.00	MML284	---	---	---	8.80
267	98714.0	50837.0	19.00	20.00	MML303	---	---	---	0.80
268	98709.0	50621.0	0.00	1.00	MNC330	---	---	---	3.90
268	98709.0	50621.0	1.00	2.00	MNC331	---	---	---	1.00
272	98790.0	50924.0	0.00	1.00	MNC285	---	---	---	1.30

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
272	98790.0	50924.0	1.00	2.00	MNC286	---	---	---	1.20
273	98800.0	50590.0	0.00	1.00	MNC345	---	---	---	4.40
273	98800.0	50590.0	1.00	2.00	MNC346	---	---	---	1.30
277	98900.0	50925.0	0.00	1.00	MNC280	---	---	---	2.30
277	98900.0	50925.0	1.00	2.00	MNC281	---	---	---	1.00
278	98898.0	50590.0	0.00	1.00	MNC350	---	---	---	5.10
278	98898.0	50590.0	1.00	2.00	MNC351	---	---	---	1.00
281	99000.0	50925.0	0.00	1.00	MNC275	---	---	---	1.70
281	99000.0	50925.0	1.00	2.00	MHN779	---	---	---	1.10
281	99000.0	50925.0	1.00	2.00	MNC276	---	---	---	1.60
282	99900.0	50592.0	0.00	1.00	MNB481	---	---	---	1.60
282	99900.0	50592.0	1.00	2.00	MNB482	---	---	---	1.50
287	99098.0	51002.0	0.00	1.00	MNC290	---	---	---	1.50
287	99098.0	51002.0	1.00	2.00	MNC291	---	---	---	1.30
288	99100.0	50925.0	0.00	1.00	MNC270	---	---	---	3.70
288	99100.0	50925.0	1.00	2.00	MNC271	---	---	---	1.30
290	99100.0	50592.0	0.00	1.00	MNB486	---	---	---	3.70
290	99100.0	50592.0	1.00	2.00	MNB487	---	---	---	1.20
292	99202.0	50990.0	0.00	1.00	MHN780	---	---	---	1.40
292	99202.0	50990.0	0.00	1.00	MNC295	---	---	---	1.50
292	99202.0	50990.0	1.00	2.00	MNC296	---	---	---	1.40
293	99200.0	50925.0	0.00	1.00	MNC265	---	---	---	6.30
293	99200.0	50925.0	1.00	2.00	MNC266	---	---	---	1.30
294	99216.0	50800.0	0.00	1.00	MNC203	2.30	---	---	10.90
294	99216.0	50800.0	1.00	2.00	MNC204	1.30	---	---	5.80
294	99216.0	50800.0	2.00	3.00	MHN765	1.00	---	---	3.60
294	99216.0	50800.0	2.00	3.00	MNC205	1.30	---	---	3.40
294	99216.0	50800.0	3.00	4.00	MNC206	1.00	---	---	2.50
294	99216.0	50800.0	4.00	5.00	MNC207	1.00	---	---	2.80
294	99216.0	50800.0	5.00	6.00	MNC208	1.00	---	---	2.40
294	99216.0	50800.0	6.00	7.00	MNC209	0.70	---	---	3.40
294	99216.0	50800.0	7.00	8.00	MNC210	1.00	---	---	1.30
294	99216.0	50800.0	8.00	9.00	MNC211	0.70	---	---	0.80
294	99216.0	50800.0	9.00	10.00	MNC212	0.70	---	---	0.90
294	99216.0	50800.0	10.00	11.00	MNC213	0.70	---	---	1.00
294	99216.0	50800.0	11.00	12.00	MNC214	0.70	---	---	0.90

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
295	99215.0	50698.0	0.00	1.00	MNC198	---	---	---	7.20
295	99215.0	50698.0	1.00	2.00	MNC199	---	---	---	1.20
296	99217.0	50635.0	0.00	1.00	MNC193	---	---	---	17.20
296	99217.0	50635.0	1.00	2.00	MNC194	---	---	---	3.50
298	99300.0	50992.0	0.00	1.00	MNC300	---	---	---	2.00
298	99300.0	50992.0	1.00	2.00	MNC301	---	---	---	1.30
299	99300.0	50925.0	0.00	1.00	MNC260	---	---	---	3.50
299	99300.0	50925.0	1.00	2.00	MNC261	---	---	---	1.40
300	99300.0	50800.0	0.00	1.00	MNC220	---	---	---	3.10
300	99300.0	50800.0	1.00	2.00	MNC221	---	---	---	1.00
301	99300.0	50700.0	0.00	1.00	MNC183	3.30	---	---	2.70
301	99300.0	50700.0	1.00	2.00	MNC184	1.30	---	---	1.30
301	99300.0	50700.0	2.00	3.00	MNC185	1.00	---	---	1.10
301	99300.0	50700.0	3.00	4.00	MNC186	0.70	---	---	1.30
301	99300.0	50700.0	4.00	5.00	MHN764	0.70	---	---	1.30
301	99300.0	50700.0	4.00	5.00	MNC187	1.00	---	---	1.20
301	99300.0	50700.0	5.00	6.00	MNC188	1.00	---	---	2.70
301	99300.0	50700.0	6.00	7.00	MNC189	1.00	---	---	1.10
301	99300.0	50700.0	7.00	8.00	MNC190	1.30	---	---	1.30
301	99300.0	50700.0	8.00	9.00	MNC191	1.30	---	---	1.50
301	99300.0	50700.0	9.00	10.00	MNC192	1.30	---	---	1.10
303	99388.0	50963.0	0.00	1.00	MNC305	---	---	---	1.50
303	99388.0	50983.0	1.00	2.00	MNC306	---	---	---	1.20
305	99500.0	50980.0	0.00	1.00	MNC310	---	---	---	4.10
305	99500.0	50980.0	1.00	2.00	MNC311	---	---	---	1.10
307	99600.0	50980.0	0.00	1.00	MHN761	---	---	---	6.00
307	99600.0	50980.0	0.00	1.00	MNC315	---	---	---	5.50
307	99600.0	50980.0	1.00	2.00	MNC316	---	---	---	2.20
309	99715.0	50943.0	0.00	1.00	MML370	---	---	---	8.20
309	99715.0	50943.0	1.00	2.00	MML371	---	---	---	1.20
310	99700.0	50900.0	0.00	1.00	MNB521	---	---	---	3.80
310	99700.0	50900.0	1.00	2.00	MNB522	---	---	---	1.50
312	99800.0	50956.0	0.00	1.00	MML354	---	---	---	1.30
312	99800.0	50956.0	14.00	15.00	MML368	---	---	---	0.60

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
318	99900.0	50947.0	0.00	1.00	MML384	---	---	---	4.20
318	99900.0	50947.0	1.00	2.00	MML385	---	---	---	1.30
329	100000.0	51000.0	0.00	1.00	MHN712	---	---	---	2.10
329	100000.0	51000.0	0.00	1.00	MNB541	---	---	---	2.30
329	100000.0	51000.0	1.00	2.00	MNB542	---	---	---	1.80
392	99400.0	50800.0	0.00	1.00	MNC173	3.30	---	---	2.70
392	99400.0	50800.0	1.00	2.00	MNC174	2.00	---	---	1.40
392	99400.0	50800.0	2.00	3.00	MNC175	1.30	---	---	1.80
392	99400.0	50800.0	3.00	4.00	MNC176	1.00	---	---	1.40
392	99400.0	50800.0	4.00	5.00	MNC177	1.00	---	---	1.10
392	99400.0	50800.0	5.00	6.00	MNC178	0.70	---	---	1.00
392	99400.0	50800.0	6.00	7.00	MHN763	0.70	---	---	1.10
392	99400.0	50800.0	6.00	7.00	MNC179	0.70	---	---	1.10
392	99400.0	50800.0	7.00	8.00	MNC180	1.00	---	---	1.20
392	99400.0	50800.0	8.00	9.00	MNC181	1.00	---	---	2.50
392	99400.0	50800.0	9.00	10.00	MNC182	1.00	---	---	1.20
393	99400.0	50700.0	0.00	1.00	MNC137	3.00	---	---	1.50
393	99400.0	50700.0	1.00	2.00	MNC138	1.00	---	---	1.30
393	99400.0	50700.0	2.00	3.00	MNC139	2.00	---	---	1.50
393	99400.0	50700.0	3.00	4.00	MNC140	1.00	---	---	1.10
393	99400.0	50700.0	4.00	5.00	MNC141	1.00	---	---	1.40
393	99400.0	50700.0	5.00	6.00	MNC142	1.00	---	---	1.20
393	99400.0	50700.0	6.00	7.00	MNC143	1.00	---	---	1.10
393	99400.0	50700.0	7.00	8.00	MHN760	0.70	---	---	1.00
393	99400.0	50700.0	7.00	8.00	MNC144	1.00	---	---	1.10
393	99400.0	50700.0	8.00	9.00	MNC145	1.00	---	---	1.40
393	99400.0	50700.0	9.00	10.00	MNC146	1.00	---	---	1.50
393	99400.0	50700.0	10.00	11.00	MNC147	1.30	---	---	1.30
393	99400.0	50700.0	11.00	12.00	MNC148	1.00	---	---	1.10
394	99500.0	50800.0	0.00	1.00	MNC161	3.30	---	---	2.10
394	99500.0	50800.0	1.00	2.00	MNC162	1.00	---	---	0.80
394	99500.0	50800.0	2.00	3.00	MNC163	0.70	---	---	1.20
394	99500.0	50800.0	3.00	4.00	MNC164	0.70	---	---	2.10
394	99500.0	50800.0	4.00	5.00	MNC165	0.70	---	---	0.90
394	99500.0	50800.0	5.00	6.00	MNC166	1.00	---	---	1.10
394	99500.0	50800.0	6.00	7.00	MNC167	1.00	---	---	1.10
394	99500.0	50800.0	7.00	8.00	MHN762	0.70	---	---	1.20
394	99500.0	50800.0	7.00	8.00	MNC168	0.70	---	---	1.00
394	99500.0	50800.0	8.00	9.00	MNC169	1.00	---	---	1.30
394	99500.0	50800.0	9.00	10.00	MNC170	1.00	---	---	1.30
394	99500.0	50800.0	10.00	11.00	MNC171	1.00	---	---	1.20
394	99500.0	50800.0	11.00	12.00	MNC172	1.00	---	---	1.20

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
395	99500.0	50700.0	0.00	1.00	MNC149	3.00	---	---	1.10
395	99500.0	50700.0	1.00	2.00	MNC150	2.30	---	---	0.80
395	99500.0	50700.0	2.00	3.00	MNC151	1.30	---	---	1.20
395	99500.0	50700.0	3.00	4.00	MNC152	1.00	---	---	1.30
395	99500.0	50700.0	4.00	5.00	MNC153	1.00	---	---	1.00
395	99500.0	50700.0	5.00	6.00	MNC154	1.00	---	---	1.00
395	99500.0	50700.0	6.00	7.00	MNC155	1.00	---	---	0.90
395	99500.0	50700.0	7.00	8.00	MNC156	0.70	---	---	2.10
395	99500.0	50700.0	8.00	9.00	MHN761	0.70	---	---	0.90
395	99500.0	50700.0	8.00	9.00	MNC157	1.00	---	---	1.10
395	99500.0	50700.0	9.00	10.00	MNC158	0.70	---	---	1.10
395	99500.0	50700.0	10.00	11.00	MNC159	1.00	---	---	1.30
395	99500.0	50700.0	11.00	12.00	MNC160	1.00	---	---	1.30
396	99600.0	50800.0	0.00	1.00	MNC235	5.30	---	---	1.80
396	99600.0	50800.0	1.00	2.00	MNC236	1.00	---	---	1.20
396	99600.0	50800.0	2.00	3.00	MNC237	1.00	---	---	1.10
396	99600.0	50800.0	3.00	4.00	MNC238	1.00	---	---	1.40
396	99600.0	50800.0	4.00	5.00	MNC239	1.00	---	---	1.10
396	99600.0	50800.0	5.00	6.00	MNC240	1.00	---	---	1.10
396	99600.0	50800.0	6.00	7.00	MNC241	1.00	---	---	1.10
396	99600.0	50800.0	7.00	8.00	MHN768	0.70	---	---	1.10
396	99600.0	50800.0	7.00	8.00	MNC242	0.70	---	---	1.20
396	99600.0	50800.0	8.00	9.00	MNC243	0.70	---	---	1.30
396	99600.0	50800.0	9.00	10.00	MNC244	0.70	---	---	0.90
397	99600.0	50700.0	0.00	1.00	MNC225	12.90	---	---	1.90
397	99600.0	50700.0	1.00	2.00	MNC226	1.70	---	---	1.10
397	99600.0	50700.0	2.00	3.00	MNC227	0.70	---	---	1.00
397	99600.0	50700.0	3.00	4.00	MNC228	0.70	---	---	0.90
397	99600.0	50700.0	4.00	5.00	MNC229	1.00	---	---	0.90
397	99600.0	50700.0	5.00	6.00	MNC230	1.00	---	---	1.00
397	99600.0	50700.0	6.00	7.00	MHN767	0.30	---	---	1.00
397	99600.0	50700.0	6.00	7.00	MNC231	0.70	---	---	1.20
397	99600.0	50700.0	7.00	8.00	MNC232	0.70	---	---	1.00
397	99600.0	50700.0	8.00	9.00	MNC233	0.70	---	---	1.00
397	99600.0	50700.0	9.00	10.00	MNC234	1.00	---	---	1.20
398	99400.0	50925.0	0.00	1.00	MHN778	---	---	---	1.20
398	99400.0	50925.0	0.00	1.00	MNC255	---	---	---	1.40
398	99400.0	50925.0	1.00	2.00	MNC256	---	---	---	1.30
398	99400.0	50925.0	2.00	3.00	MNC257	---	---	---	0.90
398	99400.0	50925.0	3.00	4.00	MNC258	---	---	---	2.00
398	99400.0	50925.0	4.00	5.00	MNC259	---	---	---	1.20
399	99500.0	50925.0	0.00	1.00	MHN787	---	---	---	2.70
399	99500.0	50925.0	0.00	1.00	MNC250	---	---	---	2.60

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
399	99500.0	50925.0	1.00	2.00	MNC251	---	---	---	1.20
399	99500.0	50925.0	2.00	3.00	MNC252	---	---	---	1.40
399	99500.0	50925.0	3.00	4.00	MNC253	---	---	---	0.90
399	99500.0	50925.0	4.00	5.00	MNC254	---	---	---	1.00
400	99600.0	50925.0	0.00	1.00	MNC245	---	---	---	4.30
400	99600.0	50925.0	1.00	2.00	MNC246	---	---	---	0.90
400	99600.0	50925.0	2.00	3.00	MNC247	---	---	---	0.90
400	99600.0	50925.0	3.00	4.00	MNC248	---	---	---	1.30
400	99600.0	50925.0	4.00	5.00	MNC249	---	---	---	0.80
401	99598.0	50585.0	0.00	1.00	MNB199	7.90	---	---	---
401	99598.0	50585.0	1.00	2.00	MHN737	6.00	---	---	---
401	99598.0	50585.0	1.00	2.00	MNB200	6.60	---	---	---
401	99598.0	50585.0	2.00	3.00	MNB201	1.30	---	---	---
401	99598.0	50585.0	3.00	4.00	MNB202	1.00	---	---	---
401	99598.0	50585.0	4.00	5.00	MNB203	2.00	---	---	---
403	99700.0	50800.0	0.00	1.00	MNB516	7.30	---	---	---
403	99700.0	50800.0	1.00	2.00	MNB517	1.00	---	---	---
403	99700.0	50800.0	2.00	3.00	MNB518	2.00	---	---	---
403	99700.0	50800.0	3.00	4.00	MHN792	<0.30	---	---	---
403	99700.0	50800.0	3.00	4.00	MNB519	1.00	---	---	---
403	99700.0	50800.0	4.00	5.00	MNB520	1.00	---	---	---
404	99900.0	50900.0	0.00	1.00	MNB526	7.90	---	---	---
404	99900.0	50900.0	1.00	2.00	MNB527	1.30	---	---	---
404	99900.0	50900.0	2.00	3.00	MNB528	1.30	---	---	---
404	99900.0	50900.0	3.00	4.00	MNB529	1.00	---	---	---
404	99900.0	50900.0	4.00	5.00	MNB530	0.70	---	---	---
405	99699.0	50583.0	0.00	1.00	MNB144	<0.30	---	---	---
405	99699.0	50583.0	1.00	2.00	MNB145	0.70	---	---	---
405	99699.0	50583.0	2.00	3.00	MNB146	0.70	---	---	---
405	99699.0	50583.0	3.00	4.00	MNB147	0.70	---	---	---
405	99699.0	50583.0	4.00	5.00	MNB148	1.70	---	---	---
406	99800.0	50800.0	0.00	1.00	MNB511	12.20	---	---	---
406	99800.0	50800.0	1.00	2.00	MNB512	1.70	---	---	---
406	99800.0	50800.0	2.00	3.00	MNB513	1.30	---	---	---
406	99800.0	50800.0	3.00	4.00	MNB514	0.70	---	---	---
406	99800.0	50800.0	4.00	5.00	MNB515	1.30	---	---	---
407	99800.0	50700.0	0.00	1.00	MNB506	9.60	---	---	---
407	99800.0	50700.0	1.00	2.00	MNB507	1.00	---	---	---
407	99800.0	50700.0	2.00	3.00	MNB508	1.00	---	---	---
407	99800.0	50700.0	3.00	4.00	MNB509	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
407	99800.0	50700.0	4.00	5.00	MHN791	9.90	---	---	---
407	99800.0	50700.0	4.00	5.00	MNB510	0.70	---	---	---
503	99900.0	50800.0	0.00	1.00	WSC289	<2.10	1.60	1.70	---
503	99900.0	50800.0	1.00	2.00	WSC290	<1.80	1.30	1.30	---
641	98690.0	50800.0	0.00	1.00	UNC434	2.10	1.00	0.70	---
641	98690.0	50800.0	1.00	2.00	UNC435	1.20	1.20	1.20	---
641	98690.0	50800.0	2.00	3.00	UNC463	1.80	1.20	1.50	---
641	98690.0	50800.0	3.00	4.00	UNC464	2.10	0.90	1.10	---
641	98690.0	50800.0	4.00	5.00	UNC457	3.80	1.10	1.00	---
647	98800.0	50592.0	0.00	1.00	UNC433	4.10	1.50	0.70	---
647	98800.0	50592.0	1.00	2.00	UNC430	3.00	1.40	1.20	---
650	99100.0	50925.0	0.00	1.00	UNC429	3.50	1.40	1.10	---
650	99100.0	50925.0	1.00	2.00	UNC444	2.70	1.50	1.20	---
650	99100.0	50925.0	2.00	3.00	UNC448	2.30	1.40	1.20	---
650	99100.0	50925.0	3.00	4.00	UNC447	<1.10	1.00	1.50	---
650	99100.0	50925.0	4.00	5.00	UNC450	<1.10	1.00	0.80	---
651	99100.0	50592.0	0.00	1.00	UNC420	1.80	1.60	0.70	---
651	99100.0	50592.0	1.00	2.00	UNC419	1.30	1.20	0.60	---
651	99100.0	50592.0	2.00	3.00	UNC458	1.90	0.40	1.00	---
651	99100.0	50592.0	3.00	4.00	UNC459	0.80	1.70	1.20	---
651	99100.0	50592.0	4.00	5.00	UNC460	<1.30	1.40	1.50	---
651	99100.0	50592.0	5.00	6.00	UNC461	1.10	1.40	1.00	---
651	99100.0	50592.0	6.00	7.00	UNC462	<1.10	1.00	1.40	---
651	99100.0	50592.0	7.00	8.00	UNC453	3.30	1.40	1.10	---
651	99100.0	50592.0	8.00	9.00	UNC451	<1.40	1.00	1.20	---
651	99100.0	50592.0	9.00	10.00	UNC449	2.30	0.80	1.30	---
653	99215.0	50800.0	0.00	1.00	UNC408	<1.80	5.90	1.90	9.00
653	99215.0	50800.0	1.00	2.00	UNC411	<1.50	7.00	1.60	---
653	99215.0	50800.0	2.00	3.00	UNC412	<1.60	9.30	1.40	---
653	99215.0	50800.0	3.00	4.00	UNC428	<2.70	25.60	1.70	---
653	99215.0	50800.0	4.00	5.00	UNC407	<2.80	14.90	1.80	---
653	99215.0	50800.0	5.00	6.00	UNC409	<2.70	18.30	2.20	---
653	99215.0	50800.0	6.00	7.00	UNC410	<2.30	12.90	1.20	---
653	99215.0	50800.0	7.00	8.00	UNC425	<2.40	26.60	1.80	---
653	99215.0	50800.0	8.00	9.00	UNC427	0.70	1.30	1.20	---
653	99215.0	50800.0	9.00	10.00	UNC426	0.80	1.50	1.40	---
653	99215.0	50800.0	10.00	11.00	UNC406	<1.40	1.30	1.50	---
653	99215.0	50800.0	11.00	12.00	UNC405	<1.20	1.20	1.30	---
656	99400.0	50925.0	0.00	1.00	UNC446	<1.20	1.20	1.40	---
656	99400.0	50925.0	1.00	2.00	UNC438	2.60	1.40	1.30	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 9

East Raffinate Pits Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
656	99400.0	50925.0	2.00	3.00	UNC437	2.80	1.20	1.20	—
656	99400.0	50925.0	3.00	4.00	UNC441	<1.40	1.50	1.50	—
656	99400.0	50925.0	4.00	5.00	UNC442	1.50	1.50	1.40	—
659	99500.0	50925.0	0.00	1.00	UNC431	1.90	1.40	1.30	—
659	99500.0	50925.0	1.00	2.00	UNC432	2.50	1.20	1.90	—
659	99500.0	50925.0	2.00	3.00	UNC439	3.00	1.70	2.30	—
659	99500.0	50925.0	3.00	4.00	UNC440	<1.20	1.20	1.20	—
659	99500.0	50925.0	4.00	5.00	UNC445	<1.20	0.80	1.40	—
664	99900.0	50800.0	0.00	0.50	MNC017	9.30	7.50	6.90	—
665	99900.0	50700.0	0.00	0.50	MNC062	17.20	1.70	5.00	—
667	100000.0	51000.0	0.00	1.00	UNC416	5.90	1.00	1.10	—

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 10

South Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
153	99521.0	50263.0	0.00	1.00	MNC656	1.00	---	---	---
153	99521.0	50263.0	1.00	2.00	MNC657	3.00	---	---	---
153	99521.0	50263.0	2.00	3.00	MNC658	0.30	---	---	---
153	99521.0	50263.0	3.00	4.00	MNC659	0.70	---	---	---
153	99521.0	50263.0	4.00	5.00	MNC660	0.70	---	---	---
154	99861.0	50143.0	0.00	1.00	MNB030	27.80	---	---	---
154	99861.0	50143.0	1.00	2.00	MHN730	0.30	---	---	---
154	99861.0	50143.0	1.00	2.00	MNB026	5.30	---	---	---
154	99861.0	50143.0	2.00	3.00	MNB027	0.30	---	---	---
154	99861.0	50143.0	3.00	4.00	MNB028	0.30	---	---	---
154	99861.0	50143.0	4.00	5.00	MNB029	1.30	---	---	---
163	99400.0	49900.0	0.00	1.00	MNB454	24.50	---	---	---
163	99400.0	49900.0	1.00	2.00	MNB455	2.30	---	---	---
163	99400.0	49900.0	2.00	3.00	MNB456	1.70	---	---	---
163	99400.0	49900.0	3.00	4.00	MHN789	<0.30	---	---	---
163	99400.0	49900.0	3.00	4.00	MNB457	1.00	---	---	---
163	99400.0	49900.0	4.00	5.00	MNB458	1.30	---	---	---
164	99440.0	50065.0	0.00	1.50	MNB501	1.30	---	---	---
164	99440.0	50065.0	1.50	2.00	MNB502	1.30	---	---	---
164	99440.0	50065.0	2.00	3.00	MNB503	1.00	---	---	---
164	99440.0	50065.0	3.00	4.00	MNB504	1.00	---	---	---
164	99440.0	50065.0	4.00	5.00	MNB505	1.00	---	---	---
165	99400.0	50200.0	0.00	1.00	MNB496	5.60	---	---	---
165	99400.0	50200.0	2.00	3.00	MNB498	15.90	---	---	---
165	99400.0	50200.0	3.00	4.00	MHN790	2.60	---	---	---
165	99400.0	50200.0	3.00	4.00	MNB499	4.00	---	---	---
165	99400.0	50200.0	4.00	5.00	MNB500	1.30	---	---	---
167	99507.0	50496.0	0.00	1.00	MNB164	5.30	---	---	---
167	99507.0	50496.0	1.00	2.00	MNB165	2.60	---	---	---
167	99507.0	50496.0	2.00	3.00	MNB166	0.70	---	---	---
167	99507.0	50496.0	3.00	4.00	MNB167	0.70	---	---	---
167	99507.0	50496.0	4.00	5.00	MNB168	0.30	---	---	---
168	99500.0	49700.0	0.00	1.00	MNC578	6.30	---	---	---
168	99500.0	49700.0	1.00	2.00	MNC579	1.00	---	---	---
168	99500.0	49700.0	2.00	3.00	MNC580	0.70	---	---	---
168	99500.0	49700.0	3.00	4.00	MNC581	<0.30	---	---	---
168	99500.0	49700.0	4.00	5.00	MNC582	<0.30	---	---	---
168	99500.0	49700.0	5.00	6.00	MNC583	<0.30	---	---	---
169	99600.0	50500.0	0.00	1.00	MNB159	4.00	---	---	---
169	99600.0	50500.0	1.00	2.00	MNB160	12.20	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 10

South Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
169	99600.0	50500.0	2.00	3.00	MNB161	3.30	---	---	---
169	99600.0	50500.0	3.00	4.00	MHN733	26.50	---	---	---
169	99600.0	50500.0	3.00	4.00	MNB162	19.20	---	---	---
169	99600.0	50500.0	4.00	5.00	MNB163	0.70	---	---	---
170	99300.0	50300.0	0.00	1.00	MML304	53.30	---	---	---
170	99300.0	50300.0	1.00	2.00	MML305	17.50	---	---	---
170	99300.0	50300.0	2.00	3.00	MML306	1.00	---	---	---
170	99300.0	50300.0	3.00	4.00	MML307	0.70	---	---	---
170	99300.0	50300.0	4.00	5.00	MML308	0.70	---	---	---
171	99600.0	49925.0	0.00	1.00	MNB449	51.60	---	---	---
171	99600.0	49925.0	1.00	2.00	MHN759	6.00	---	---	---
171	99600.0	49925.0	1.00	2.00	MNB450	7.30	---	---	---
171	99600.0	49925.0	2.00	3.00	MNB451	2.60	---	---	---
171	99600.0	49925.0	3.00	4.00	MNB452	1.70	---	---	---
171	99600.0	49925.0	4.00	5.00	MNB453	3.60	---	---	---
172	99600.0	49600.0	0.00	1.00	MNB459	6.60	---	---	---
172	99600.0	49600.0	1.00	2.00	MNB460	1.70	---	---	---
172	99600.0	49600.0	2.00	3.00	MNB461	0.70	---	---	---
172	99600.0	49600.0	3.00	4.00	MNB462	1.00	---	---	---
172	99600.0	49600.0	4.00	5.00	MNB463	1.00	---	---	---
173	99635.0	50315.0	0.00	1.00	MNB251	2.60	---	---	---
173	99635.0	50315.0	1.00	2.00	MNB252	1.70	---	---	---
173	99635.0	50315.0	2.00	3.00	MNB253	1.30	---	---	---
173	99635.0	50315.0	3.00	4.00	MNB254	0.70	---	---	---
173	99635.0	50315.0	4.00	5.00	MNB255	1.30	---	---	---
174	99635.0	50100.0	0.00	1.00	MNB258	2.00	---	---	---
174	99635.0	50100.0	1.00	2.00	MNB259	3.30	---	---	---
174	99635.0	50100.0	2.00	3.00	MNB260	1.00	---	---	---
174	99635.0	50100.0	3.00	4.00	MNB261	1.00	---	---	---
174	99635.0	50100.0	4.00	5.00	MHN743	<0.30	---	---	---
174	99635.0	50100.0	4.00	5.00	MNB262	0.70	---	---	---
175	99700.0	50500.0	0.00	1.00	MNB154	17.90	---	---	---
175	99700.0	50500.0	1.00	2.00	MNB155	9.90	---	---	---
175	99700.0	50500.0	2.00	3.00	MNB156	5.00	---	---	---
175	99700.0	50500.0	3.00	4.00	MNB157	1.30	---	---	---
175	99700.0	50500.0	4.00	5.00	MNB158	2.00	---	---	---
176	99700.0	50400.0	0.00	1.00	MNB246	3.60	---	---	---
176	99700.0	50400.0	1.00	2.00	MNB247	4.00	---	---	---
176	99700.0	50400.0	2.00	3.00	MNB248	3.30	---	---	---
176	99700.0	50400.0	3.00	4.00	MNB249	2.60	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 10

South Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
176	99700.0	50400.0	4.00	5.00	MNB250	1.70	---	---	---
176	99700.0	50400.0	5.00	6.00	MNB256	1.30	---	---	---
176	99700.0	50400.0	6.00	7.00	MHN742	0.30	---	---	---
176	99700.0	50400.0	6.00	7.00	MNB257	1.30	---	---	---
177	99700.0	50300.0	0.00	1.00	MNB241	3.60	---	---	---
177	99700.0	50300.0	1.00	2.00	MNB242	36.40	---	---	---
177	99700.0	50300.0	2.00	3.00	MNB243	1.00	---	---	---
177	99700.0	50300.0	3.00	4.00	MNB244	1.70	---	---	---
177	99700.0	50300.0	4.00	5.00	MNB245	1.00	---	---	---
178	99730.0	50100.0	0.00	1.00	MNB263	1.30	---	---	---
178	99730.0	50100.0	1.00	2.00	MNB264	1.30	---	---	---
178	99730.0	50100.0	2.00	3.00	MNB265	1.30	---	---	---
178	99730.0	50100.0	3.00	4.00	MNB266	1.00	---	---	---
178	99730.0	50100.0	4.00	5.00	MNB267	1.00	---	---	---
180	99800.0	50500.0	0.00	1.00	MNB169	1.00	---	---	---
180	99800.0	50500.0	1.00	2.00	MNB170	2.30	---	---	---
180	99800.0	50500.0	2.00	3.00	MNB171	0.30	---	---	---
180	99800.0	50500.0	3.00	4.00	MHN734	0.70	---	---	---
180	99800.0	50500.0	3.00	4.00	MNB172	1.30	---	---	---
180	99800.0	50500.0	4.00	5.00	MNB173	1.30	---	---	---
181	99799.0	50384.0	0.00	1.00	MNB219	5.30	---	---	---
181	99799.0	50384.0	1.00	2.00	MNB220	1.00	---	---	---
181	99799.0	50384.0	2.00	3.00	MHN739	1.00	---	---	---
181	99799.0	50384.0	2.00	3.00	MNB221	2.00	---	---	---
181	99799.0	50384.0	3.00	4.00	MNB222	1.30	---	---	---
181	99799.0	50384.0	4.00	5.00	MNB223	1.00	---	---	---
182	99800.0	50300.0	0.00	1.00	MNB236	13.20	---	---	---
182	99800.0	50300.0	1.00	2.00	MNB237	2.30	---	---	---
182	99800.0	50300.0	2.00	3.00	MHN741	3.30	---	---	---
182	99800.0	50300.0	2.00	3.00	MNB238	4.00	---	---	---
182	99800.0	50300.0	3.00	4.00	MNB239	2.60	---	---	---
182	99800.0	50300.0	4.00	5.00	MNB240	1.30	---	---	---
183	99800.0	49920.0	0.00	1.00	MNB444	0.30	---	---	0.60
183	99800.0	49920.0	1.00	2.00	MNB445	<0.30	---	---	0.50
183	99800.0	49920.0	2.00	3.00	MHN716	1.70	---	---	0.90
183	99800.0	49920.0	2.00	3.00	MNB446	0.30	---	---	1.50
183	99800.0	49920.0	3.00	4.00	MNB447	1.30	---	---	1.20
183	99800.0	49920.0	4.00	5.00	MNB448	0.30	---	---	1.20
184	99894.0	50247.0	0.00	1.00	MHN740	4.00	---	---	---
184	99894.0	50247.0	0.00	1.00	MNB229	3.60	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 10

South Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
184	99894.0	50247.0	1.00	2.00	MNB230	5.60	---	---	---
184	99894.0	50247.0	2.00	3.00	MNB231	1.70	---	---	---
184	99894.0	50247.0	3.00	4.00	MNB232	1.70	---	---	---
184	99894.0	50247.0	4.00	5.00	MNB233	2.80	---	---	---
184	99894.0	50247.0	5.00	6.00	MNB234	1.00	---	---	---
184	99894.0	50247.0	6.00	7.00	MNB235	1.00	---	---	---
185	99925.0	50498.0	0.00	1.00	MNB174	1.30	---	---	---
185	99925.0	50498.0	1.00	2.00	MHN735	0.30	---	---	---
185	99925.0	50498.0	1.00	2.00	MNB175	1.70	---	---	---
185	99925.0	50498.0	2.00	3.00	MNB176	1.00	---	---	---
185	99925.0	50498.0	3.00	4.00	MNB177	1.00	---	---	---
185	99925.0	50498.0	4.00	5.00	MNB178	0.70	---	---	---
186	99900.0	50290.0	0.00	1.00	MNB224	18.50	---	---	---
186	99900.0	50290.0	1.00	2.00	MNB225	1.30	---	---	---
186	99900.0	50290.0	2.00	3.00	MNB226	1.30	---	---	---
186	99900.0	50290.0	3.00	4.00	MNB227	1.00	---	---	---
186	99900.0	50290.0	4.00	5.00	MNB228	0.70	---	---	---
187	99950.0	50088.0	0.00	1.00	MNB268	4.60	---	---	---
187	99950.0	50088.0	1.00	2.00	MNB269	0.70	---	---	---
187	99950.0	50088.0	2.00	3.00	MNB270	1.30	---	---	---
187	99950.0	50088.0	3.00	4.00	MHN744	<0.30	---	---	---
187	99950.0	50088.0	3.00	4.00	MNB271	1.30	---	---	---
187	99950.0	50088.0	4.00	5.00	MNB272	1.70	---	---	---
189	100003.0	50500.0	0.00	1.00	MNB179	32.10	---	---	---
189	100003.0	50500.0	1.00	2.00	MNB180	7.90	---	---	---
189	100003.0	50500.0	2.00	3.00	MNB181	1.70	---	---	---
189	100003.0	50500.0	3.00	4.00	MNB182	1.00	---	---	---
189	100003.0	50500.0	4.00	5.00	MNB183	1.30	---	---	---
190	100000.0	50300.0	0.00	1.00	MNB273	14.20	---	---	---
190	100000.0	50300.0	1.00	2.00	MNB274	2.30	---	---	---
190	100000.0	50300.0	2.00	3.00	MNB275	2.00	---	---	---
190	100000.0	50300.0	3.00	4.00	MHN745	0.30	---	---	---
190	100000.0	50300.0	3.00	4.00	MNB276	0.70	---	---	---
190	100000.0	50300.0	4.00	5.00	MNB277	0.70	---	---	---
191	100000.0	49900.0	0.00	1.00	MNB439	20.50	---	---	---
191	100000.0	49900.0	1.00	2.00	MNB440	2.00	---	---	---
191	100000.0	49900.0	2.00	3.00	MNB441	2.00	---	---	---
191	100000.0	49900.0	3.00	4.00	MNB442	1.00	---	---	---
191	100000.0	49900.0	4.00	5.00	MNB443	2.00	---	---	---
425	99542.0	50321.0	0.00	1.00	MNC661	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 10

South Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
425	99542.0	50321.0	1.00	2.00	MNC662	0.30	---	---	---
425	99542.0	50321.0	2.00	3.00	MNC663	0.70	---	---	---
425	99542.0	50321.0	3.00	4.00	MNC664	0.30	---	---	---
425	99542.0	50321.0	4.00	5.00	MNC665	<0.30	---	---	---
430	99260.0	50000.0	0.00	1.00	MML314	7.30	---	---	---
430	99260.0	50000.0	16.00	17.00	MHN873	5.60	---	---	1.30
430	99260.0	50000.0	16.00	17.00	MML328	6.30	---	---	1.30
430	99260.0	50000.0	17.00	18.00	MML329	<0.30	---	---	0.80
430	99260.0	50000.0	18.00	19.00	MML330	<0.30	---	---	0.90
430	99260.0	50000.0	19.00	20.00	MML331	0.30	---	---	1.00
654	99238.0	49950.0	0.00	0.42	WSC311	89.60	1.60	1.50	5.20
655	99300.0	50300.0	0.00	0.50	MNC051	13.60	19.40	12.80	---
657	99400.0	50000.0	0.00	0.50	MNC052	96.00	1.20	0.80	---
658	99400.0	49805.0	0.00	0.50	MNC012	64.20	1.50	0.40	---
658	99400.0	49805.0	0.00	0.50	UNC394	65.20	1.60	0.20	---
660	99500.0	50000.0	0.00	0.50	MNC053	82.80	0.80	0.90	---
661	99500.0	49805.0	0.00	0.50	MNC013	70.20	3.50	1.00	---
662	99565.0	49900.0	0.00	0.50	MNC001	---	1.60	1.10	---
663	99700.0	49925.0	0.00	0.50	MNC002	---	1.90	1.60	---
666	99900.0	49920.0	0.00	0.50	MNC003	---	2.80	1.60	---
668	100000.0	49800.0	0.00	0.50	MNC004	33.80	1.50	1.50	---
669	100000.0	49700.0	0.00	0.50	MNC005	3.30	0.30	0.40	---
669	100000.0	49700.0	0.00	0.50	UNC392	2.70	0.50	0.20	---
756	99850.0	49700.0	0.00	0.50	WSC392	9.30	1.00	1.40	---
757	99875.0	49680.0	0.00	0.50	WSC393	3.00	0.80	0.60	---
758	99650.0	49700.0	0.00	0.50	WSC395	204.20	451.90	5.40	---
759	99700.0	49620.0	0.00	0.50	WSC396	4.90	1.20	0.80	---
760	99950.0	49700.0	0.00	0.50	WSC397	20.70	1.00	6.90	---
761	99750.0	49700.0	0.00	0.50	WSC400	12.60	1.20	1.80	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 10

South Buildings Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
762	99725.0	49675.0	0.00	0.50	WSC402	5.50	1.40	0.50	—
763	99725.0	49650.0	0.00	0.50	WSC404	5.30	0.90	0.40	—
767	99430.0	50010.0	0.00	1.00	WSC442	1839.20	<0.80	<1.00	—
767	99430.0	50010.0	1.00	2.00	WSC448	514.40	<0.60	0.50	—
767	99430.0	50010.0	2.00	3.00	WSC449	294.90	1.10	1.00	—
768	99400.0	50075.0	0.00	1.00	WSC443	2008.80	<0.70	4.10	—
768	99400.0	50075.0	0.00	1.00	WSC444	1808.80	<0.60	3.80	—
769	99650.0	49720.0	0.00	1.00	WSC445	8.10	17.30	1.80	—
769	99650.0	49720.0	0.00	1.00	WSC446	<7.60	102.90	1.40	—
769	99650.0	49720.0	0.00	1.00	WSC447	20.50	10.20	1.10	—
769	99650.0	49720.0	1.00	2.00	WSC450	9.10	8.90	1.10	—
769	99650.0	49720.0	2.00	3.00	WSC451	15.00	9.80	1.40	—
769	99650.0	49720.0	3.00	4.00	WSC452	6.10	2.70	0.90	—

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 11

Southeast Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
375	98300.0	50789.0	0.00	1.00	MNB112	---	---	---	2.20
375	98300.0	50789.0	1.00	2.00	MNB113	---	---	---	1.30
375	98300.0	50789.0	2.00	3.00	MNB114	---	---	---	1.50
375	98300.0	50789.0	3.00	4.00	MNB115	---	---	---	1.40
375	98300.0	50789.0	4.00	5.00	MHN708	---	---	---	1.40
375	98300.0	50789.0	4.00	5.00	MNB116	---	---	---	1.10
376	98290.0	50700.0	0.00	1.00	MNB117	---	---	---	0.90
376	98290.0	50700.0	1.00	2.00	MNB118	---	---	---	1.30
376	98290.0	50700.0	2.00	3.00	MNB119	---	---	---	1.30
376	98290.0	50700.0	4.00	5.00	MNB120	---	---	---	1.30
376	98290.0	50700.0	5.00	6.00	MNB121	---	---	---	1.00
376	98290.0	50700.0	6.00	7.00	MNB127	---	---	---	1.50
376	98290.0	50700.0	7.00	8.00	MNB128	---	---	---	1.30
378	98400.0	50300.0	0.00	1.00	MNB129	2.30	---	---	---
378	98400.0	50300.0	1.00	2.00	MNB130	1.00	---	---	---
378	98400.0	50300.0	2.00	3.00	MNB131	1.00	---	---	---
378	98400.0	50300.0	3.00	4.00	MNB132	0.70	---	---	---
378	98400.0	50300.0	4.00	5.00	MNB133	0.70	---	---	---
381	98500.0	50800.0	0.00	1.00	MNB107	---	---	---	0.80
381	98500.0	50800.0	1.00	2.00	MNB108	---	---	---	0.50
381	98500.0	50800.0	2.00	3.00	MNB109	---	---	---	1.30
381	98500.0	50800.0	3.00	4.00	MNB110	---	---	---	1.30
381	98500.0	50800.0	4.00	5.00	MNB111	---	---	---	1.20
382	98500.0	50600.0	0.00	1.00	MNB122	---	---	---	0.90
382	98500.0	50600.0	1.00	2.00	MNB123	---	---	---	0.70
382	98500.0	50600.0	2.00	3.00	MNB124	---	---	---	1.30
382	98500.0	50600.0	3.00	4.00	MNB125	---	---	---	1.40
382	98500.0	50600.0	4.00	5.00	MHN709	---	---	---	1.30
382	98500.0	50600.0	4.00	5.00	MNB126	---	---	---	1.30
387	98761.0	50182.0	0.00	1.00	MNB464	---	---	---	1.20
387	98761.0	50182.0	1.00	2.00	MNB465	---	---	---	3.10
387	98761.0	50182.0	2.00	3.00	MHN71	---	---	---	1.70
387	98761.0	50182.0	2.00	3.00	MNB466	---	---	---	1.70
387	98761.0	50182.0	3.00	4.00	MNB467	---	---	---	2.00
387	98761.0	50182.0	4.00	5.00	MNB468	---	---	---	2.00
388	98800.0	50400.0	0.00	1.00	MNB139	10.30	---	---	---
388	98800.0	50400.0	1.00	2.00	MNB140	11.60	---	---	---
388	98800.0	50400.0	2.00	3.00	MNB141	4.30	---	---	---
388	98800.0	50400.0	3.00	4.00	MHN731	1.00	---	---	---
388	98800.0	50400.0	3.00	4.00	MNB142	0.70	---	---	---
388	98800.0	50400.0	4.00	5.00	MNB143	0.70	---	---	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 11

Southeast Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
389	98864.0	50290.0	0.00	1.00	MNB469	---	---	---	1.00
389	98864.0	50290.0	1.00	2.00	MNB470	---	---	---	1.40
389	98864.0	50290.0	2.00	3.00	MNB471	---	---	---	1.40
389	98864.0	50290.0	3.00	4.00	MNB472	---	---	---	1.30
389	98884.0	50290.0	4.00	5.00	MNB473	---	---	---	1.40
390	98901.0	50409.0	0.00	1.00	MNB134	---	---	---	5.70
390	98901.0	50409.0	1.00	2.00	MNB135	---	---	---	2.10
390	98901.0	50409.0	2.00	3.00	MNB136	---	---	---	1.20
390	98901.0	50409.0	3.00	4.00	MNB137	---	---	---	1.40
390	98901.0	50409.0	4.00	5.00	MNB138	---	---	---	1.20
391	99000.0	50500.0	0.00	1.00	MNB474	---	---	---	3.90
391	99000.0	50500.0	1.00	2.00	MNB475	---	---	---	2.80
391	99000.0	50500.0	2.00	3.00	MHN711	---	---	---	0.80
391	99000.0	50500.0	2.00	3.00	MNB476	---	---	---	0.90
391	99000.0	50500.0	3.00	4.00	MNB477	---	---	---	0.40
391	99000.0	50500.0	4.00	5.00	MNB478	---	---	---	1.10
391	98000.0	50500.0	5.00	6.00	MNB479	---	---	---	1.30
391	99000.0	50500.0	6.00	7.00	MNB480	---	---	---	1.10
422	98780.0	50175.0	0.00	1.00	MNC584	6.00	---	---	---
422	98780.0	50175.0	1.00	2.00	MNC585	2.00	---	---	---
422	98780.0	50175.0	2.00	3.00	MNC586	1.00	---	---	---
422	98780.0	50175.0	3.00	4.00	MNC587	0.30	---	---	---
422	98780.0	50175.0	4.00	5.25	MNC588	<0.30	---	---	---
422	98780.0	50175.0	9.00	10.00	MNC589	<0.30	---	---	---
422	98780.0	50175.0	10.00	11.00	MNC590	0.30	---	---	---
422	98780.0	50175.0	11.00	12.00	MNC591	<0.30	---	---	---
422	98780.0	50175.0	12.00	13.00	MHN863	<0.30	---	---	---
422	98780.0	50175.0	12.00	13.00	MNC592	<0.30	---	---	---
434	98740.0	50175.0	0.00	1.00	MNE293	6.60	---	---	---
434	98740.0	50175.0	7.00	8.00	MNE298	2.30	---	---	0.30
434	98740.0	50175.0	8.00	9.00	MNE299	1.30	---	---	0.40
434	98740.0	50175.0	9.00	10.00	MNE300	0.70	---	---	0.40
434	98740.0	50175.0	10.00	11.00	MNE301	<0.30	---	---	1.00
622	98300.0	50800.0	0.00	1.00	UNC379	13.14	1.70	0.93	---
622	98300.0	50800.0	1.00	2.00	UNC380	<1.87	2.03	1.51	---
622	98300.0	50800.0	2.00	3.00	UNC381	<5.98	1.09	1.39	---
622	98300.0	50800.0	3.00	4.00	UNC382	<1.86	1.76	1.43	---
622	98300.0	50800.0	4.00	5.00	UNC383	<2.74	1.46	1.27	---
631	98450.0	50350.0	0.00	0.50	WSC307	2.40	0.70	0.50	---

TABLE F-1 Weldon Spring Radionuclide Data (Continued)

Region 11

Southeast Area

Sample Location	Northing	Westing	Top Depth (ft)	Bottom Depth (ft)	Sample #	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Th-230 (pCi/g)
640	98650.0	50300.0	0.00	0.50	WSC306	<1.20	0.70	0.50	—
643	98725.0	50125.0	0.00	0.50	WSC309	7.10	0.80	1.00	2.30
644	98745.0	50120.0	0.00	0.50	MHN853	5.60	1.10	1.10	---
644	98745.0	50120.0	0.00	0.50	MNC114	5.00	0.90	1.00	---
644	98745.0	50120.0	0.50	1.00	MNC115	2.30	1.20	0.90	---
645	98750.0	50200.0	0.00	0.42	WSC310	14.70	1.50	0.80	---
646	98758.0	50200.0	0.00	0.50	MNC116	7.90	0.80	0.40	---
648	98800.0	50410.0	2.00	3.00	UNC465	<1.20	1.30	0.80	---
648	98800.0	50410.0	3.00	4.00	UNC455	<1.30	1.50	1.40	---
648	98800.0	50410.0	4.00	5.00	UNC466	2.40	1.50	0.60	---
649	98950.0	50250.0	0.00	0.50	WSC308	<2.10	1.60	1.30	---
652	99100.0	50500.0	0.00	0.50	MNC030	16.50	0.80	<0.10	—