Final Report July 1997

Type B Accident Investigation Board Report of the Plutonium Intake, Between August 4, 1996–February 10, 1997, By a Crane Operator At the Savannah River Site F-Canyon

Savannah River Operations Office

This report is an independent product of an accident investigation board appointed by Dr. Mario P. Fiori, Manager, Savannah River Operations Office, U.S. Department of Energy.

The board was appointed to perform a Type B Investigation of this accident and to prepare an investigation report in accordance with DOE 225.1*, Accident Investigations*.

The discussion of facts, as determined by the board, and the views expressed in the report do not assume and are not intended to establish the existence of any duty at law on the part of the U.S. Government, its employees or agents, contractors, their employees or agents, or subcontractors at any tier, or any other party.

This report neither determines nor implies liability.

On May 1, 1997, I established a Type B Accident Investigation Board to investigate the plutonium intake by a crane operator at the Savannah River Site F-Canyon.

The Board's responsibilities have been completed with respect to this incident. The analysis process; identification of direct, contributing and root causes; and development of judgments of need during the investigation were accomplished in accordance with DOE Order 225.1, *Accident Investigations*.

I accept the findings of the Board and authorize the release of this report for general distribution.

Mario P. Fiori, Manager
Savannah River Operations Office

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ACRONYMS AND GLOSSARY OF TERMS

ACRONYMS

ARA	Airborne Radioactivity Area
ALARA	As Low As Reasonably Achievable
CA	Contamination Area
CAM	Continuous Air Monitor
CEDE	Committed Effective Dose Equivalent
CFR	Code of Federal Regulations
cfm	cubic feet per minute
DAC	derived air concentration
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EBR	Experimental Breeder Reactor
FARM	Facility Annual Review of Radiation Monitoring (Equipment)
FEB	Facility Evaluation Board
HEPA	High-Efficiency Particulate Air (Filter)
ICRP	International Commission on Radiological Protection
JHA	Job Hazards Analysis
NMSS	Nuclear Materials Stabilization and Storage
Radcon	Radiological controls
RBA	Radiological Buffer Area
RCI	Radiological Control Inspector
RCO	Radiological Control Operations
rem	Roentgen equivalent man
RMA	Radioactive Material Area
RWP	Radiological Work Permit
RWT	Radiological Worker Training
scfm	standard cubic feet per minute
SOM	Shift Operations Manager
SRS	Savannah River Site
S&H	Safety and Health
TRR	Taiwan Research Reactor
WSRC	Westinghouse Savannah River Company

GLOSSARY OF TERMS

Activity Median Aerodynamic Diameter: The diameter of a sphere having a density of 1 g/cm^3 and the same terminal settling velocity in air as that of the aerosol particle whose activity is the median for the entire aerosol.

Airborne Radioactivity Area: Any area where the concentration of airborne radioactivity above natural background exceeds or is likely to exceed 10 percent of the derived air concentration (DAC) values.

B-25 box: A 96 cubic foot sheet metal box used for the temporary storage of radioactive material and the permanent disposal of radioactive waste. A separate lid may either be temporarily secured by chain and lock, or permanently secured with metal clips hammered in place.

bioassay: A determination of the kinds, quantities, or concentrations (and, in some cases, locations) of radioactive material in the human body by direct measurement or by analysis and evaluation of radioactive materials excreted or removed from the human body.

Committed Effective Dose Equivalent (CEDE): The sum of the committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor. A committed dose equivalent is the dose equivalent calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body.

Contamination Area: An area where the removable or total contamination levels exceed the limits in Table 2-2 of the DOE Radiological Control Manual.

continuous air monitor (CAM): An instrument that continuously samples and measures the levels of airborne radioactive materials on a “real-time” basis and has alarm capabilities at preset levels.

derived air concentration (DAC): For certain radionuclides, the airborne concentration that equals the annual limit on intake divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of 2400 cubic meters per year).

disintegration per minute (dpm): The rate of transformation by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for the background count rate, detector, efficiency, and geometric factors associated with the instrumentation.

micro (μ): one millionth (10^{-6})

nano (n): one billionth (10^{-9})

PERIPHERAL WORK: Work in support of, but not directly related to, separations chemical processing (including area decontamination operations, jumper gasket replacement, installation and removal of radiological huts, waste handling, and general housekeeping). These activities are usually routine and not necessarily perceived to require a high technical skill level.

probe: When used as a verb, a term used to describe the action, by RCO personnel, of measuring a quantity of contamination or radiation by using portable instruments. The term may be used to describe measuring radioactive material accumulated on air sampler collection media to make interim estimates of levels of airborne radioactivity.

Radiological Work Permit (RWP): A permit that identifies radiological conditions, establishes worker protection and monitoring requirements, and contains specific approvals for radiological work activities.

rem: Unit of dose equivalent.

Sand Filters: An engineered concrete structure approximately 240 feet long by 100 feet wide by 16 feet deep containing seven layers of filter material in decreasing size from coarse gravel (bottom) to fine sand (top). The sand filter has an efficiency of 99.5 percent in removing airborne radioactive particulate greater than 0.3 micrometer in diameter size.

EXECUTIVE SUMMARY

Introduction

On February 10, 1997, a Savannah River Site F-Canyon crane process operator (the CRANE OPERATOR) submitted a routine, semi-annual bioassay sample which was analyzed in April as positive for plutonium. The CRANE OPERATOR's prior routine sample submitted on August 4, 1996, had been analyzed as negative. It was therefore concluded the CRANE OPERATOR had been internally contaminated between August 4, 1996, and February 10, 1997. When the investigation began there was no known direct causal event for this intake. Follow-up bioassay samples and analyses indicated the CRANE OPERATOR may have received an occupational exposure of approximately 17 rem, 50-year Committed Effective Dose Equivalent (CEDE), based on an assumed mid-point intake date of November 7, 1996. Analysis of the bioassay samples indicated inhalation as the mechanism for the intake. This conclusion was based on the rate and pathways of elimination of the contamination from the body. Additionally the samples reflected significant alpha radioactivity, while the amount of beta and gamma radioactivity was below minimum detection levels. This indicated absence of measurable quantities of fission products. Since the estimated 50-year CEDE met the criteria for a Type B Accident Investigation in accordance with DOE Order 225.1, "Accident Investigation," Attachment 2, a Type B Accident Investigation Board (the Board) was formed on May 1, 1997.

The estimated 17 rem CEDE results in an actual first year dose of approximately 750 millirem (mrem).

Investigation Methodology

The Board's efforts initially focused on identifying a direct causal event for the intake during the August 4, 1996, to February 10, 1997, time frame. These efforts included developing a timeline of F-Canyon activities, focusing on the CRANE OPERATOR's specific work. As the timeline was developed the Board screened the CRANE OPERATOR's work activities to determine which activities presented a high potential for his intake. The criteria used for this screening were specific work activities consistent with bioassay results (work with large quantities of predominantly alpha emitting contamination) AND unusual radiological conditions OR lack of Radiological Control Operations (RCO) coverage. The screening process identified four activities which were determined to be high potential scenarios for the intake.

- Warm Canyon Cell Cover Activity: Unauthorized work may have resulted in contamination of the CRANE OPERATOR'S protective clothing and subsequent internal contamination of the CRANE OPERATOR in the Old Warm Crane Cab.
- Old Warm Crane Operation: The CRANE OPERATOR may have been exposed, by two different methods, to high airborne levels of radioactivity in the crane cab without respiratory protection.
- Warm Gang Valve Corridor Decontamination: The CRANE OPERATOR may have performed decontamination work in an Airborne Radioactivity Area without proper respiratory protection.
- Warm Gang Valve Corridor Hut Removal: The CRANE OPERATOR may have been exposed to an airborne radioactivity release without respiratory protection during removal of the hut.

The remainder of the investigation focused on these activities.

Results of Analysis

<u>Uncertainty with specific work activity:</u>
There was uncertainty in the CRANE OPERATOR's specific work activities due to lack of records, lack of sufficient detail in records that were available, and lack of memory recall. The Board was only able to account for approximately 30 percent of the CRANE OPERATOR's activities for the period under investigation. As a result, the direct causal event was indeterminate at the conclusion of the Board's analysis. In spite of this, the Board concluded sufficient data existed for known activities to enable proper analysis. The commonality of causal factors for each of the four analyzed scenarios enabled the Board to determine with confidence, direct, root and contributing causes.

<u>Context of findings:</u>
The Board's findings were associated with selected PERIPHERAL WORK activities in radiological areas in F-Canyon. PERIPHERAL WORK was work in support of, but not directly related to, separations chemical processing. It included such work as area decontamination, jumper gasket replacement, installation and

removal of radiological huts, waste handling and general housekeeping. These activities were usually routinely performed without supervision and were not necessarily perceived to require a high technical skill level. PERIPHERAL WORK did not normally receive routine management attention.

Causal factors and other management issues:
The causal factors identified during the investigation and listed below are a result of commonalties identified with the four scenarios investigated by the Board. The following factors were determined to be common to most, if not all, of the scenarios:

- Failure to determine source of elevated contamination levels
- Failure to adequately characterize work place radiological conditions
- Failure to properly post and control radiological control boundaries
- Improper use of respiratory protection equipment
- Inadequate Radiological Work Permits
- Inadequate job planning/work package preparation/pre-job briefs/ALARA reviews
- Failure to ensure verbatim compliance with procedures
- Inappropriate use of generic/reference procedures and reliance on "skill of the craft" to perform radiological work
- Failure to provide, maintain and perform surveillance on equipment utilized to protect workers
- Inadequate specification of who is in charge of the job
- Failure by management and supervision to perform adequate work site inspections and surveillances
- Failure to perform adequate Job Hazard Analyses
- Failure to provide adequate Radiological Engineering support of radiological work
- Improper acceptance of high levels of surface contamination and airborne radioactivity as a "Normal" work environment
- Inadequate management analyses of operating conditions

Other management issues which were identified during the investigation but were determined to not be causal factors included:
- Weakness in radiological control personnel training
- Weakness in established "for cause" bioassay criteria
- Weakness in reporting radiological deficiencies
- Weakness in documenting radiological records
- Weakness in record retention
- Weakness in documenting logs and turnover checklists in sufficient detail
- Weakness in DOE oversight of F-Canyon radiological work

An assessment of these causal factors and other management issues within the framework of Integrated Safety Management indicated the Integrated Safety Management system was not being properly implemented for PERIPHERAL WORK in F-Canyon radiological areas.

Causes

The direct cause for the CRANE OPERATOR's intake was determined to be the CRANE OPERATOR's failure to wear respiratory protection in an Airborne Radioactivity Area.

The root cause of the intake was determined to be a lack of discipline in fully implementing radiological controls and requirements for PERIPHERAL WORK in radiological areas.

The Board also determined that there were three contributing causes of the intake:

- Lack of operations supervision and management oversight for PERIPHERAL WORK
- Lack of radiological controls supervision and management oversight for PERIPHERAL WORK
- Inadequate management analysis of operational and radiological conditions associated with PERIPHERAL WORK

Conclusion and Judgments of Need

The Board's conclusions and judgments of need for recurrence prevention of this intake are presented below.

CONCLUSIONS	JUDGMENTS OF NEED (For WSRC Action)
WSRC failure to adequately implement radiological controls and requirements for PERIPHERAL WORK activities.	Improve implementation and enforcement of Radiological Conduct of Operations. Develop and implement a program which analyzes all facility activities for proper engineered radiological controls with reliance on engineered containments and ventilation systems. Improve enforcement of posting and control of radiological areas per the Radiological Control Manual.
WSRC failure to provide an adequate level of operations supervision and management oversight for PERIPHERAL WORK.	Increase involvement, surveillance and performance based assessment of PERIPHERAL WORK by operations supervision and management. Improve enforcement of Conduct of Operations. Improve enforcement of procedural compliance requirements of Conduct of Operations. Improve operating procedures to reflect specific facility operations and evaluate minimizing reference procedures. Ensure that a person has been designated to be in charge for all work activities. Analyze operations of the Old Warm Crane and improve the reliable operability of associated protective equipment, if the crane is to be used.
WSRC failure to provide an adequate level of radiological controls supervision and management oversight for PERIPHERAL WORK activities.	Evaluate all accessible canyon areas for potential reduction of contamination/radiation levels. Increase involvement, surveillance, and performance based assessment of PERIPHERAL WORK by radiological supervision and management.
WSRC failure to provide adequate management analyses of operational and radiological conditions associated with PERIPHERAL WORK activities.	Improve implementation of the Integrated Safety Management System by including PERIPHERAL WORK. Improve management and supervisory review and analysis of operational and radiological conditions for PERIPHERAL WORK (including procedures, logs, records, checklists and radiological surveys).

CONTEXT OF FINDINGS

During the course of this investigation, the Board found numerous examples as described in this report of individuals failing to adhere to established requirements for selected PERIPHERAL WORK activities in radiological areas. The Board concluded the reasons for this condition to be as follows:

- PERIPHERAL WORK is not direct separations chemical processing work. It involves activities which are usually routinely performed without supervision and are not necessarily perceived to require a high technical skill level.
  - emptying job control waste containers
  - wiping walls and floors (area decontamination)
  - building and disassembling radiological huts
  - replacing jumper gaskets
  - infrequent Old Warm Crane operation
  - general housekeeping

- PERIPHERAL WORK is addressed by generic procedures which "cover the work" with little guidance or direction. This is because the nature of work is generally perceived to not need much guidance or direction or depends on "skill of the craft" to fit specific work conditions.

- PERIPHERAL WORK receives little or no management attention due to its perceived routine nature. There is a false assumption that the infrastructure will properly deal with this type of work in the same manner it deals with "more important" direct separations chemical processing work.

- Because of the generally routine nature and perceived simplicity of this type work, lack of discipline can lead to bypassing those requirements or controls that are improperly considered by the individual to not necessarily contribute to his or her safety.

- Because enough margin of safety may still exist most of the time to preclude incidents when these requirements and controls are bypassed and since lack of supervision or management presence precludes administrative action or correction, there is lack of consequence most of the time and this continuously reinforces the condition.

The purpose of this characterization of PERIPHERAL WORK is not to rationalize the observed failures, but to explain them in a manner to properly guide corrective action.

It is in this context that the findings and conclusions of this report should be considered.

1.0 INTRODUCTION

1.1 BACKGROUND

On February 10, 1997, an F-Canyon crane process operator (the CRANE OPERATOR)[1] submitted a routine, semi-annual bioassay (urine) sample. On April 1, 1997, results of the bioassay sample indicated positive for plutonium. A previous semi-annual bioassay sample submitted on August 4, 1996, by the CRANE OPERATOR was below the detection limit for plutonium. A follow-up bioassay sample was requested on April 2, 1997. On April 21, 1997, results of the follow-up bioassay sample confirmed a positive indication for plutonium. Additional bioassay samples (urine and fecal) were subsequently requested of the CRANE OPERATOR. On April 28, 1997, results of the fecal and urine samples indicated the CRANE OPERATOR may have received an occupational exposure of approximately 17 rem, 50-year Committed Effective Dose Equivalent (CEDE). The estimated 17 rem CEDE met the criteria for a Type B investigation in accordance with DOE Order 225.1, "Accident Investigation," Attachment 2. Following the bioassay results reported on April 28, 1997, a Type B Accident Investigation Board (Board) was formed on May 1, 1997. Based on the bioassay program data, the intake of radiological contamination occurred between August 4, 1996, and February 10, 1997. When the investigation was initiated, the event which caused the CRANE OPERATOR's intake was not known.

1.2 INVESTIGATION SCOPE, CONDUCT AND METHODOLOGY

The Board commenced investigation activities on May 2, 1997, to determine the cause of the CRANE OPERATOR's intake of contamination. Because the date of the intake was unknown at the onset of the investigation, the scope included review of the CRANE OPERATOR's routine and non-routine activities between August 4, 1996, and February 10, 1997. Initial efforts included developing a timeline of F-Canyon activities, focusing on the CRANE OPERATOR's work activities. As the timeline was developed, the Board identified activities having a higher potential for an intake of contamination consistent with the bioassay results. Since these results indicated a source term of large quantities of predominantly alpha contamination, the scope of the investigation was focused on Warm Canyon and associated area activities. These higher potential activities were investigated in greater detail, and four activities were identified as having high potential for the intake. The remainder of the investigation focused on these activities.

In conducting the investigation, the Board completed extensive interviews with cognizant personnel; inspected and photographed facilities and equipment; reviewed applicable documentation; performed causal analysis; and evaluated overall management systems. Based on analyses of these data, the Board identified judgments of need for corrective actions to prevent recurrence of similar incidents.

1.3 FACILITY DESCRIPTION

The Savannah River Site (SRS) is a large Government-owned industrial complex covering more than 300 square miles in South Carolina. Under contract with the U.S. Department of Energy (DOE), Westinghouse Savannah River Company (WSRC) is responsible for integrating and managing the safe and effective operation and maintenance of site facilities.

The F Canyon is a radiochemical facility whose current mission involves separation and stabilization of nuclear materials (Exhibit 1-1). The processing equipment is isolated from the operating personnel, the environment, and the public in two parallel canyons (Hot and Warm) 15 feet wide at the bottom and 30 feet wide at the top (Figure 1-1). The canyons are housed in a blast-resistant reinforced concrete structure 835 feet long, 132 feet wide and 66 feet high. The above grade height is 52 feet. The two canyons are separated from each other by a central operating and service section that is divided into four levels.

[1] Throughout this report, the Crane Process Operator who received the intake is referred to as the CRANE OPERATOR.

Exhibit 1-1 Canyon Overview (94-1937-17)

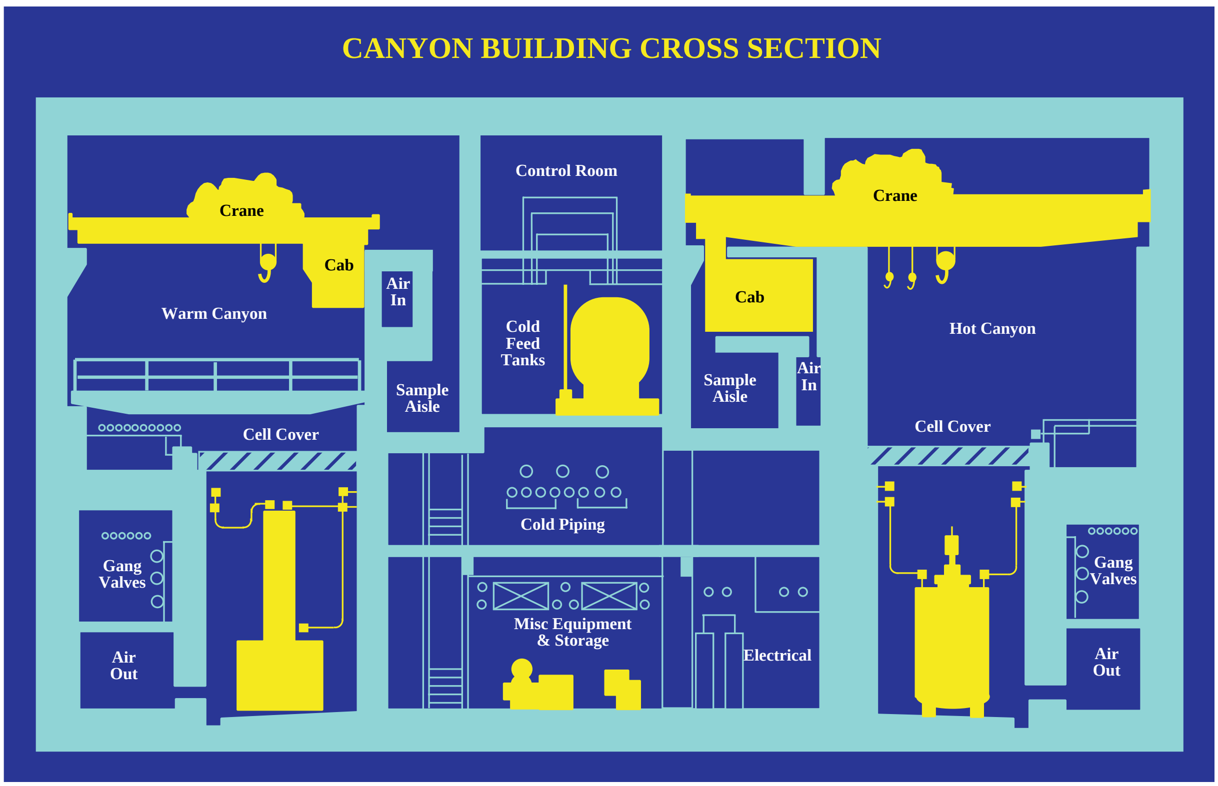


Figure 1-1 Canyon Cross Section

Fourth Level: Control room, crane control room and general office space
Third Level: Feed tank gallery, sample aisles
Second Level: Pipe gallery, mask room and tool decontamination room, canyon air supply fan room
First Level: Change rooms, services, and maintenance facilities

The building consists of seventeen 43-foot sections and one 85-foot section at the south end. The sections are numbered 1 to 18 beginning at the southernmost section (Figure 1-2). Expansion joints are provided between adjacent sections. Shipments of materials to be separated and stabilized and equipment to be used in the Hot Canyon are handled through a railroad tunnel that extends south from the end of the building. The railroad spur in the tunnel terminates at section 3 within the Hot Canyon area. Equipment for the warm side of the building enters at section 4 through a truck well.

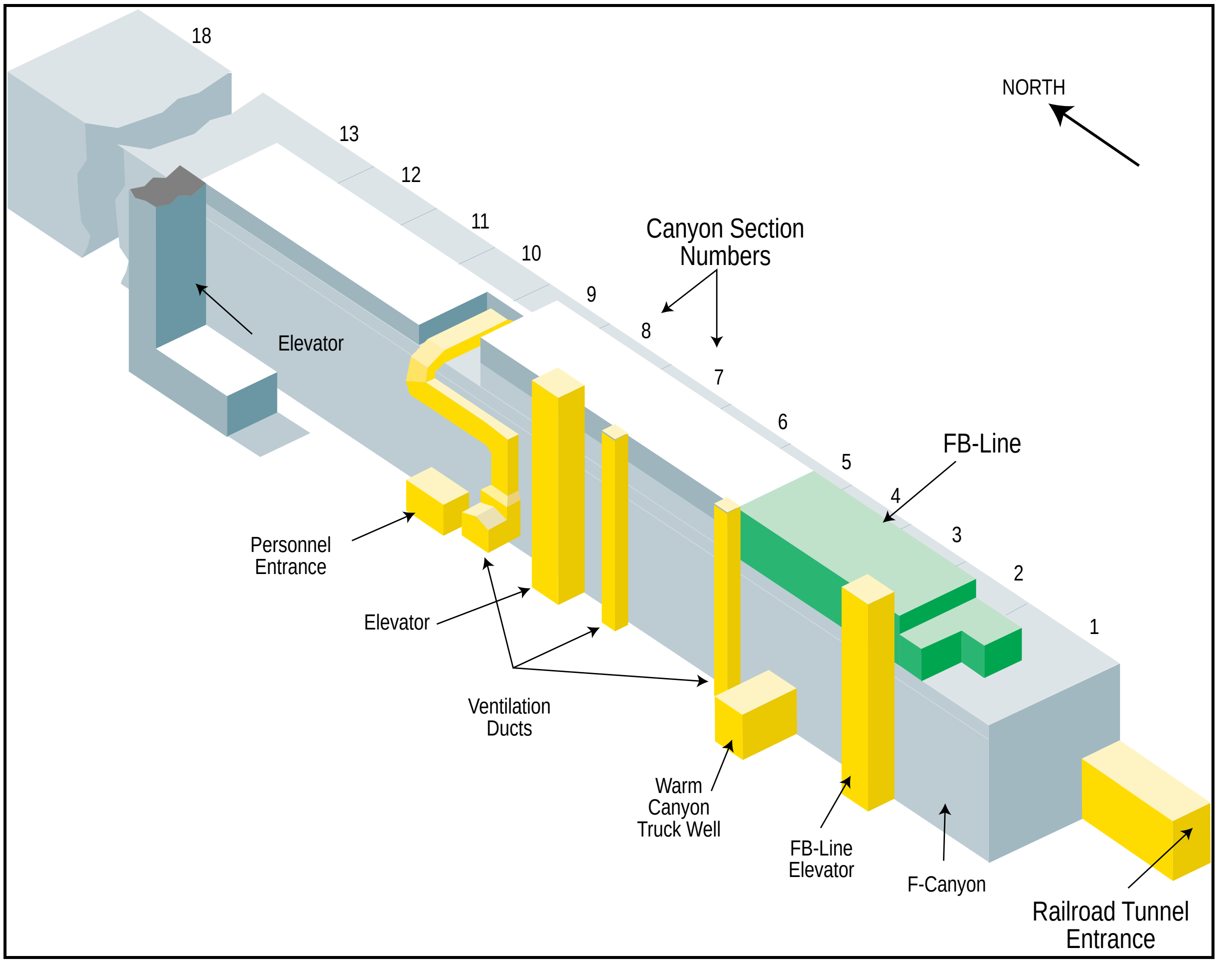


Figure 1-2 Canyon Isometric Drawing

The more highly radioactive operations such as dissolution of irradiated materials, precipitation and centrifugation (head end), bulk fission product separation and waste evaporation, are performed in the Hot Canyon and the final purification of the products is performed in the Warm Canyon.

The design of F-Canyon requires the use of cranes to make connections between process equipment in the canyon with services (such as steam and water) or with radioactive transfer lines supplied from special nozzles located along the canyon wall. There are two basic types of nozzles (electrical and piping) which mate to corresponding pieces of piping or conduit, called jumpers, that span the spaces between the service supplied to the wall and the vessel. Jumpers are individual lengths of pipe with lifting bails and special pipe connectors welded on either end to enable remote coupling with the use of overhead cranes. Typical jumpers, when lifted by the bail, balance in a position that coincides with the dimensional coordinates of the connecting nozzle. The connections are designed so they can be tightened remotely using an impact wrench. Overhead rail cranes equipped with lifting hooks and impact wrenches are used to make the connections. The overhead cranes are also used to remove and replace the large concrete or steel covers over the individual canyon cells which contain tanks and other equipment; to remove and replace canyon cell equipment such as tanks, pumps, and agitators; to unload fuel and target materials from rail casks; and to place buckets of target materials or bundles of fuel in dissolver tanks.

F-Canyon has four cranes, an old and new crane in each canyon. The old cranes were installed when the canyon was originally built in 1953. The new cranes were put in service in the late 1980s and early 1990s. The major design improvement incorporated into the new cranes is remote operation capability via the use of a control operator's console located on the fourth level of the central personnel corridor in section 16. The new cranes are equipped with cameras which allow the operators to remotely view the crane equipment (lifting hooks, impact wrenches, etc.) and any equipment to be handled.

Both the old and new cranes in each canyon share the same set of rails. Both cranes are powered from the rails which traverse the length of the canyon. Due to the physical limitations created by two cranes occupying the same rails, the old cranes are typically placed at the north end of each canyon (section 18) when not in use. The Old Warm Crane must be used for all work in section 17.8 and 18. The Old Warm Crane is also infrequently used when the New Warm Crane is not in service. When the old cranes are placed in use, the new cranes are docked in the crane maintenance areas. The crane maintenance areas are located in section 1 of each canyon on the fourth level. Each crane maintenance area can be physically isolated from the rest of the canyon via a large, electrically operated shielding door which slides into place on rails. Due to the limited physical size of the Warm Crane Maintenance Area and the sharing of rails by the old and new cranes, only the New Warm Crane can be brought into the crane maintenance areas. Maintenance on the Old Warm Crane must be performed atop a large concrete pad area on fourth level in section 2 of the Warm Canyon.

In the Warm Canyon, both cranes are equipped with an operator's cab which is located directly over the process cells. All operations performed using the Old Warm Crane are made using the local crane operator's console within the cab and by direct visual observation from the cab. When there are problems encountered with remote operability of the New Warm Crane, it can also be operated using the local crane operator's console in the cab. All of the crane cabs are equipped with a High Efficiency Particulate Air (HEPA) filtered ventilation system which maintains the pressure within the cab positive with respect to the surrounding canyon environment. All of the crane cab ventilation systems have air conditioning capability integral to the design, but for cooling only.

The power for the cranes consist of 480 volt main power with 480 volt auxiliary power. Auxiliary power enables the crane cabs to keep critical equipment operational during maintenance work that requires de-energizing the main power supply. The auxiliary power is also the only source supplied by emergency power (221-F Diesel). Only one crane in each canyon can be operated at any time due to the limitations of the main power supply system. On all cranes, the ventilation system fan and air conditioning system are continuously powered with the rails energized. On the new cranes, the ventilation system fan, air conditioner, cameras, crane controls and radio frequency equipment are all powered as long as the rails are energized.

Building 221-F Ventilation and Associated Effluent Sampling Systems

The Building 221-F ventilation and associated effluent sampling systems provide, in part, ventilation and monitoring capability for F-Canyon. These engineered ventilation and monitoring systems are necessary to confine the radioactive materials and provide a safe working environment. Additionally, adequate removal of radioactive materials from effluent air streams is necessary to minimize exposure of the public and impact on the environment. A drawing of the general ventilation system of Building 221-F is shown in Figure 1-3.

Four ventilation supply systems work jointly to provide adequate fresh air for the facilities housed within and on top of the main structure of the building. These are the Canyon, Center Section, Gang Valve Corridor, and FB-Line Supply Air Systems. The purpose of these systems is to ensure that air moves into the building, generally into areas of no radioactive contamination, and then proceeds through areas of lesser contamination to areas with higher levels of contamination.

To safely remove airborne radioactive materials emitted during operations within the building, six ventilation exhaust systems draw air from areas within the structure. These are the Canyon, Central, Process Vessel Vent, Recycle Vessel Vent, and two FB-Line Air Exhaust Systems.

Appropriate filtering is utilized to contain radioactive materials removed by the exhaust systems and thus minimize releases of such material to the environment. Air removed from high radiological areas (such as the Canyon, Recycle Vessel Vent, Process Vessel Vent, and FB-Line systems) is directed through the Sand Filter System prior to discharge to the atmosphere via a 195 foot tall structure identified as the 291-F Stack. Central Air exhaust, which includes air from the Center Section and Warm/Hot Gang Valve Corridors, is directed through a bank of HEPA filters prior to discharge via the 291-F Stack.

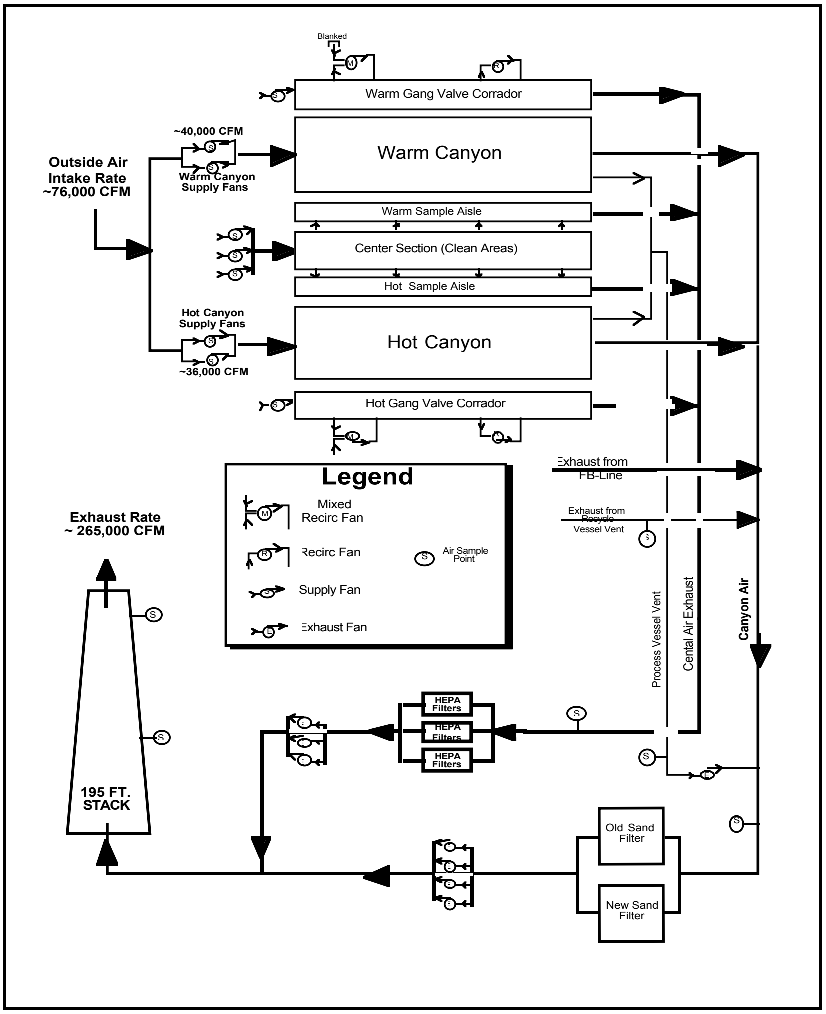


Figure 1-3 Building 221-F Ventilation System

The exhaust systems are monitored and sampled at various points to measure releases of radioactivity to the environment and to monitor occurrences within the facility that may indicate process-related problems. To detect and quantify release of radioactivity to the environment, several monitors and sampling systems collect representative samples of effluent air downstream of the various filtering systems and prior to discharge from the 291-F Stack. Emissions from the 291-F Stack are monitored for alpha emitters, general fission products and radioiodine by isokinetic collectors installed in the stack at various elevations.

Sampling to identify potential problems also occurs at various points along the ventilation flow-paths within the exhaust systems. These are referred to as unfiltered samples. The Unfiltered Canyon Air stream is sampled prior to entering the Sand Filter Buildings. This sample point collects from the combined Canyon, Process Vessel Vent, Recycle Vessel Vent and FB-Line air streams. Other sample points collect directly from the unfiltered Process Vessel Vent and Recycle Vessel Vent air streams before they join the Unfiltered Canyon Air stream. Unfiltered samples are also drawn from the Central Section air stream. The Unfiltered Canyon Air, Process Vessel Vent and Central Section samples are generally collected on workday mornings, Monday through Thursday. Sample media installed on a Thursday morning are not collected until the following Monday morning.

F-Canyon Operational History

F-Canyon was restarted by DOE in January 1995 to process the existing inventory of solutions which had been caught "in-process" when facility operations were suspended in 1992. In January 1996, upon the completion of an Operational Readiness Review by DOE, additional portions of the F-Canyon process were restarted to chemically stabilize target and fuel materials previously stored in water-filled basins at the site. The reactor targets consisted of Mk-31 targets previously used in SRS reactors for the production of plutonium-239. De-clad slugs from Experimental Breeder Reactor (EBR)-II fuel and irradiated natural uranium fuel rods from the Taiwan Research Reactor were also processed. These materials were corroded from years of storage in the basins and in most cases, the fuel or target cladding had been breached, releasing large amounts of radioactivity into the basin water. These materials are being processed by F-Canyon as part of DOE's plan in response to Recommendation 94-1 from the Defense Nuclear Facilities Safety Board.

Dissolution and processing of the Mk-31 targets began shortly after completion of the DOE Operational Readiness Review in January 1996 and were completed in January 1997. Processing of the EBR-II slugs and Taiwan Research Reactor fuel began in January 1997 and was still ongoing at the time of this report. During the period under investigation, all portions of the F-Canyon plutonium-uranium Extraction process were operated. This included dissolving, head-end, first cycle, second cycle, and all other unit operations (such as high and low activity waste and acid recovery) required for support.

1.4 FACILITY MANAGEMENT

F-Canyon is operated by the WSRC Nuclear Materials Stabilization and Storage Division (NMSS). The operating, engineering, maintenance, and quality assurance organizations are part of this Division. Radiological Control Operations (RCO) reports to the Environment, Safety, Health and Quality Assurance Division, but RCO personnel are matrixed to, and take their day-to-day direction from, the Nuclear Materials Storage and Stabilization Division (see Figure 1-4).

1.5 CRANE OPERATOR ACTIVITIES

Normally two crane operators are assigned to each shift. Crane activities include operating the Hot and Warm Canyon cranes, making piping changes between canyon vessels, changing out/repairing equipment in the canyon and performing leak checks.

Additionally, crane operators support maintenance work on the cranes such as wire rope inspections, yoke inspections, crane cab HEPA filter penetration testing and repair of crane cab equipment such as the air conditioner.

Other tasks performed by crane operators include decontamination of jumpers in the swimming pool, unloading nuclear reactor fuel/target material from cask cars, loading fuel/targets into the dissolver, decontamination of cask cars, routine housekeeping in crane maintenance areas, jumper gasket replacements, and decontamination of building areas.

Crane operators are also cross-qualified for other canyon activities including pulling samples in the sample aisle, operating processes from the control room, and patrolling the building. Samples of tanks located inside the canyons are collected to monitor process parameters and for material accountability. Building patrols are made to monitor facility conditions, such as housekeeping and potential leak sites.

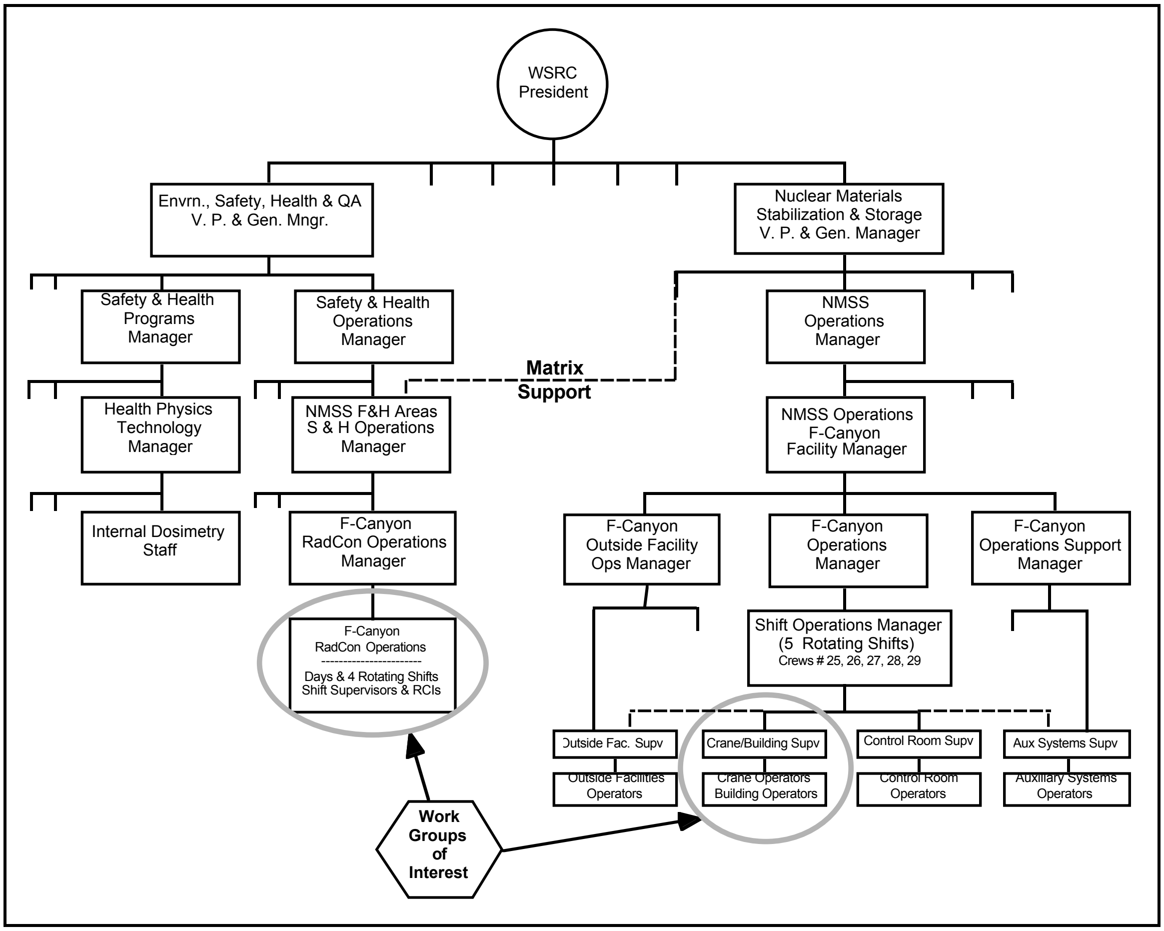


Figure 1-4 Westinghouse Savannah River Company Organization Chart

2.0 FACTS AND ANALYSIS

2.1 ACCIDENT DESCRIPTION AND CHRONOLOGY

2.1.1 Response to Bioassay Results

An Off-Normal Occurrence, identifying an internal exposure to an F-Canyon CRANE OPERATOR, was initially declared by WSRC on April 21, 1997, and subsequently upgraded to an Unusual Occurrence on April 30, 1997 (SR-WSRC-FCAN-1997-0009). The occurrence was reported based on notification of F-Canyon Management by the WSRC Internal Dosimetry staff, that analyses on a routine urine bioassay sample submitted by a CRANE OPERATOR on February 10, 1997, indicated the presence of plutonium.

The CRANE OPERATOR was informed of the bioassay results and placed on a special follow-up sampling program to provide both urine and fecal samples for additional analysis. The CRANE OPERATOR was restricted from entering all radiological areas pending completion of investigations, final dose assessment, and management review and approval. An investigation was initiated by WSRC to identify facts related to the event and determine the causes.

Based on analysis of bioassays, and an unknown intake date, WSRC estimated the CRANE OPERATOR’s intake to be approximately 40 nanocuries of Pu-239 and also estimated a 50-year CEDE to be approximately 17 rem. Although this equates to an actual first year exposure of approximately 750 millirem, the assigned dose for the year of intake will be the full 50 year CEDE (currently estimated at 17 rem) consistent with (10 CFR 835) regulatory requirements. A final evaluation and dose assessment is due by July 25, 1997.

Additional bioassay analyses were conducted to better understand the nature of the plutonium contaminant. Analysis of the contaminant elimination rates from these bioassay results (urine and fecal) demonstrated the intake to be from inhalation. The CRANE OPERATOR was also evaluated with negative results, for possible wounds that may have been accompanied by absorption or injection of plutonium material further supporting intake from inhalation. These analyses also demonstrated fission products (beta and gamma emitting contaminants) to be less than detectable.

Gamma-ray spectroscopy was also utilized to attempt detection of the presence of fission products in the CRANE OPERATOR’s body; again with less than detectable results. The CRANE OPERATOR and his urine samples were also analyzed for the presence of Americium-241, an indicator of the relative “age” of plutonium samples. The lack of such material indicated the plutonium material involved in the intake may have been recently purified by chemical separation.

Mass Spectrometer analysis indicated natural uranium in amounts that would be expected due to natural background. Mass Spectrometer analysis of the plutonium also indicated approximately 5.2 weight percent (wt%) Pu-240. These results also demonstrated the source of the CRANE OPERATOR’s intake of plutonium to be associated with activities downstream of F-Canyon’s first cycle and again most probably from Warm Canyon operations. This is supported by the fact that process material containing plutonium in the Hot Canyon typically contains significant amounts of fission products, most notably Cesium-137, and large amounts of uranium. First cycle solvent extraction processing removes most of the fission products and essentially all of the uranium. The analyses also indicate the assimilated plutonium was processed through F-Canyon within approximately 1 year prior to the intake.

In summary, the cumulative data demonstrated (1) an intake of plutonium from the “Warm” side of the canyon process, (2) an intake date between August 4, 1996, and February 10, 1997, and (3) the manner of intake to be inhalation.

2.1.2 Dose Assessment and Validation

The estimated 50 year CEDE of 17 rem was determined in the following manner. Using the date of the last known bioassay that yielded no presence of radioactive material (August 4, 1996) and the date of the sample discovered to contain plutonium material (February 10, 1997), a midpoint date of November 7, 1996, was selected due to the fact there was no known casual event for the intake. Employing dosimetry models based on ICRP 30, and applying the November date, an intake of approximately 40 nanocuries (nCi) of Pu-239 was estimated using the CAIBEC (v1.0) computer code. Utilizing the RADOSE computer code and the estimated intake, the 50-year CEDE was calculated to be approximately 17 rem. Subsequent urine and fecal bioassay samples were collected and used to confirm and refine this estimate. While all samples have continued to exhibit measurable quantities of Pu-239, urine samples collected after April 21, 1997, failed to produce quantities of Pu-238 above decision levels. By mid-June 1997 five urine samples and two fecal samples had been analyzed with all results being within an acceptable variance. At the time the Board's investigation concluded, urine sampling was planned to continue on a monthly schedule as long as additional analyses were determined to have investigative value.

The WSRC Internal Dosimetry staff concluded the manner of intake to be inhalation of a soluble compound of airborne plutonium particles with an Activity Median Aerodynamic Diameter of 1 micrometer. Assuming the intake occurred on November 7, 1996, the WSRC staff concluded the intake to be on the order of 40 nCi of Pu-239 and such an intake would result in a CEDE of approximately 17 rem.

To validate the preliminary conclusions reached by WSRC and to examine the methods and techniques used to arrive at these conclusions, the Board secured the services of an expert in the field of internal dosimetry, specifically that of dosimetry of transuranics. An independent assessment of the data resulted in a confirmation of the scope of the intake and the resulting estimate of CEDE. A review of the procedures, techniques and facilities concluded the approach utilized by WSRC was adequate and met the Board's expectations for evaluation of dose resulting from the internal deposition of Pu-239. The independent assessment also confirmed the method of intake to be inhalation and confirmed activities associated with large quantities of fission product activity were not a factor in the CRANE OPERATOR'S dose. As a result, the Board focused its investigation only on activities involving large quantities of predominantly alpha emitting material, in particular, activities directly and indirectly associated with the Warm Canyon.

2.1.3 Timeline Development and Determination of Events with High Potential for the Intake

To develop the timeline of the Crane Operator's specific work activities from August 4, 1996, to February 10, 1997, and determine activities with high potential for the intake, the Board utilized a variety of information sources including interviews; review of documentation (including Radiological Work Permit (RWP) sign-in/sign-out records, respiratory protection sign-out records, radiological survey records, radioactivity air sampler results, turnover checklists, logbooks, completed procedures, and the F-Area computerized accountability system); and facility walk-downs.

Interviews

Approximately 40 recorded and 30 unrecorded interviews were completed with personnel involved with facility work activities similar to those that the CRANE OPERATOR participated in during the time period under investigation. Personnel interviewed included crane operators, Radiological Control Inspectors (RCIs), shift supervisors, Shift Operations Managers, engineers, senior managers, and DOE personnel. Personnel were requested to describe their typical job activities, work environment, typical interfaces with other personnel and job activities which they believe could have caused the intake. Additionally, personnel were asked questions to evaluate their knowledge of radiological fundamentals, requirements for performing work in radiologically controlled areas and contamination control methods.

The information obtained from the interviews was used to provide additional support for activities identified on the timeline and to evaluate routine work activities and identify activities which warranted additional review because of their potential to cause an intake of contamination.

During the interviews, personnel had difficulty recalling significant details from job activities which in some instances had occurred 9 months prior to the interview. The accuracy of job activity descriptions obtained during the interviews is questionable because of the significant amount of time which had elapsed between the probable dates of the contamination intake and the start date of the investigation.

Radiological Work Permit (RWP) Records

RWPs identify existing radiological conditions, work suspension limits in the event that radiological conditions change beyond expected parameters, and protective clothing requirements for various tasks which may be performed in the specified area. RWPs also contain the requirements for RCI coverage and sign in frequency. Standing RWPs are written for routine tasks and are typically a maximum of a year in duration. Job-specific RWPs are written for specific tasks and generally have a shorter duration. Personnel entering radiological areas are required to read and understand the respective RWP, sign in at the time of entry, and sign out at the time of exit. RWPs were reviewed to establish entry and exit times into areas where radiological work was performed. The entry and exit times of the CRANE OPERATOR and personnel supporting his job activities were identified from the RWPs and placed on the timeline. Each job activity identified through this process was evaluated to determine the probability of intake. In reviewing this and other data it was determined that on numerous occasions personnel failed to sign in and out on RWPs as required by the site radiological control manual. For example, the CRANE OPERATOR was issued respiratory protection 33 times during the time period under investigation. Each issue of respiratory protection required sign-in on a RWP, but the CRANE OPERATOR signed in on corresponding RWPs only 18 times. The ability to establish a history of the CRANE OPERATOR's work activities was limited by these documentation inadequacies. For example, there were only 40.5 hours of radiological work documented in RWPs for the CRANE OPERATOR during the period under investigation. Sampling of other operator work activities indicate that these documentation inadequacies were not limited to the CRANE OPERATOR.

Respiratory Protection Records

Respiratory protection records are maintained to identify the names of personnel obtaining respirators, names of personnel issuing respirators, time of respirator issue, type of respirator issued and the RWP which personnel have signed in on to perform the work requiring respiratory protection. The basis for this documentation is to assure checkout of proper equipment as well as medical and technical qualification of the user. Respiratory protection records were reviewed to establish the history of respiratory protection use by the CRANE OPERATOR and personnel supporting his job activities, and determine if respiratory protection was issued each time it was required by the RWP. In reviewing this and other data it was determined that on numerous occasions respiratory protection was obtained without documenting the distribution as required by the site Industrial Hygiene Manual**.** For example, the CRANE OPERATOR signed in on 21 RWPs which required the use of respiratory protection, but signed out respiratory protection for the corresponding RWPs only 13 times.

The Board also found that for the period under investigation, the F-Canyon respirator issuance room was not required to be continuously staffed 24 hours a day. When the room was not staffed, an individual needing a respirator was to find someone qualified to issue a respirator. However, during interviews personnel indicated they would sometimes obtain a respirator without a qualified issuer being present. When a qualified issuer later came to the respirator room, he would check the sign-out sheet and sign as the issuer for any respirators that had been signed-out without a qualified issuer present. Personnel also indicated during interviews that they would sign out respirators for each other. The ability to establish a history of the CRANE OPERATOR's work activities was limited by documentation inadequacies in respiratory protection records.

Radiological Survey Records

Radiological surveys are completed by RCIs to document radiological conditions for work areas. The information on the surveys is used to develop work instructions and inform radiological workers of conditions. Radiological survey records were reviewed to identify areas with significant levels of predominantly alpha contamination entered by the CRANE OPERATOR during the time period under investigation. Summaries of the survey information were entered on the time line for the respective dates. Although many useful surveys were found, the ability to establish a history of radiological contamination levels in some areas frequently accessed by the CRANE OPERATOR was limited because of the lack of radiological surveys completed for those areas. For example, the interior of the Old Warm Crane was surveyed less than five times during the period investigated.

Air Sample Results

Air samples are typically collected and analyzed to characterize the routine or average airborne radiological hazard as required by 10 CFR 835 and the DOE Radiological Control Manual and to specifically characterize radiological conditions at each unique work-site.

Records of the routine and job specific air samples were reviewed for indicators of an event that could be related to the CRANE OPERATOR'S intake. However, several circumstances prevented a comprehensive picture of facility conditions from being established. Some areas of the facility are not entered daily, therefore, sample media may not be collected except when areas are entered. While this in itself is acceptable by requirements, it does not allow an uninterrupted profile of the airborne hazard in the area of interest. The practice may become unacceptable if workers enter the area without RCI knowledge or coverage.

Extended periods between filter media surveys were observed indicating that the sample media had collected material for many weeks (up to 8) without changing media. The results from these surveys were then averaged over the entire sampling period making any determination of short term conditions impossible. This was noted for many unfiltered air samples of process areas and for the Old Warm Crane cab.

Another observed problem was the number of errors and miscalculations found in some air sample summary sheets. It was noted the situation had already been recognized by RCO management and a computer based reporting system was being implemented as the investigation was being conducted. A demonstration of the computer generated calculation sheets was reviewed and found to adequately resolve the issue.

Crane Operator Turnover Checklists

The crane operator checklists are used for shift turnover to summarize crane status, job activities in progress and facility conditions. All available crane operator turnover checklists completed during the period under investigation were reviewed. Significant activities identified from the checklists that the CRANE OPERATOR could have participated in were entered on the timeline. Information recorded on the crane operator checklists was minimal, and instances were identified where work activities were not adequately documented. For example, the remarks section of the checklist would note that a leak check was completed, but the section for "Work/Testing Completed," which should note all procedures performed, would have an entry of "none." Additionally, checklists were missing for some of the dates being investigated. As a result, little significant information was obtained that could be used in establishing a complete history of the CRANE OPERATOR's work activities.

Logbooks

Logbooks are maintained by personnel in key facility operations positions such as Shift Operations Manager, shift supervisor and Shift Technical Engineer to record job activities in progress, abnormal facility conditions and unexpected conditions. Shift Operations Manager, shift supervisor, Building and Crane Supervisor, RCO Supervisor, and Shift Technical Engineer logbooks completed during the period under investigation were reviewed. Any significant information identified in the logbooks that could have been related to the CRANE OPERATOR's intake was entered on the timeline. Information recorded in the logbooks provided only minimal relevant data and did not provide significant details of facility operations in progress or abnormal facility conditions**.** Instances were identified where PERIPHERAL work activities were in progress with unusual radiological conditions, but not included in the operations logbooks. For example, the Shift Operations Manager/Control Room Supervisor Log for December 21, 1996, did not mention the hut removal or Continuous Air Monitor (CAM) alarms. Although some information in the logbooks was utilized in the development of the timeline, information obtained from the logbooks was not of significant value in establishing a history of the CRANE OPERATOR's work activities.

Procedures

The completed procedures for facility operations which the CRANE OPERATOR could have participated in or resulted in a condition that could have affected the CRANE OPERATOR were requested. In many instances, completed copies of procedures could not be located by facility management. For example, during interviews with crane operators, the operators discussed frequent jumper gasket replacement activities and references to jumper gasket replacement activities were made in logbooks. However, only five completed procedures could be found for the period under investigation, and completed procedures could not be found to support logbook entries. Logbook entries referenced two separate instances of authorized work on top of cell covers in section 5; however no completed procedures for the work could be found.

During interviews, crane operators also discussed frequent waste transfer jumper leak checks and there were references to 34 separate jumper leak checking activities on crane operators' checklists. However, only 17 completed procedures could be found for the corresponding information obtained from the checklists.

Decontamination activities were performed in section 11 of the Warm Gang Valve Corridor approximately 25 times during the time period under investigation**.** However, only one completed copy of the decontamination procedure, which is a "Use Every Time" procedure, could be found that may have been used for section 11 activities. That procedure stated it was used to decontaminate floor and walls, but did not give the location of the decontamination activity.

F-Area Computerized Accountability System

The F-Area computerized accountability system is maintained for personnel accountability purposes in the event of an emergency response. The system maintains a record of all F-Area facility entry and exit times for all personnel. The records for the period under investigation were obtained and the times of entry and exit for the CRANE OPERATOR were entered on the timeline. This aided the Board in determining whether the CRANE OPERATOR had been present in the security controlled area during any unusual facility conditions or work activities.

Two other accountability system records were reviewed to determine if the CRANE OPERATOR had entered either FB-Line or accessed the crane walkway through the security door. No entries to FB-Line were found for the CRANE OPERATOR. It was determined that the CRANE OPERATOR accessed the crane walkway through the security door five times.

Facility Walk-downs

Facility walk-downs were completed by investigation team members to evaluate work area conditions and obtain a more thorough understanding of the CRANE OPERATOR's work environment. Areas involving significant quantities of predominantly alpha contamination and areas where unusual radiological conditions had occurred or abnormal work conditions existed were reviewed more extensively. For example, the Warm Gang Valve Corridor where the CRANE OPERATOR performed radiological decontamination activities was walked down to obtain a more thorough understanding of ventilation flows, work area temperatures, locations of air sampling devices and other significant equipment. The Warm Gang Valve Corridor is maintained as a Contamination Area. Additionally, the Warm Canyon and Old Warm Crane Cab were accessed by Board members to better understand the working conditions in the Warm Canyon and crane cab and to better understand the process of entering and exiting the crane cab. The Warm Canyon is a High Contamination Area and an Airborne Radioactivity Area requiring respiratory protection.

2.2 CHRONOLOGY OF EVENTS AND ANALYSES FOR FOUR SELECTED SCENARIOS

During the investigation, the Board screened the CRANE OPERATOR's work activities to determine which were high potential for his intake. The criteria used for this screening were: specific work activities consistent with bioassay results, AND unusual radiological conditions OR lack of RCO coverage. The screening identified four activities which were determined to be high potential scenarios for the intake, each of which constituted PERIPHERAL work. These scenarios involve Warm Canyon cell cover activity; operation of the Old Warm Crane Cab; Warm Gang Valve Corridor decontamination; and Warm Gang Valve Corridor hut removal. Each scenario is discussed in detail below.

2.2.1 Warm Canyon Cell Cover Activity

On May 13, 1997, while performing a walkdown of the Warm Canyon, the Board discovered tools and protective clothing on top of the section 18 cell covers, section 18 stairwell landing, section 18 platform, and the maintenance bridge in the Warm Canyon (Figures 2-1, 2-2). Because of the worker safety implications of these discoveries, WSRC management was notified. Subsequently, WSRC conducted a separate investigation to determine when, how, and why the tools and protective clothing were located in these areas of the Warm Canyon. The results of the WSRC investigation are discussed in Appendix D.

Characterization of Material

On May 22, 1997, the cell covers and the material found on the cell covers were surveyed. Gloves and shoe covers were found in close proximity to tools and equipment, which included a ball peen hammer, thin blade screwdriver, and pliers. Some of the plastic shoes covers were manufactured by FABOHIO Inc., a type not used in F-Canyon prior to April 1996 (Exhibit 2-1). The maximum transferable contamination found on the cell covers was 300,000 dpm/100 cm^2 alpha and the maximum transferable on any item was 200,000 dpm/100 cm^2 alpha, which was found on a snap ring, a screw driver and a plastic shoe cover.

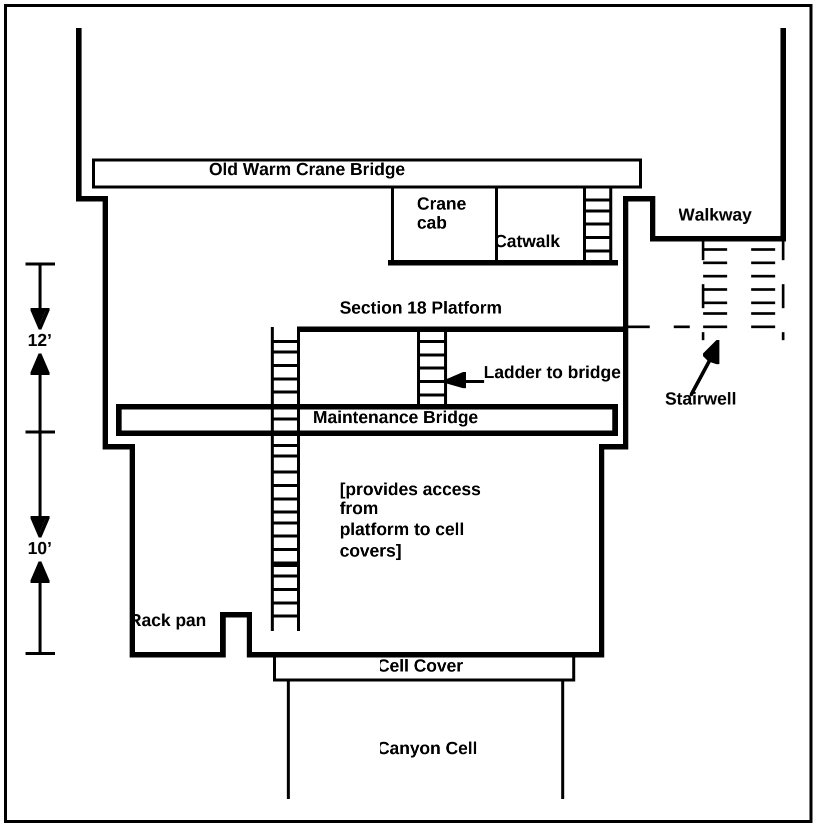


Figure 2-1 Typical Warm Canyon Section 18 (Cross Section Looking North)

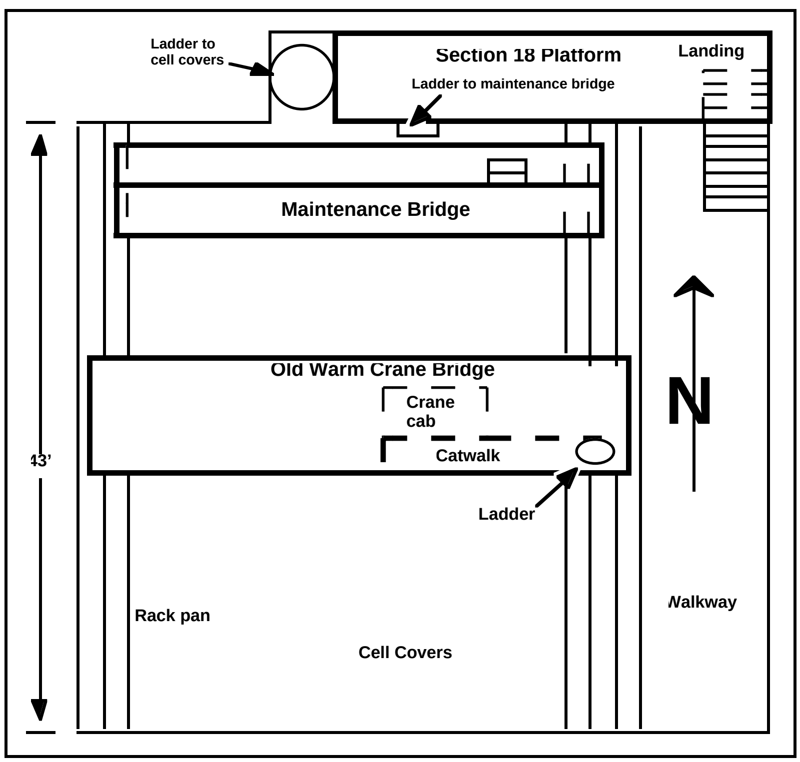


Figure 2-2 Top View Warm Canyon Section 18

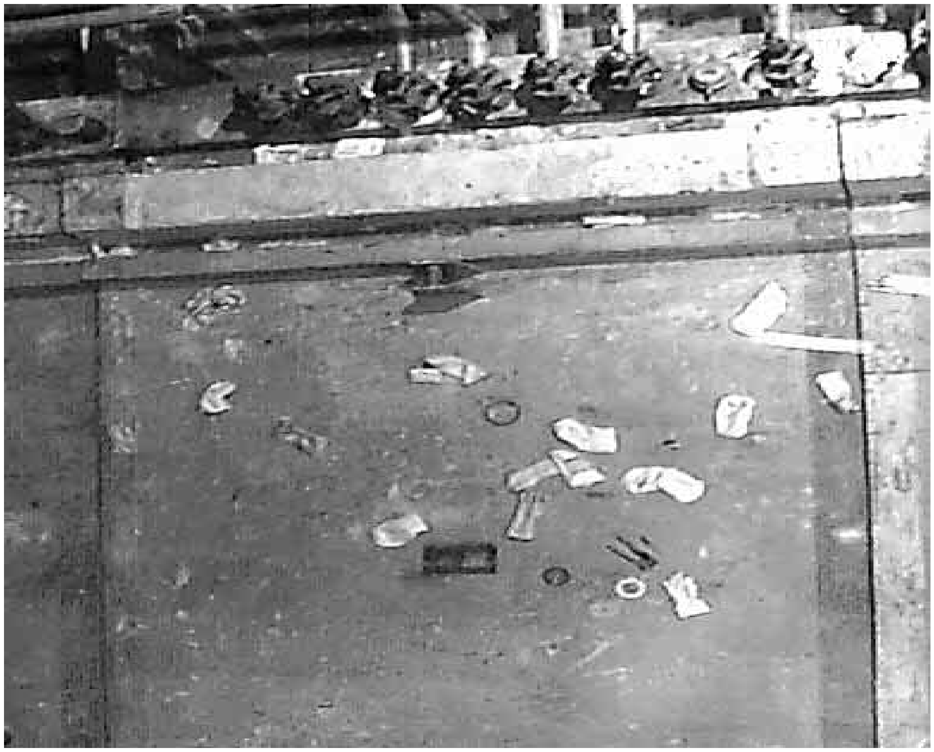


Exhibit 2-1 Protective Clothing and Tools on Cell Covers

The protective clothing found on the platform and landing included rubber gloves, cloth coveralls, plastic shoe covers, cloth hoods, cloth booties, plastic suit bottoms, and giant rubber shoes (Exhibits 2-2 and 2-3). An adapter hook, screwdriver, jumper gaskets and snap rings were also found. The material was surveyed on May 28, 1997. The highest contamination levels were found on the rubber shoes (300,000 dpm/100 cm^2 alpha and 150 mrad/hour/100 cm^2 beta-gamma) and the adapter hook (500,000 dpm/100 cm^2 alpha). On a follow-up survey conducted on June 3, 1997, rubber shoes taken from section 18.8 probed 3,000,000 dpm/100 cm^2 alpha. An isotopic analysis of the rubber shoes indicated that the contamination came from processing more than a year ago, indicating that the shoe covers were not recently worn or the contamination source was from a source of material not recently processed, such as the section 18 waste tank.

The maintenance bridge was surveyed on May 29, 1997 (Exhibit 2-4). The highest level of alpha contamination found was 40,000 dpm/100 cm^2. Beta-gamma levels as high as 300,000 dpm/100 cm^2 were also found. The alpha contamination levels indicate all the material on the cell covers could not be the result of material falling off the maintenance bridge or Warm Canyon Cranes.

Exhibit 2-2 Protective Clothing and Tools on Platform

Exhibit 2-3 Protective Clothing on Landing

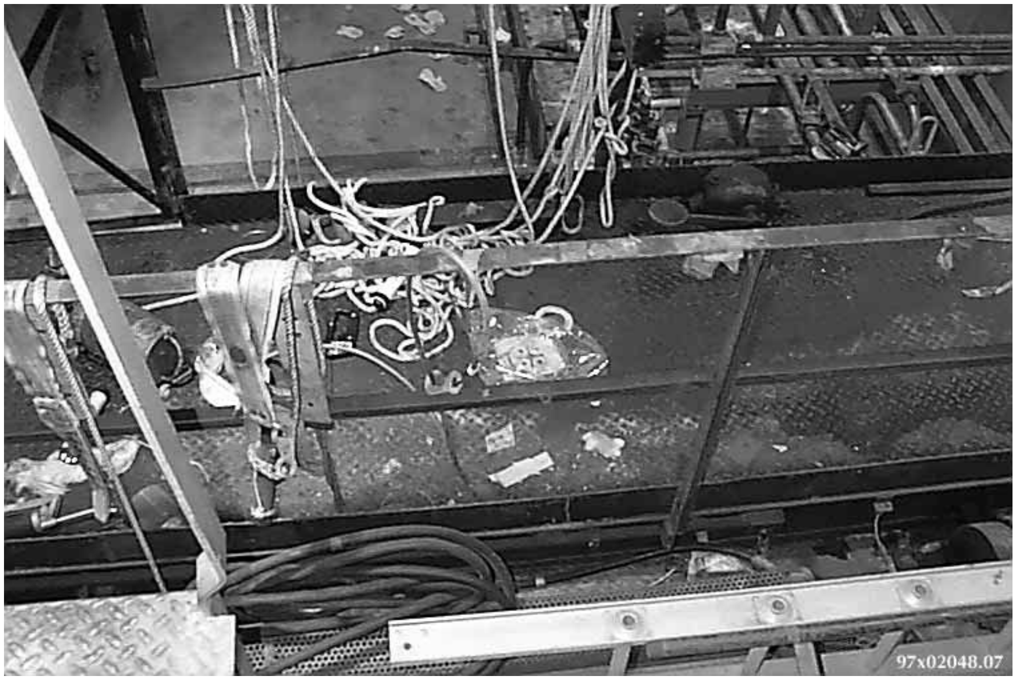


Exhibit 2-4 Material on Bridge

The Board concluded that unauthorized work may have been performed in section 18 of the canyon within the last year because:

- high contamination levels were found on plastic shoe covers and rubber shoes which did not correlate to normally accessible areas
- the types of tools and equipment found were indicative of work such as jumper gasket replacements
- some of the shoe covers were of a type not used in F-Canyon prior to April 1996
- the grouping of material found together indicated that they may have been left in place after being used for work, as opposed to randomly falling from the crane.

If performed, the work would have been conducted under the following circumstances:

Since such work in section 18 would have been unauthorized, it would have been performed without following procedures. This premise is supported by the following observations. There are no procedures for performing work on the section 18 cell covers. Procedure 221-F-10618, "Working on Top of Warm Canyon Cell Covers," allows work only on the section 5 cell covers. The Building and Crane Supervisor's log entries on October 6, 1996, and November 6, 1996, state that jumpers were regasketed on the section 4 cell covers, but no completed copies of procedure 221-F-10618 or procedure 221-F-10255, "Repair of Canyon Piping Leaks or Replacement of Jumper or Rack Pipe," could be found. Procedure 221-F-10255 is the procedure covering jumper gasket replacement. Additionally, as with other work covered by crane operators' standard operating procedures, no JHA would have existed for this work.

No standing or job specific RWPs allow work on the section 18 cell covers of the Warm Canyon. The work would not have been conducted with an RWP, a pre-job brief, or ALARA review. Workers would not have worn the proper respiratory equipment. The proper equipment for work on cell covers is air supplied plastic suit or hood. There are no air manifolds in section 18 of the canyon. No RCI coverage would have been provided during the work activity and no radiological surveys of the area would have been performed since there would not have been a RWP covering the job. This premise is supported by the fact that crane operators routinely accessed the Old Warm Crane in section 18 without RCI coverage or a current survey of the crane cab conditions. The cab is not required to be surveyed until the crane is parked on the pad in section 2. No surveys of the canyon near section 18 were found except for the monthly surveys of the Warm Canyon walkway.

In addition, management and supervision would not have provided oversight for normal activities in the Warm Canyon. This is evidenced by the amount of material in section 18 that had gone undetected, presenting both housekeeping and safety problems, and the infrequent entry of WSRC management into Contaminated and Airborne Radioactivity Areas.

Analysis of Cell Cover Activity

The Board then analyzed a scenario for the CRANE OPERATOR regasketing a jumper on the section 18 cell covers, contaminating his protective clothing and subsequently contaminating himself in the Old Warm Crane Cab. Given the levels of contamination found in the Warm Canyon, the potential existed for the CRANE OPERATOR to receive an intake during this work activity if he did not wear respiratory equipment while in the cab (calculations supporting this scenario are shown in Appendix C). Although this scenario is not likely to have caused the CRANE OPERATOR'S intake due to the conservatism of the bounding assumptions, it was analyzed for purposes of this investigation.

A barrier analysis was performed on this scenario as shown in Tables 2-1 and 2-2. The failed barriers include personal contamination clothing, respiratory protection, RWPs, operating procedures, job hazards analysis, RCI coverage and line management oversight. The commonality of findings and causal factors associated with this PERIPHERAL WORK to the other scenarios gives credence to the Board's determination of causes and conclusions.

2.2.2 Operation of the Old Warm Crane Cab

Since the Old Warm Crane was in service approximately 15 percent of the time during the period of the investigation, the Board reviewed the operational history of the Old Warm Crane personnel protection equipment, the history of radiological conditions, and procedures related to Old Warm Crane use. The Board also interviewed crane operators and other personnel involved in crane activities. The Board determined that the CRANE OPERATOR could possibly have received an intake while operating the Old Warm Crane without a respirator due to the number and types of problems discussed below.

Old warm crane operations could have been performed without personnel protection equipment on the crane cab operational**.** This premise is supported by the review of records for the period of interest. The Old Warm Crane was "in service" for some portion of each of 31 days. In reviewing the operational history of the Old Warm Crane Cab protective equipment (CAM, air sampler, and ventilation system), the Board identified numerous problems, summarized below:

- Ventilation system fan ("Dravo" trademark): out of service from January 8, 1997, to April 8, 1997.
- HEPA filter(s): failed filter penetration test on August 21, 1996 (99.96 percent efficiency); passed on September 4, 1996.
- Air conditioner: out of service from August 20, 1996, to October 9, 1996.
- Air sampler filter paper: checked/changed-out eight times during the period under investigation, should have been checked at least 31 times (not checked/changed-out at all from December 11, 1996, to February 9, 1997).
- CAM: checked 22 times during the period under investigation (failed on September 8 and 10, 1996); should have been checked at least 31 times.
- CAM: following a source check, the CAM would be returned to service by re-installation of the old planchet and ranging the instrument up scale.

Table 2-1 Barrier Analysis for Cell Cover Activities (1 of 3)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation
Breathing Airborne Contamin-ation	Improper use of respirators	Air-fed hood not worn as required by typical RWP for gasket replacement	Training less than adequate Lack of management enforcement of complying with requirements Air Connection not available	Internal exposure greater than allowed by 10 CFR 835	Reexamine training adequacy Management Enforcement of requirements is necessary Air Connection not needed
	Radiological Work Permit (RWP)	CRANE OPERATOR not complying with the requirements for work in radiological controlled areas	Personnel error Lack of management enforcement of employee compliance with requirements		Management should reinforce the compliance to all requirements to ensure worker safety
	Operating Procedures	CRANE OPERATOR does not utilize procedures as required for gasket replacement or cell cover work operations	Personnel error Lack of management facility presence and lack of review of records to ensure workers are complying with requirements. Lack of management enforcement of employee compliance with requirements		Management should be present in the facility and should review records to ensure that procedures are being utilized Management should reinforce the compliance to all requirements to ensure worker safety

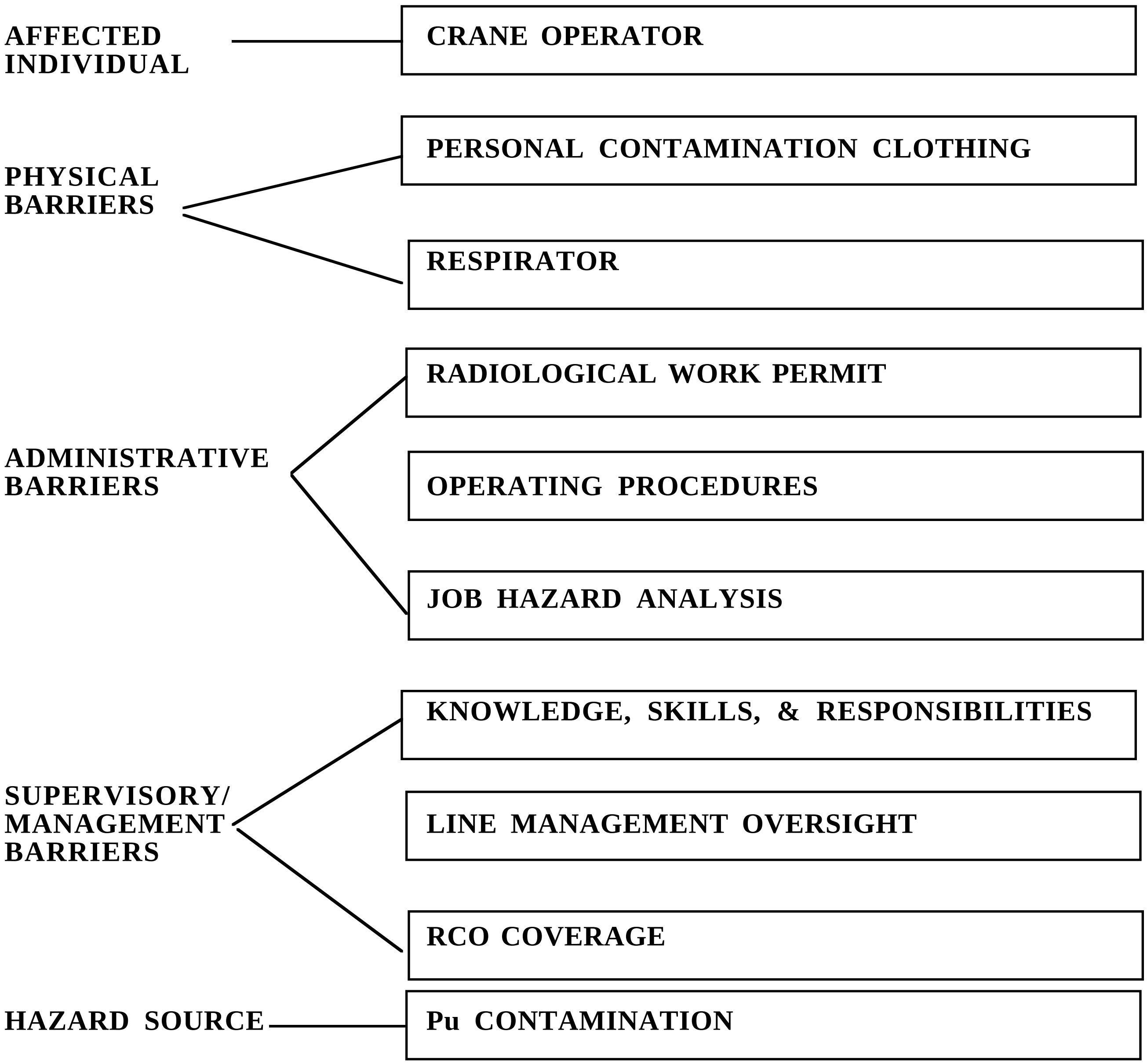
Table 2-1 Barrier Analysis for Cell Cover Activities (2 of 3)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation
Breathing Airborne Contamin-ation	Job Hazard Analysis (JHA)	Job Hazard Analysis has not been performed for the CRANE OPERATOR activities using the OWC	Management inattention to worker safety as related to routine activities	Internal exposure greater than that allowed by 10 CFR 835	Perform a Job Hazards analysis for PERIPHERAL WORK
	Knowledge/Skills/ Responsibilities	CRANE OPERATOR knowledge is not sufficient to understand the scope of the hazards that are present in the facility Analysis of the CRANE OPERATOR actions indicate that he is not taking responsibility for his own safety.	Lack of management enforcement to ensure worker safety responsibilities are understood by workers		Management should reinforce the compliance to all requirements to ensure worker safety and worker responsibilities
	Line management oversight	Lack of facility presence Lack of performance-based assessments to evaluate worker compliance with requirements Lack of employee enforcement of compliance with requirements to ensure worker safety	Management inattention to worker safety as related to routine activities		Management should maintain a strong presence in the facility by monitoring work evolutions (performance-based assessments)

Table 2-1 Barrier Analysis for Cell Cover Activities (3 of 3)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation
Breathing Airborne Contamin-ation	Line management oversight	Disciplined operations is subsequently not enforced		Internal exposure greater than that allowed by 10 CFR 835	Management should reinforce the compliance to all requirements to ensure worker safety and worker responsibilities
	No RCI coverage for section 18 work	Section 18 is a highly contaminated environment which deters personnel from entering the area on a routine basis as required to ensure that any special requirements (respirator required) are identified to the CRANE OPERATOR.	Lack of management knowledge of PERIPHERAL WORK to recognize the need for radiological oversight		Management should provide RCI coverage for authorized entries into highly contaminated areas where a high hazard potential exits to the worker Periodic management tours needed.
	Failure to wear proper personal contamination clothing	Training requirements not enforced by management Failure of worker to comply with requirements	Training less than adequate Lack of management enforcement of complying with requirements		Reexamine training adequacy Management enforcement of requirements is necessary

Table 2-2 Barrier Analysis Summary for Cell Cover Activities



A simplified schematic of the Old Warm Crane Cab ventilation system is shown in Figure 2-3. Air from the surrounding canyon environment is pulled by a fan through a single-stage HEPA filter. The air then passes across the air conditioning cooling coils prior to a second-stage HEPA filter. Air is supplied to the cab through a register located in the ceiling near the cab door. The design rate of supply air into the crane cab is 400 cfm. The ventilation system includes a recycle loop from the crane cab which has design flow rate of 200 to 300 cfm. At the request of the Board, WSRC measured the supply and re-circulation flow rates. The measured flow rates roughly correlated with the design flow rates and resulted in a positive pressurization of 0.035 inches water column of the crane cab with respect to the surrounding canyon environment with the cab door closed (0.0004 inches water column with the door open).

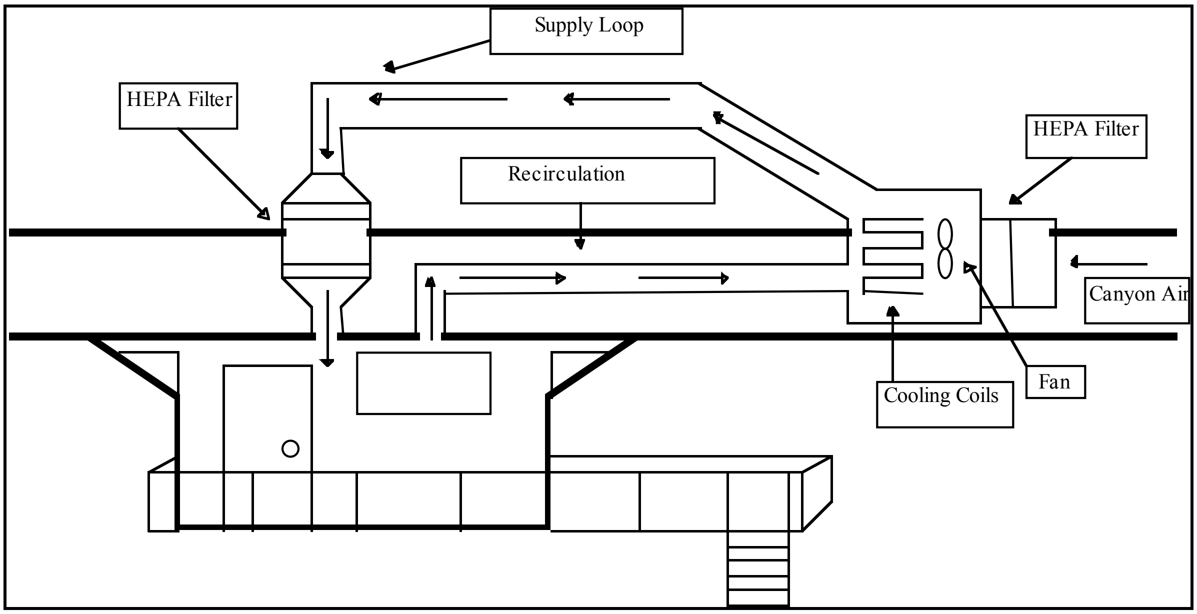


Figure 2-3 Old Warm Crane Cab Ventilation System

In reviewing the procedure and records for filter penetration testing of the Old Warm Crane Cab ventilation system, the Board found the physical arrangement for performing the filter penetration test on the HEPA filters for the ventilation system tested the filters only in combination as a unit. The physical arrangement did not provide for independent testing of each HEPA filter. It was also unclear from the records when the second HEPA filter had been replaced. The first, or inlet HEPA filter, was known to have been replaced after the system failed a filter penetration test on August 21, 1996.

At the request of the Board, WSRC performed a test of the second HEPA filter on June 4, 1997. The second HEPA filter was tested with the system in two different physical configurations: (a) with the inlet HEPA filter unblanked (i.e., with normal or partial re-circulation of air); and (b) with a blank inserted over the inlet HEPA filter (full re-circulation of cab air). The filter penetration test results for each configuration were: (a) 99.38 percent efficiency, and (b) 99.60 percent efficiency. Both results constitute test failure, but were not indicative of any gross failure of the HEPA filter. Based on a quality assurance decal found affixed to the filter housing dated 1987, the second HEPA filter had not been replaced in approximately 10 years.

The Old Warm Crane Cab is not equipped with any indication of operability of the ventilation system fan, CAM, air sampler, or differential pressure between the cab and the surrounding canyon environment. Additionally, the crane operators indicate the ventilation system fan cannot be heard whether inside or outside the crane cab. They also stated the positive differential pressure between the crane cab and the surrounding canyon environment is not perceptible when opening or closing the cab door. Members of the Board confirmed this assessment through several walkdowns of the crane cab and results of the ventilation flow test.

All of the cranes and their supporting equipment are functionally classified as “production support.” The WSRC hierarchy of functional classification for structures, systems, and components has four groups. In decreasing level of importance to safety, these are safety class, safety significant, production support, and general support. Only structures, systems, or components with a functional classification of safety class or safety significant are considered for coverage or inclusion by Technical Safety Requirements (TSR). As part of the Basis for Interim Operation, F-Canyon currently uses a safety-related system procedure to govern surveillance requirements to ensure operability of key equipment instead of TSRs**.** The F-Canyon safety-related system procedure does not include any of the protective equipment associated with the Old Warm Crane Cab.

The radiological postings and controls for entry into the old warm crane could have been incorrect or inconsistent with the radiological conditions present. This premise is supported by review of radiological surveys, canyon air monitoring data, and filter paper results from the Old Warm Crane Cab air sampler to determine the history of radiological conditions which the CRANE OPERATOR might have encountered during the period of interest. The Warm Crane Maintenance Area and Warm Canyon walkway areas were maintained as High Contamination Areas and Airborne Radioactivity Areas continuously during the period under investigation. Both areas are normally accessed by personnel in the process of operating or performing maintenance on the Old Warm Crane. Based on radiological surveys, the highest recorded levels of transferable contamination in the Warm Canyon accessible areas were 100,000 dpm/100 cm^2 alpha. Surveys of equipment handled by the Warm Canyon cranes indicate maximum levels of transferable contamination encountered were 1,000,000 dpm/100 cm^2 alpha.

The Board found that few radiological surveys in the Old Warm Crane Cab were taken during the period under investigation**.** At the request of the Board, an extensive radiological survey of the Old Warm Crane Cab was performed on May 6, 1997. The maximum transferable contamination levels found in the cab were 735 dpm/100 cm^2 alpha.

The protective clothing, dosimetry, and respiratory protection requirements for routine access to the cranes via the canyon walkways and both the hot and warm crane maintenance areas are specified by RWP 96-FC-013. This is a Standing RWP used to “Perform routine crane operations in the crane cabs, and routine observations in warm and hot crane maintenance areas at floor levels.” The protective clothing requirements specified are: one set of cotton coveralls, one set of disposable coveralls (or a second set of cotton coveralls if disposal ones are not available), cotton hood, cotton glove liners, two pair rubber gloves, one pair cotton booties, one pair rubber shoe covers, and two pairs of plastic shoe covers. The RWP also contains provisions for “extra shoe covers, plastic bags, and rubber gloves [to] be carried to the Old Crane as required for proper exit (return).” Dosimetry requirements are a thermo-luminescent dosimeter and a self-reading dosimeter. The respiratory protection requirements specified are a full face respirator. The RWP also contains “special precautions” requiring personnel to “remove outer shoe covers and gloves prior to entry into crane cabs,” “comply with one-time use of protective clothing/equipment (respirator and hood)” and “contact RCO to clear/survey the Old Hot Crane or Old Warm Crane prior to placing in service.” The RWP does not explicitly state the requirements for the situation where the old warm crane cab has been removed from respiratory protection (i.e., “off mask”).

Personnel (crane operators in general or the CRANE OPERATOR) could have been wearing no respiratory protection equipment. Based on the available records, the crane cab was maintained as a Contamination Area and Airborne Radioactivity Area throughout the period under investigation, except for a brief period of time between September 5-8, 1996, when the Crane Cab had been removed from respiratory protection requirement (i.e., “off mask”). Additionally, crane operators could have removed their respiratory protection equipment due to improper posting (not posted) of the crane cab as an Airborne Radioactivity Area.

Crane operators indicated they frequently enter the Old Warm Crane Cab alone. Crane operators are required to request RCO personnel to survey the crane cab and perform functional checks of equipment (alpha CAM and air sampler) when the crane is initially placed in service, as required by the RWP. However, as described by the crane operators this is normally done after the crane has been brought to section 2, which is inconsistent with the RWP and procedure.

When asked about working conditions within the Old Warm Crane Cab, several operators recall having experienced uncomfortably warm temperatures in the cab (as high as 87 degrees Fahrenheit) when the ventilation fan and/or the cooling system was out of service. This could have led crane operators to temporarily remove their respiratory protection equipment due to personal discomfort.

Crane operators could have been exposed to high levels of airborne radioactivity in the Old Warm Crane Cab due to either of two situations: (a) crane operators could have transferred high levels of contamination into the crane cab or onto their protective clothing and equipment, or (b) an external canyon event. The Board found evidence potentially high airborne radioactivity levels could have been present in the Old Warm Crane cab during the period of interest. This was based on the radioactivity levels collected on the filter paper at the Old Warm Crane cab air sampler on two separate occasions. On December 10, 1995, the activity levels on filter paper probed 10,000 dpm alpha. The filter paper had been in-place from December 5–10, 1996. On February 10, 1997, activity levels on the filter paper probed 200,000 dpm alpha. However, the filter paper had not been replaced since December 10, 1996. Radiological control personnel improperly averaged the contamination levels found over the time period collected. The levels could have been the result of a single event. WSRC management failed to investigate or determine the source of elevated levels of activity on the air sampler filter paper in the Old Warm Crane cab.

The processes described by crane operators for placing the Old Warm Crane in service were generally consistent. However, the protocol concerning which articles of protective clothing to remove upon initial entry to the Old Warm Crane Cab varied among the operators dependent upon whether the cab was on respiratory protection ("on mask") or not. All crane process operators consistently described the practice of removing rubber gloves and plastic shoe covers prior to entry of the cab. However, there was variability in describing the proper sequence or articles to be removed if the crane cab was "off mask." Some operators indicated removal of the respirator, but not the removal of their cotton hood. The hood is worn over the respirator and masking tape is applied around the perimeter of the respirator to provide a seal to the cotton hood. Additionally, the practice described for taking a second respirator (and cotton hood) into the cab when "off mask" varied among the crane operators. Most described carrying a second respirator contained within a plastic bag into the cab. A few operators described taking a second cotton hood into the crane cab. One operator described the practice of taking a second respirator and cotton hood to the cab tucked underneath the outer pair of cotton coveralls. This indicates some routine work practices not in compliance with the applicable RWP or sound radiological fundamentals to minimize the spread of contamination.

The crane operators indicated the Old Warm Crane Cab may be periodically decontaminated when directed by radiological control personnel. While performing a walkdown, members of the Board saw several plastic bottles of isopropyl alcohol both inside and outside the cab (on the catwalk leading to the cab doorway). Crane operators indicated the alcohol was periodically used for decontamination of the cab interior. However, the Board found no documentation of radiological surveys for the Old Warm Crane Cab corresponding with decontamination efforts by the crane operators. This indicates crane operators had the potential to remove high levels of transferable contamination without the presence of radiological control personnel.

The CRANE OPERATOR was asked about any unusual conditions noted during operation of the Old Warm Crane during the period of interest, either in the Old Warm Crane Cab or the canyon. The CRANE OPERATOR recalled one event in the Warm Canyon while performing a visual leak check of equipment in section 11 with the cell cover removed. He recalled seeing a rusty-looking cloud escape from the base of the agitator on tank 11.8 and smelling fumes through the full-face respirator. The CRANE OPERATOR believed a nitrite adjustment was being made to tank 11.8 at the time. He estimated the relative time frame of the event as approximately 5 or 6 months previously (December 1996 or January 1997). At that time, the CRANE OPERATOR did not notify facility management.

The Board reviewed procedures and logs to determine when any chemical additions had been made to either tank 11.8 or tank 12.5 (an adjacent tank). The dates of chemical additions for these two tanks were added to the timeline and analyzed for those dates when the CRANE OPERATOR was on shift. The Board found the CRANE OPERATOR was the only crane process operator on shift the night of December 13, 1996, when a $NaNO_2$ addition was made to tank 11.8.

<u>Analysis of Scenarios Involving the Old Warm Crane Cab</u>

Based on the above facts, the Board evaluated the potential for the CRANE OPERATOR to have been exposed to high airborne levels of radioactivity in the Old Warm Crane Cab. Analyses were performed for two scenarios. Scenario (a) "Contamination in Crane Cab," postulated that contamination occurred when high levels of transferable contamination were introduced into the crane cab and the CRANE OPERATOR was exposed to high airborne levels without respiratory protection. Scenario (b) “Canyon Event,” postulated that a canyon event external to the Old Warm Crane created high airborne levels which got into the crane cab and exposed the CRANE OPERATOR without respiratory protection. The two scenarios are both hypothetical and the analyses were performed deterministically (i.e., probability of 1) in order to determine the feasibility of the scenario to produce high enough airborne radioactivity levels consistent with the CRANE OPERATOR’s bioassay data. Calculations supporting the analyses are included in Appendix C.

(a) “Contamination in Crane Cab” Scenario

The Board determined by calculation that it is theoretically possible, by using a combination of extremely conservative or “worst case” assumptions, to obtain radiological conditions in the Old Warm Crane Cab which could have led to the uptake. However, the calculation is extremely sensitive to the assumption on a re-suspension fraction. Re-suspension fractions can vary from 10^{-2} to 10^{-6}. The re-suspension fraction used (10^{-2}) is extremely unlikely given the type of material worn as protective clothing (cotton) and the mechanisms available to re-suspend the contamination within the cab given the assumptions (no ventilation flow).

Given the sensitivity of the calculation to propagation of extremely conservative or “worst case” assumptions, the potential for the intake to have occurred from a scenario involving contamination inside the Old Warm Crane Cab, while possible, is considered unlikely. For purposes of the investigation, the scenario was still analyzed.

(b) “Canyon Event” Scenario

As previously stated, the Board determined the CRANE OPERATOR had performed a leak check from the old warm crane on December 13, 1996, when a $NaNO_2$ addition was made to tank 11.8. This may have been the activity associated with his remembrance of a rusty looking cloud escaping from the base of the tank agitator. The Board also ascertained the following conditions existed during this time frame:

- Activity levels of 200,000 dpm alpha accumulated on the filter paper of the old warm crane cab air sampler some time between December 10, 1996 and February 10, 1997.
- Unfiltered canyon air activity levels of 425 μCi alpha accumulated between December 12 - 16, 1996.
- Process vessel ventilation air activity levels of 168 μCi alpha accumulated between December 12 - 16, 1996.

The Board noted the Old Warm Crane Cab would be suspended approximately 30 feet above an uncovered cell. As such, it would take a potentially energetic event to overcome the slight downward air flow (approximately 5-10 feet per minute velocity) in order to create airborne radioactivity levels near the crane cab. If a process upset were energetic enough to overcome the downward flow of air, it would be expected to result in the eructation of process solution outside the tank. Solution forced from the tank due to an eructation would be expected to collect in the sump located in the bottom of the cell, resulting in liquid level indication and remote alarms in the main control room. In performing a record review, the Board found no correlation between sump alarms, chemical additions to tanks 11.8 and 12.5, and monitoring data from sampled air discharge streams (prior to their exhaust through the sand filter). However, if the exothermic reaction within the tank was just enough to create gas generation rates exceeding the removal capacity of the process vessel ventilation system (approximate 50 scfm per tank) without causing overflow of the tank contents, no sump alarm would be expected. This postulated event would produce conditions consistent with those described by the CRANE OPERATOR. No strip charts were available for tank liquid level indication to verify whether an eructation might have occurred in tanks 11.8 or 12.5. The data reviewed by the Board indicate the conditions and event described by the CRANE OPERATOR are plausible.

As previously stated, the Board determined the fan for the ventilation system on the old warm crane cab was found “out-of-service” on January 8, 1997. Based on the available records, the old warm crane was only used some portion of seven (7) shifts between December 13, 1996 and January 8, 1997. Given the lack of operability indication and interview statements regarding crane operators’ inability to hear the fan, the Board concluded the fan (and hence the ventilation system) could have been out of service as early as December 13, 1996. As previously described, the old warm crane cab is equipped with a CAM which samples air at a rate of approximately 40 scfm. If the ventilation system is out of service, the CAM would create an environment within the crane cab which is negative with respect to the surrounding canyon air environment. This would provide a motive force for ingress of unfiltered canyon air into the crane cab. Previously identified problems with returning the CAM to service could have prevented the CAM from properly detecting airborne radioactivity.

Given the problems noted previously with access procedures, RWP compliance, radiological surveys and posting of the old warm crane cab, the CRANE OPERATOR may have removed his respirator after accessing the crane cab on December 13, 1996. Coupled with the extent of problems noted on the personnel protective equipment on the crane and the physical evidence supporting the event described, the CRANE OPERATOR's intake from this scenario is plausible if he had not been wearing a respirator in the old warm crane cab.

Barrier Analysis for Old Warm Crane Cab Operations

An Events and Causal Factors chart was developed to analyze the CRANE OPERATOR and his operations within the Warm Canyon and the Old Warm Crane (Figure 2-4). Barrier analysis was then performed utilizing the data from the events and causal factors chart. The barrier analysis conducted by the Board addressed three types of barriers associated with the events during the time period: physical barriers, administrative barriers, and management barriers. These barriers either failed or were missing. Successful performance by any of these barriers may have prevented or mitigated the severity of a postulated event related to operation inside the Old Warm Crane Cab.

The barrier analysis worksheet is shown in Table 2-3, and a barrier analysis summary is shown in Table 2-4. Physical barriers that may have failed include improper removal of personal contamination clothing, lack of respirator usage, Old Warm Crane Cab safety equipment not functioning, cell covers that had been removed, and a process tank eructation. Administrative barriers that failed were lack of compliance with RWPs, inadequate use operating procedures, and lack of a Job Hazard Analysis for crane operation. Supervisory/management barriers that failed included a lack of worker knowledge related to hazards in the facility, lack of line management oversight to ensure requirements were being met, and lack of RCO coverage during highly contaminated work.

The likelihood of the CRANE OPERATOR's intake from scenario (a) is low. Conversely, the likelihood of his intake from scenario (b) is plausible. In any case, the commonality of findings and associated causal factors of this PERIPHERAL WORK to the other scenarios analyzed again gives credence to the Board's determination of causes and conclusions.

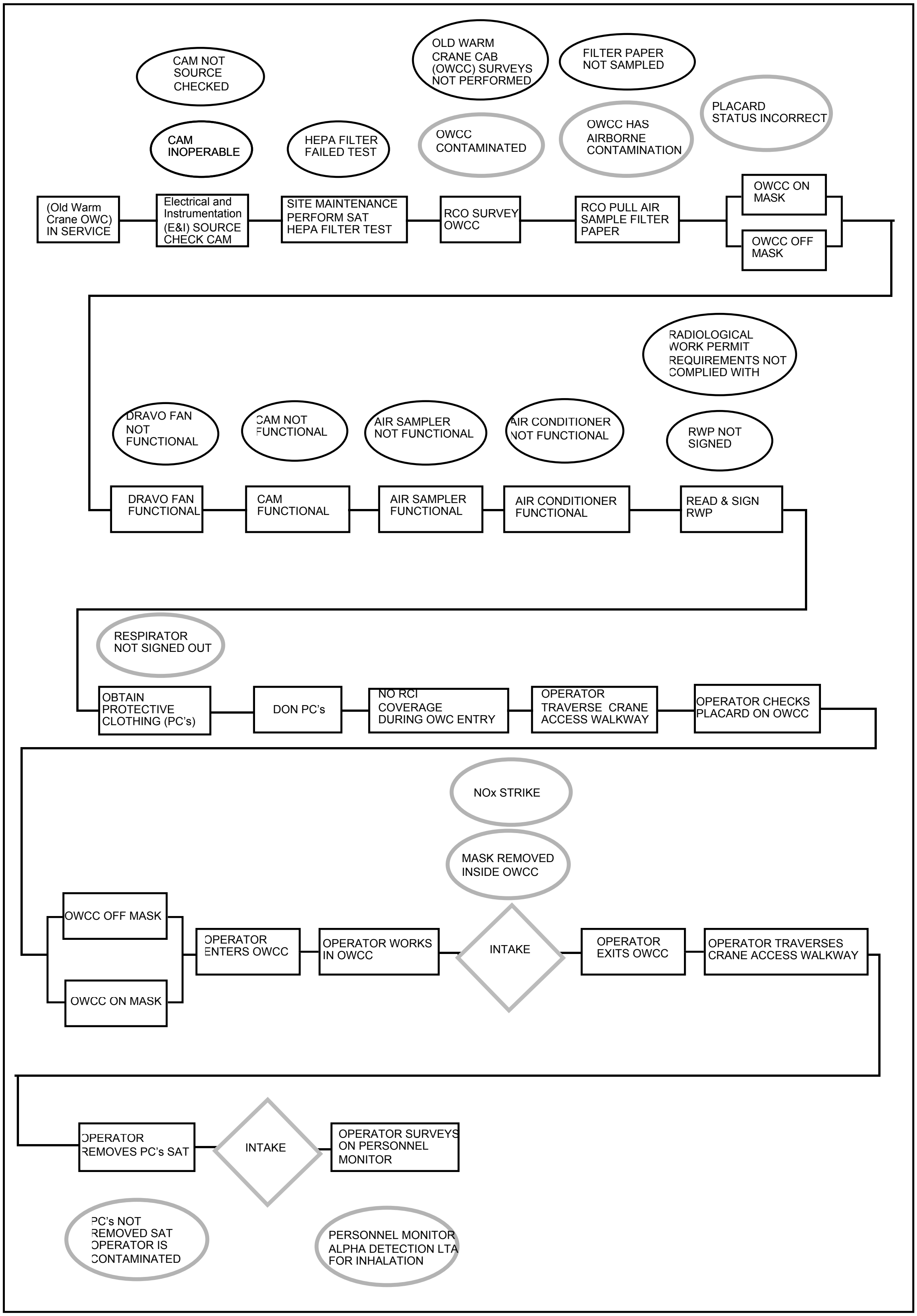


Figure 2-4 Old Warm Crane Cab Events and Causal Factors Chart.

Table 2-3 Old Warm Crane Cab Barrier Analysis (1 of 3)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation
Breathing Airborne Contamin-ation	Failure to properly remove personal contamination clothing	Training requirements not enforced by management Failure of the worker to comply with requirements	Training Less Than Adequate. Lack of management enforcement of complying with requirements	Internal exposure greater than that allowed by 10 CFR 835	Reexamine training adequacy Management enforcement of requirements is necessary
	Improper use of respirators	Respirator not worn as required by the RWP	Training less than adequate Lack of management enforcement of complying with requirements		Reexamine training adequacy Management enforcement of requirements is necessary
	Failure of Old Warm Crane Cab (OWCC) safety equipment utilized to protect the crane operator	CAM not functioning Air Sampler not functioning Electrical & Instrumentation source check not performed Dravo ventilation fan not functioning RCI cab surveys not performed	Old Warm Crane (OWC) is located in a highly contaminated environment which deters personnel from entering the area on a routine basis as required to ensure that the cab is in a safe status or any special requirements (respirator required) are identified to the crane operator. Lack of management attention to OWCC conditions.		Management should ensure the OWCC must be in safe as possible condition, with all safety equipment functioning properly in order to safely protect the crane operator
	Removal of the cell covers which exposes the process vessels	Leak Check procedures require that the OWCC crane operator view directly a jumper during an actual transfer to ensure no leaks.	Procedure places the crane operator over a potential vessel eructation which could cause a plume to reach the OWCC.		Revise procedures to evacuate or remove the crane operator to a safe position away from a potential exposure to chemicals and/or contamination

Table 2-3 Old Warm Crane Cab Barrier Analysis (2 of 3)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation
Breathing Airborne Contamin-ation	11.8 Process Tank	Possible eructation of a process vessel during transfers/additions	Process operator error	Internal exposure greater than that allowed by 10 CFR 835	If the crane operator is removed from the vicinity that action would remove him from the hazard
	Radiological Work Permit (RWP)	Crane operator not complying with the requirements for work in radiological controlled areas	Personnel error, Lack of management enforcement of employee compliance with requirements		Management should reinforce the compliance to all requirements to ensure worker safety
	Operating Procedures	Crane operator does not utilize procedures as required for crane operations	Personnel error Lack of management facility presence and lack of review of records to ensure workers are complying with requirements. Lack of management enforcement of employee compliance with requirements		Management should be present in the facility and should review records to ensure that procedures are being utilized Management should reinforce the compliance to all requirements to ensure worker safety
	Job Hazard Analysis	Job Hazard analysis has not been performed for the crane operator activities using the OWC	Management inattention to worker safety as related to routine activities		Perform a Job Hazards Analysis for the use of the OWC

Table 2-3 Old Warm Crane Cab Barrier Analysis (3 of 3)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation
Breathing Airborne Contamin-ation	Knowledge/ Skills/ responsibil-ities	Crane operator knowledge is not sufficient to understand the scope of the hazards that are present in the facility Analysis of the crane operator actions indicate that he is not taking responsibility for his own safety.	Lack of management enforcement to ensure worker safety responsibilities are understood by workers	Internal exposure greater than that allowed by 10 CFR 835	Management should reinforce the compliance to all requirements to ensure worker safety and worker responsibilities
	Line management oversight	Lack of facility presence Lack of performance-based assessments to evaluate worker compliance with requirements Lack of employee enforcement of compliance with requirements to ensure worker safety Disciplined operations is subsequently not enforced	Non-compliance with requirements		Management should maintain a strong presence in the facility by monitoring work evolutions (performance-based assessments) Management should reinforce the compliance to all requirements to ensure worker safety and worker responsibilities
	No RCI coverage for entries into the OWC	OWC is located in a highly contaminated environment which deters personnel from entering the area on a routine basis as required to ensure that the cab is in a safe status or any special requirements (respirator required) are identified to the crane operator.	Lack of management knowledge of operations to recognize the need for radiological oversight to ensure worker safety in highly contaminated environments		Management should provide RCI coverage for entries into highly contaminated areas where a high hazard potential exits to the worker

Table 2-4 Old Warm Crane Cab Barrier Analysis Summary

AFFECTED INDIVIDUAL	CRANE OPERATOR
PHYSICAL BARRIERS	PERSONAL CONTAMINATION CLOTHING
	RESPIRATOR
	OLD WARM CRANE CAB SAFETY EQUIPMENT
	CELL COVERS OPEN
	11.8 PROCESS TANK ERUCTATION
ADMINISTRATIVE BARRIERS	RADIOLOGICAL WORK PERMIT
	OPERATING PROCEDURES
	JOB HAZARD ANALYSIS
SUPERVISORY/ MANAGEMENT BARRIERS	KNOWLEDGE, SKILLS, & RESPONSIBILITIES
	LINE MANAGEMENT OVERSIGHT
	RCO COVERAGE
HAZARD SOURCE	Pu CONTAMINATION

2.2.3 Warm Gang Valve Corridor Decontamination Activities

Warm Gang Valve Corridor Description

The F-Canyon Warm Gang Valve Corridor runs north and south, parallel to the Warm Canyon from section 4 to section 18, between the canyon and outer building walls at approximately ground level (Figure 2-5). The corridor is located above the canyon air exhaust tunnel. Each section is 43 feet long and the entire corridor is approximately 650 feet long, 10 feet in width and 10 feet in height. Gang valve piping located on the canyon wall and miscellaneous instrumentation and equipment located on the corridor walls reduce the general passage area of the corridor to approximately 5 feet in width. The purpose of the gang valves is to provide steam from a remote location to canyon jets and process air to air blow steam lines after jetting operations. The jets are used to perform material transfers within the canyon.

Ventilation is provided to the Warm Gang Valve Corridor from the north end of the corridor through an air conditioner located outside the building. Air flows from the north end of the corridor to the south end at approximately 7,500 standard cubic feet per minute (scfm). The air exhausts through dampers in section 4, then passes through sand filters in 292-F, and is discharged via fans through the 291-F stack. There are also two recirculation air conditioners and three free standing air conditioning units for cooling the air in the corridor. The temperature in the Warm Gang Valve Corridor typically ranges between 80 and 120 degrees Fahrenheit.

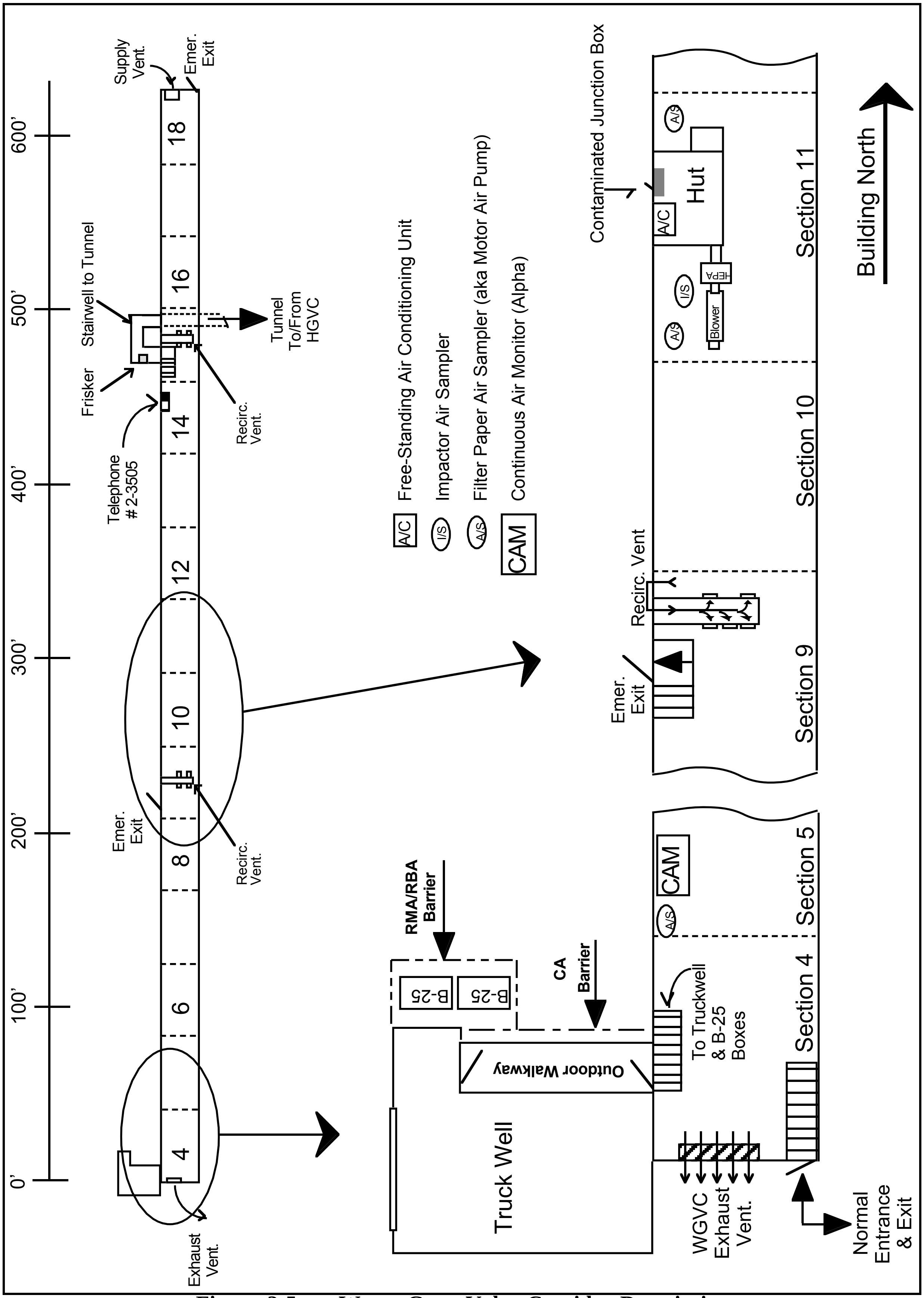


Figure 2-5 Warm Gang Valve Corridor Description

Warm Gang Valve Corridor Entry and Exit Locations

There are five entry and exit points for the Warm Gang Valve Corridor, with locations as follows:

a) east side at section 4
b) west side at section 4
c) west side at section 9 (emergency exit)
d) west side at section 15
e) north end at section 18 (emergency exit)

The Warm Gang Valve Corridor is typically entered and exited from the east side at section 4, which is closest to the RCO offices located on the first level. Stairs lead from section 15 of the Warm Gang Valve Corridor to a tunnel which crosses beneath the Warm and Hot Canyons to the Hot Gang Valve Corridor. The Hot Gang Valve Corridor is similar in layout to the warm gang valve corridor.

Air Monitoring Equipment

There is one CAM located in the Warm Gang Valve Corridor in section 5 (Exhibit 2-5). The unit detects alpha emitting airborne radionuclides and displays data output as counts per minute on both a count rate meter and a chart recorder. Alarms are enunciated locally, using an audible device and a large flashing red beacon. The monitor draws ambient air through a device that abruptly changes the direction of the air stream in order to cause airborne particles to impinge on a lightly greased plastic planchet placed in the air stream. Under the thin layer of grease, the planchet is also coated with a thin layer of Zinc-Sulfide (ZnS) crystals. The airborne particles trapped in the layer of grease on the planchet emit alpha radiation from the radioactive material attached to airborne particles. The ZnS crystals scintillate (emit flashes of light) as they are struck by alpha radiation. A light sensitive photomultiplier tube converts the light pulses from the ZnS to current and presents the result as counts on the rate meter and recorder. Should the count rate exceed a predetermined value selected by the attending staff, the alarm circuit activates the audible and visual devices. DOE requirements state such devices shall be sufficiently sensitive to detect airborne radioactivity in the range of 8 DAC-hours under laboratory conditions. Field conditions frequently reduce the practical sensitivity to between 18 and 24 DAC-hours. Although the audible alarm device is designed to be quite loud, ambient noise in the Warm Gang Valve Corridor typically prevents workers more than several sections away hearing the signal. The visual alarm device is a large red beacon that is visible for practically the entire length of the valve corridor. Placement of the CAM at the southern most end (section 5) of the valve corridor is due to the movement of air in the corridor that flows from north at section 18 to south at section 4. In theory, any release of airborne radioactive material in the Warm Gang Valve Corridor would be swept by the air flow pattern toward the CAM. A drawback to keeping a single CAM in this area is the delay in any alarms in the northern sections due to the required time for the contaminant to reach the CAM, and difficulty in alerting the workers in this area.

To provide assistance in characterizing the airborne radiological hazard in the Warm Gang Valve Corridor, several other air sampling devices such as Motor Air Pumps and Impactor samplers are utilized. Motor Air Pumps are small, portable vacuum pumps fitted with a collector head containing a filter through which air is drawn at rates of approximately 5 cfm and airborne particulate material is trapped. The Motor Air Pumps are typically allowed to run continuously. The filters are frequently surveyed in place for both alpha and beta-gamma emitting radioactivity with portable radiation detecting instruments. This practice is known as “probing” and provides a quick estimate of airborne conditions. Twice weekly, or whenever precise information is needed, the filters are removed and counted for radioactivity in laboratory analyzers. Four Motor Air Pumps are permanently located at specific locations in the Warm Gang Valve Corridor as part of a procedurally defined air sampling effort known as the Facility Annual Radiation Monitoring (FARM) program. The FARMs units are in sections 5, 8, 11, and 16. Impactor samplers, like Motor Air Pumps, are small, portable air samplers used to sample airborne radioactivity. They differ from Motor Air Pumps in that they use a high volume blower (i.e., approximately 45 cubic feet per minute) to quickly draw air through collector heads similar to the collectors used in the CAMs. The planchet samples are then either “probed” at the work site for a quick estimate and/or delivered to a counting facility for a more precise determination of the levels of airborne radioactivity. Impactor samplers and additional Motor Air Pumps may be used wherever necessary to meet special sampling needs at specific work locations.

Exhibit 2-5 Warm Gang Valve Corridor Continuous Air Monitor

Local Air Flow Conditions

Fresh air is supplied to the Warm Gang Valve Corridor at a rate of 7,500 scfm through an air conditioner located outside the north end of section 18. The air flow proceeds, with no additions to the total flow rate, southward to the exhaust duct at the south end of the corridor in section 4.

There are two recirculation air conditioners, one located at section 9 and one at section 15. The air flow rates and cooling process through each air conditioner are similar. Air enters the recirculation air conditioners, passes over cooling coils and is then returned to the Warm Gang Valve Corridor. The air flow rates through each air conditioner is approximately 6,500 scfm. Approximately 2,000 scfm is redistributed into the Warm Gang Valve Corridor via ducts facing north. The remaining 4,500 is redistributed into the Warm Gang Valve Corridor via ducts facing south. The air flow from the ducts facing north causes extensive turbulence, disrupting the flow of air from the north end of the Warm Gang Valve Corridor to the south end.

There are three free standing air conditioners. One is located at section 6, one located at section 11, and one located at section 14. The free standing air conditioners pull air from the Warm Gang Valve Corridor and redistribute the air back to the corridor after passing over cooling coils. The air flow rate through each of the free standing air conditioners is approximately 2,000 scfm. The air flow from the free standing air conditioners discharges transverse to the corridor, causing some turbulence and further disrupting the flow of air from the north end of the Warm Gang Valve Corridor to the south end.

Instrument Rack at Section 11.

The instrument rack at section 11 consists of a vertical frame approximately 2 feet wide and 5 feet tall. Instrumentation in the Warm Gang Valve Corridor includes various pressure indicators and temperature indicators. The rack was radiologically contaminated with contamination levels similar to those found in the area of the west wall of section 11 of the Warm Gang Valve Corridor from September 1996 to May 1997.

Fireye System

The fire protection system junction boxes and associated components are commonly referred to as the Fireye system by facility personnel. Only minimal written technical information could be found for the Fireye system. The system was installed during canyon construction in the 1950s and because the system sensors located in the canyon failed when continuously exposed to radiation, the system soon became unreliable. Extensive analysis was completed during the development of the most recent Safety Analysis Report and it was determined from the analysis that a fire in the Warm Canyon was not a credible event. Therefore, the Fireye system was abandoned in place in 1994. The source of contamination at section 11 of the Warm Gang Valve Corridor is believed to be contamination from the canyon entering the corroded Fireye system conduit or the annular space between the conduit and the concrete, and flowing into the junction box located in section 11 of the Warm Gang Valve Corridor.

A typical Fireye sensing unit consists of a fire sensing device located in the canyon where processing occurs, carbon steel conduit and wiring between the fire sensing device and the Fireye junction box, the junction box, and the fire detection box. The fire sensing devices would typically be installed on electrical nozzles in the canyon to make the electrical connection between the fire sensing device and the Fireye junction box; however, the fire sensing devices have been removed from each of the nozzles in section 11 of the canyon. There are three Fireye nozzles located in section 11 of the Warm Canyon which were electrically connected to the Fireye junction box located at the north end of section 11 in the Warm Gang Valve Corridor. The conduit which houses the electrical wiring is embedded in concrete between the Warm Canyon wall and the Warm Gang Valve Corridor and is approximately 15-20 feet in length. An annular space exists between the conduit and the concrete. The conduit enters the gang valve corridor through the ceiling near the wall opposite the canyon and enters the junction box which is mounted on the Warm Gang Valve Corridor wall approximately 2 feet below the corridor ceiling (Figure 2-6). During inspection with the new Warm Canyon crane cameras, small cracks and damaged concrete were observed in the canyon wall directly above one of the electrical nozzles (nozzle 85). In the past, the conduit between the fire sensing devices and the junction boxes was corroded, providing a flow path between the canyon processing area and the junction boxes. Similar corrosion is believed to have occurred in the conduit between the canyon and Warm Gang Valve Corridor in section 11. Additionally, the annular space provides another flow path for contamination ingress. Nozzle 85 is located near the piping jumper and nozzle connection used for transferring second plutonium cycle feed (2AF) from the adjustment tank (12.5) to the feed tank (11.8). Records (canyon scroll) indicate that the nozzle for the piping jumper is damaged and therefore the connection most probably leaks. Additionally, based on visual observation, it appears that there is residue from material which leaked from the piping jumper connection and flowed down into the cracked/damaged concrete where the Fireye system conduit is embedded.

The bioassay results indicate that the plutonium intake the CRANE OPERATOR received most likely came from the Warm Canyon, second plutonium cycle and was most likely processed within 1 year of the intake. The contamination found in section 11 of the Warm Gang Valve Corridor most likely originated from a leaking jumper connection used to transfer second plutonium cycle feed. The leakage from the jumper connection is believed to have entered the corroded conduit or annular space via the cracks in the concrete and subsequently flowed into the Fireye junction box.

Chronology of Decontamination Activities at Section 11

On September 1, 1996, during routine radiological surveys of the Warm Gang Valve Corridor, the RCI identified alpha contamination of 100,000 dpm/100 cm^2 and beta gamma contamination probing 12 mrad/hour/100 cm^2 in section 11. The high readings were found at the instrument rack. A job-specific RWP (96-FC-245) was written for operations personnel to decontaminate the area and for RCO to survey.

RWP 96-FC-245 cited procedure 221-F-52117, “Decontamination of Equipment and Facilities in 221-F and OF-F.” Since this is a “Use Every Time” procedure, a completed copy of the procedure should have been found for each of the 25 decontamination activities performed in section 11. However, only three completed copies of the procedure could be found for the time period under investigation. Two of the completed copies were for decontamination of a railroad cask car and railroad rails. The third completed copy was used to “decon floor and wall with swipes, rags, and cleaner” but did not give a location. It was completed on September 15, 1996, and could have been used for the work in section 11.

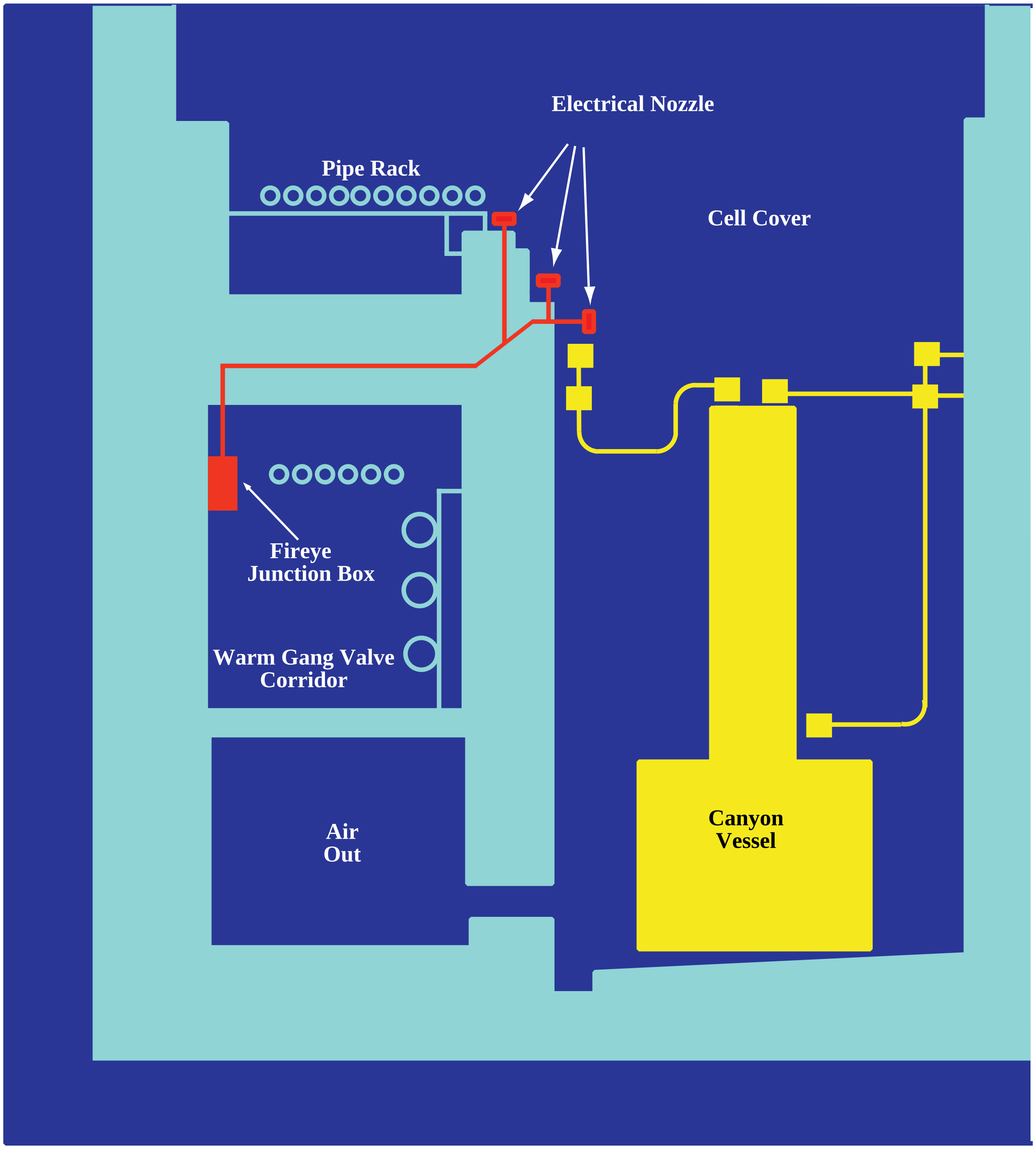


Figure 2-6 Fireye Detection System

The procedure cited above is a generic procedure for essentially any decontamination activity and provides only general instructions. For example, the procedure states "remove waste as necessary… ensure that RCO surveys waste… and remain alert to changing conditions at the job-site," but it does not provide specific instructions for how to perform decontamination. Instead, the procedure relies primarily on "skill of the craft" to successfully accomplish decontamination. The procedure identifies three items to be written into the completed procedure for a specific job:

- List the type of waste that shall be generated, methods used to minimize the amount of waste generated, and how waste shall be disposed.
- Describe the work to be performed and decontamination technique.
- List safety concerns.

The items are to be completed by the operator performing the procedure and approved by the Shift Operations Manager. There is no review of the written inputs by engineering personnel or personnel with strong radiological protection knowledge, such as health protection technical personnel.

Decontamination efforts began in section 11 at 0130 hours and continued until 0530 hours on September 2, 1996, under RWP 96-FC-245 Rev. 0. Respiratory protection requirements were a full face respirator. Surveys performed during this work activity found 80,000 dpm/100 cm^2 alpha and 400,000 dpm/100 cm^2 beta gamma. The RWP was revised as a result of this survey. Respiratory protection requirements were changed to a fresh air hood. The decontamination continued under Revision 1 of the RWP from 1300 to 1600 hours on September 2, 1996. There was no air monitoring with alarm capability in the vicinity of the decontamination activity.

At 2030 hours on September 2, 1996, the CRANE OPERATOR, two operations personnel, and one RCI entered the Warm Gang Valve Corridor to continue decontamination in section 11. A pre-job briefing was held at 2000 hours. According to the Respiratory Protection Equipment Log, no respirators or fresh air hoods were signed out. Personnel indicated during interviews that they wore respiratory protection, although they could not recall what type. The RWP sign-in sheet indicates that all four left the area at 2200 hours and the CRANE OPERATOR immediately returned to the corridor and did not exit again until 0100 hours on September 3, 1996. Also according to the RWP sign-in sheet, the other three personnel re-entered at 0100 hours and left at 0330 hours. During the interviews, all four personnel stated they exited at 2200 hours and re-entered at 0100 hours together.

A survey performed at 0800 hours on September 3, 1996, found 40,000 dpm/100 cm^2 alpha and 600,000 dpm/100 cm^2 beta-gamma contamination on a pipe behind the instrument rack. The RCI documented on the survey that "the leak appears to be originating from the junction box above instrument rack labeled 11B37. There are three conduit pipes leading from the top of junction box into the ceiling. Since the leak is ongoing, further decontamination efforts are futile and should be discontinued until the conduits can be traced to the source of contamination." Decontamination continued at 0430 hours on September 4, 1996. Four more entries to perform decontamination work were made into section 11 under RWP 96-FC-245, Rev. 1, between September 4-15, 1996; post-decontamination surveys are summarized below.

Date	**Alpha (dpm/100 cm^2)**	**Beta-gamma (dpm/100 cm^2)**
September 4	5,000	50,000
September 5	8,000	60,000
September 14	2,500	80,000
September 15	2,000	100,000

In addition, RCO personnel made five entries during this time period to survey the area. The contamination levels ranged from 2,000 to 8,000 dpm/100 cm^2 alpha and 20,000 to 400,000 dpm/100 cm^2 beta-gamma.

Decontamination efforts resumed on September 16, 1996, citing a new RWP, RWP 96-FC-251, on the respirator sign out sheet and the RCI survey. According to the records, RWP 96-FC-251 was never completed or issued. The RCI survey states that work was halted due to sparking of a receptacle on the wall next to the 11W sump gauge indicator. A survey was completed on September 21, 1996, under standing RWP 96-FC-012, the standing RWP for RCI surveillance**.** Decontamination was performed on September 22, 1996, and according to the RCI survey was performed again under the non-existent RWP 96-FC-251.

A RCI survey on October 16, 1996, found 200,000 dpm/100 cm^2 alpha and 100 mrad/hour/100 cm^2 beta-gamma contamination. On October 17, 1996, operations personnel decontaminated in Section 11 under RWP 96-FC-267, Rev. 0. The RWP cited procedure 221-F-52117 for performing decontamination work, but no completed copies were found. The RWP required plastic suits for decontaminating, housekeeping and repairing (caulking) the leak. Revision 1 of the RWP was issued on October 17, 1996, to include an additional task of performing inspections and repairing instrumentation. The RCI survey from October 17, 1996, indicated that the transmitter rack and wall were decontaminated and wrapped in yellow plastic. Decontamination activities were conducted on October 18, 19, and 20, 1996. On October 21, 1996, Revision 2 of the RWP was issued. According to the RCI survey, plastic was removed from instrument rack but the junction box remained covered. More decontamination was conducted on October 24 and 25, 1996, under Revision 2.

Construction of a containment hut in section 11 began on October 26, 1996, under RWP 96-FC-267 Rev. 3 (Figure 2-7). A Job Hazard Analysis for constructing and removing plastic huts had not been performed (one was scheduled to be completed June 30, 1997). The hut should have been constructed according to procedure 221-F-55230, a "Use Every Time" procedure entitled "Constructing a Plastic Hut." A complete copy of this procedure for the hut construction in section 11 could not be found. The hut was not constructed according to the procedure requirements. The procedure calls for the ceiling to be continuous with the sides. This was not the case since the ceiling was placed both over and under piping and taped to the piping, making it impossible to bring down the hut in one piece. Personnel involved with the installation stated that the taping to, around, and over the piping required 12 rolls of duct tape. Since surveys of the area had not accurately characterized the contamination area, the hut did not completely enclose the contamination. There was contamination behind the instrument rack which was not enclosed in the hut. Work on the hut continued on October 27, 28 and 29, 1996. The HEPA filter on the hut was filter penetration-tested on October 29, 1996.

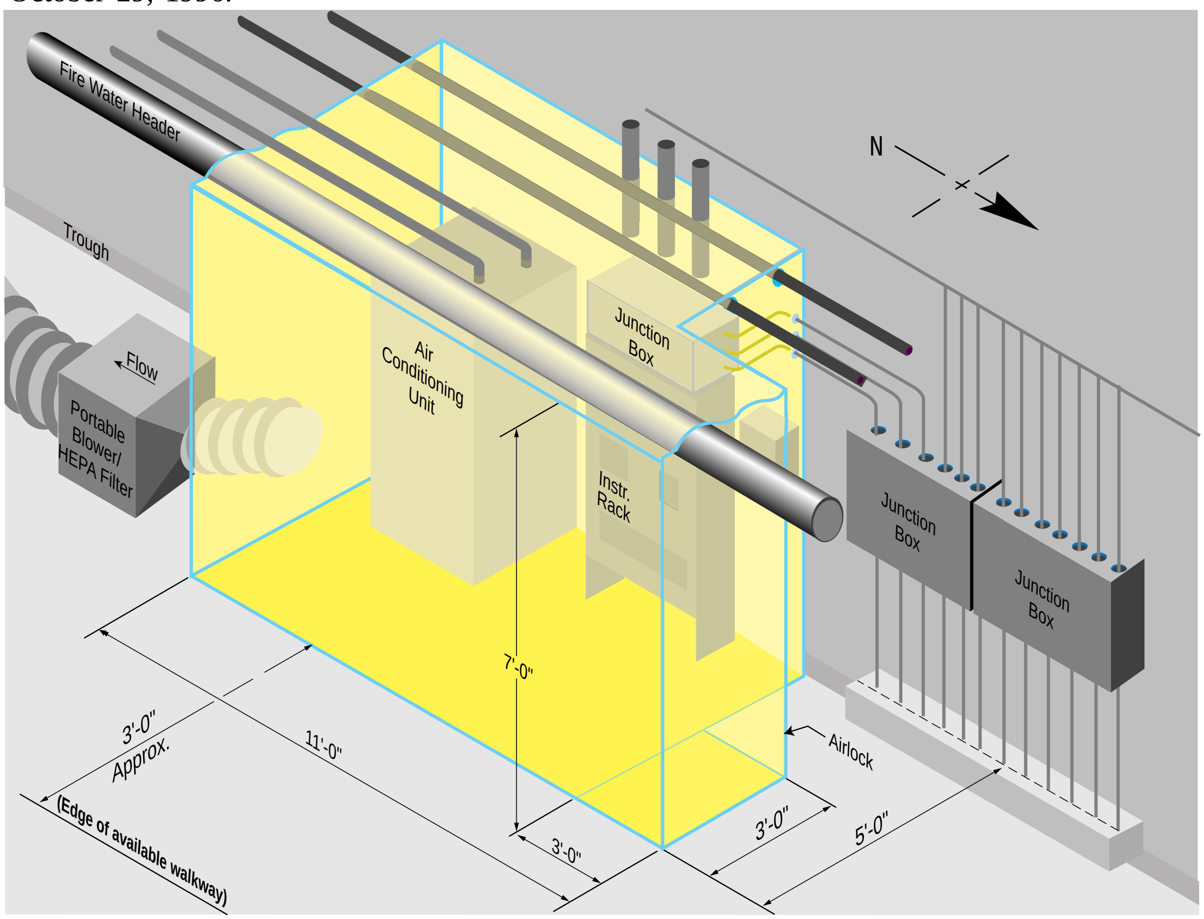


Figure 2-7 Warm Gang Valve Corridor Containment Hut

On November 25, 1996, RCI surveyed the hut using standing RWP 96-FC-012. The levels were found to be 2,000 dpm/100 cm^2 alpha and 100,000 dpm/100 cm^2 beta-gamma at the base of the instrument rack. On November 29, 1996, during routine RCI surveys of the Warm Gang Valve Corridor, it was discovered that the chart paper on the alpha CAM was not advancing. The routine survey on December 1, 1996, had the same notation.

RWP 96-FC-281, Rev. 0, was issued on December 4, 1996, to remove the Fireye junction box, steam transmitters, steam instrument tubing, and conduit tied to the Fireye junction box inside the hut. An ALARA briefing was held on December 4, 1996, with an operations manager, shift supervisor and Radiological Control Supervisor attending. Work began under this RWP on December 6, 1996, with no record of a pre-job briefing being conducted. The RWP cited Standard Operating Procedure 221-

F-650011, “Removing Fire-Eye Junction Box in Warm Gang Valve Corridor.” The procedure specified that a pre-plan meeting would be held and all involved personnel would sign-in on the RWP and pre-plan attendance sign-in sheet. The procedure called for removing the fire-eye junction box and associated equipment and sealing the end of the conduits and placing pipe caps on the ends. It also called for sealing the piping that was removed. During the investigation, the completed procedure could not be located. Plastic suits were required for this work. The RCI survey for the job showed 40,000 dpm/100 cm^2 alpha and 50,000 dpm/100 cm^2 beta-gamma contamination and 68.07 DAC inside the hut. On December 10 and 12, 1996, entries were made into the hut to decontaminate and remove waste.

A survey performed under RWP 96-FC-012 on December 13, 1996, found contamination levels of 60,000 dpm/100 cm^2 alpha and 120,000 dpm/100 cm^2 beta-gamma on the floor of the hut underneath the junction box location. On December 17, 1996, two Electrical and Instrumentation mechanics and the RCI entered the hut under Revision 3 of RWP 96-FC-267 to repair instruments. On December 21, 1996, under RWP 96-FC-027, an operator and a RCI entered the hut to spray paint (fix loose surface contamination) and survey it. The survey indicates that it was too wet to survey and that the field DAC estimate was 22 alpha inside the hut.

Removal of the hut commenced at approximately 1500 hours on December 21, 1996 (activities surrounding the hut removal are covered in detail in Section 2.2.4 of this report).

On December 22, 1996, decontamination continued in section 11 under RWP 96-FC-267 Rev. 3. The RCI survey indicated that maximum contamination prior to decontamination was 60,000 dpm/100 cm^2 alpha and 100,000 dpm/100 cm^2 beta-gamma. The survey also stated that plastic was placed around the area for containment. The CRANE OPERATOR signed in on RWP 96-FC-267 as well as standing RWP 96-FC-005 on December 22, 1996. He signed in on the standing RWP with two Electrical and Instrumentation mechanics who went into Section 11 to check the sump instrumentation. During interviews, the mechanics could not recall that the CRANE OPERATOR was with them.

Decontamination of section 11 continued on December 23 and 28, 1996, under Revision 4 of RWP 96-FC-267. Periodic surveys were ongoing after the period under investigation. A survey of the area behind the plastic was performed on April 2, 1997, and indicated contamination levels of 200,000 dpm/100 cm^2 alpha and 300,000 dpm/100 cm^2 beta-gamma. A dose rate survey performed on April 26, 1997, indicated 340 mrem/hour extremity dose rate, with 30 mrem/hour skin dose rate and 2 mrem/hour whole body dose rate. The maximum contamination found was 200,000 dpm/100 cm^2 alpha and 100,000 dpm/100 cm^2 beta-gamma on the tubing and wiring behind the instrument rack. The survey sheet states that the “job was suspended because RWP suspension guide limits were exceeded.” These surveys and dose rates indicate that the source of contamination is extensive and has still not been eliminated. There is no indication that management ever assigned anyone to be in charge of resolving the contamination problems in section 11.

Analysis of Scenarios Involving Warm Gang Valve Corridor

During the period under investigation, the CRANE OPERATOR is known to have worked in section 11 on two days (September 2 and December 22, 1996) other than the December 21, 1996, hut removal which is covered in Section 2.2.4 of this report. On September 2, 1996, the CRANE OPERATOR entered the Warm Gang Valve Corridor, section 11 area in order to decontaminate the area. The area was posted as an Airborne Radioactivity Area. Contamination levels as high as 100,000 dpm/100 cm^2 alpha and 400,000 dpm/100 cm^2 beta-gamma were known to have existed in this area. According to the respirator sign-in sheets, the CRANE OPERATOR did not sign out any respiratory protection equipment for performing the radiological decontamination work. The RWP required fresh air hoods to protect personnel from airborne contamination. According to the times on the RWP, the CRANE OPERATOR worked alone in section 11 for approximately three hours without RCI coverage. Given the levels of contamination found in the area, the potential existed for the CRANE OPERATOR to receive an intake during this work activity if he did not wear the required respiratory equipment (calculations supporting this scenario are shown in Appendix C). An Events and Causal Factors Chart (Figure 2-8) was used to analyze the September 2, 1996, activity in section 11. Four causal factors were identified for this activity:

- The source of contamination was not identified or characterized.
- There was no air monitoring in the vicinity of the decontamination activity (the CAM was located in section 5).
- The CRANE OPERATOR did not wear respiratory equipment (a presumptive causal factor).
- No procedure was used for decontamination activities.

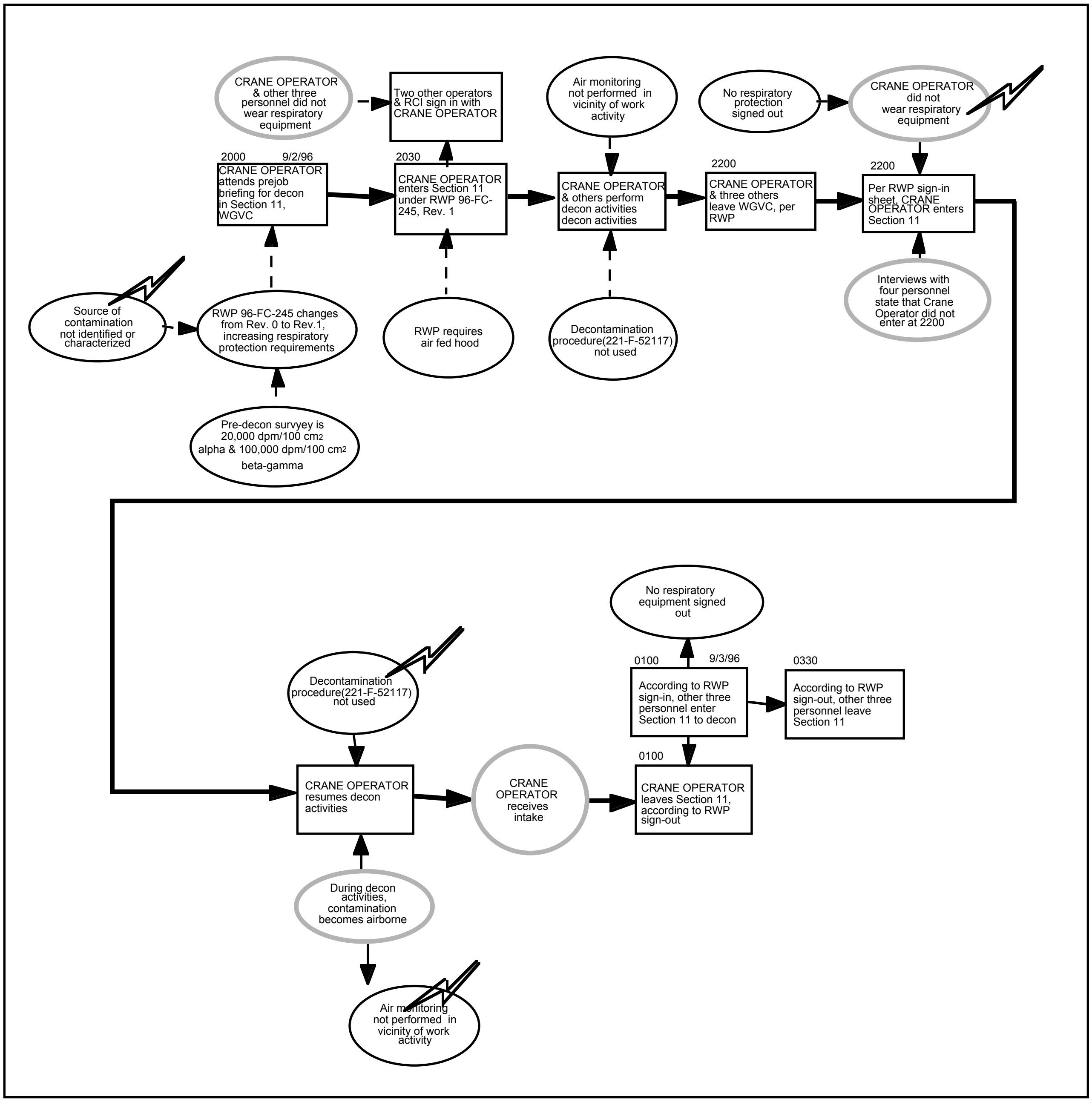


Figure 2-8 Warm Gang Valve Corridor Decontamination Events and Causal Factors Chart.

On December 22, 1996, the CRANE OPERATOR signed in on two RWPs for work in the Warm Gang Valve Corridor. For the first one, RWP 96-FC-267, Rev. 3, the CRANE OPERATOR had the appropriate respiratory protective equipment and RCI coverage was provided. For the second entry, under RWP 96-FC-005, the CRANE OPERATOR signed in with two Electrical and Instrumentation mechanics. Appropriate respiratory protective equipment was signed out. From the records and interviews, it is not clear what work the CRANE OPERATOR performed during this entry.

Conclusion for the Warm Gang Valve Corridor Scenario

Analysis of the decontamination activities in section 11 of the Warm Gang Valve Corridor, and the CRANE OPERATOR's activities in particular, identified several causal factors that could have contributed to the intake, as described below. The commonality of the causal factors between this PERIPHERAL WORK scenario and the other analyzed scenarios again gives credence to the Board's determination of overall causal factors and conclusions.

There was a lack of proper management awareness and attention in assigning priority to stopping the continual egress of radioactivity into the Warm Gang Valve Corridor. On September 3, 1996, the RCI survey noted that decontamination should be suspended until the source was identified. However, the decontamination efforts continued. There was no indication that management assigned anyone to be in charge of the contamination problems in section 11.

There was a lack of discipline in following detailed work requirements. For example:

- Work and turnover logs did not capture in detail what occurred during the work shift. An example is the CRANE OPERATOR's second entry into the Warm Gang Valve Corridor on December 22, 1996. Review of work logs gave no indication of what work was performed. Without detailed logs, the status of facility condition is not adequately communicated.
- There was a lack of adherence to the respirator issue and control program. Instances were found where personnel were signed-in on a RWP without having signed out the proper respiratory protective equipment.
- RWPs were not properly used. For example, two entries were made into section 11 without a documented RWP. Respirators were issued and surveys completed against RWP 96-FC-251, which was never issued according to the RWP log and was not found in the RWP files. Without the proper use of RWPs, workers are not aware of the conditions for the activities they are performing. For ongoing activities such as the decontamination in section 11, workers are not cognizant of changing conditions for the work activities, such as changes in postings and required respiratory protection equipment.
- Work was performed without pre-job briefings. For example, on December 6, 1996, under RWP 96-FC-281, work was performed to remove the Fireye junction box and related equipment from section 11 with no record of a pre-job briefing, as required by the RWP. Without the pre-job briefing, the workers are not informed of hazards and methods to minimize risk.
- Work occurred without required procedures. Decontamination was performed in section 11 numerous times but only one completed copy of the required procedure (221-F-52117) could be found that may have been used for the section 11 work. By not using procedures, there is no disciplined process to ensure proper work techniques.
- Some procedures were inadequate. Procedure 221-F-52117 did not give detailed instructions for performing decontamination. The procedure requires that the description of work and decontamination technique be completed for each use of the procedure. In the completed copies reviewed (three for the entire facility for the time period of the investigation) little detail was given on the decontamination technique.

There was a lack of supervisory oversight of work activities. Logs and RWP sign-in sheets were reviewed by supervision without detecting the problems described above. Although supervision is responsible for conducting pre-job briefings, there were instances found where there was not a documented pre-job briefing. As indicated by the lack of sign-in by supervision on RWPs, supervision provided little on-the-job oversight of jobs related to the section 11 decontamination activities. Management oversight was inadequate, and as a result management was not aware of problems and radiological work practice deficiencies in the facility.

There were inadequate engineered controls. Personnel typically worked in airborne and high contamination areas with respiratory protection as single barrier protection. Contamination should be isolated as close as possible to the source with glove bags or other similar soft-sided containments. Respiratory protection should only be used as the second barrier between contamination and personnel. If a glove bag had been properly installed over the actual contamination source, the CRANE OPERATOR could not have received the intake if he entered the area without respiratory protection.

There was inadequate radiological engineering support for the section 11 decontamination activities. For example, appropriate air monitoring with alarm capability was not provided during decontamination activities. Also, the design of the hut was inadequate and did not provide a barrier to contamination.

2.2.4 Warm Gang Valve Corridor Hut Removal

Time Line of Events for the Hut Removal

After the junction box removal work had been completed in the hut on December 17, 1996, and after several decontamination efforts inside the hut, the decision was made to remove the hut on Saturday December 21, 1996.

The facility has a Standard Operating Procedure for removing a plastic hut (221-F-52251, “Removing a Plastic Hut,” Rev. 1). This procedure is a reference procedure, which means the procedure does not have to be at the job site, but still must be followed. This procedure requires a RCO survey of the area in and around the hut within one shift prior to dropping the hut.

Removal of this hut was being controlled under job-specific RWP 96-FC-267, Rev. 3. This RWP was originally written to decontaminate and repair a leak in section 11 of the Warm Gang Valve Corridor. Revision 3 allowed a hut to be built and repairs made**.** However, removal of the hut was not identified on the RWP as an authorized task.

The interior of the hut had been spray painted on the previous shift to fix any transferable contamination. However, because the paint remained wet, no additional surface contamination surveys were taken before the entry was made to start the hut removal process.

A pre-job brief was held early in the afternoon of December 21, 1996, by the building supervisor. Signing the attendance sheet were crane operator #2, a building operator, and a RCI. The CRANE OPERATOR stated in his interviews that he was present at the pre-job brief but did not sign the attendance sheet.

The building supervisor discussed the procedure for taking the hut down and the RCI discussed the RWP. Crane operator #2, in a plastic air-fed suit, was to take the hut down; the building operator, in a full face respirator, was to act as standby for the crane operator #2; the CRANE OPERATOR, in a full face respirator, was to be the waste handler for the job, and the RCI, in a full face respirator, was to provide radiological controls coverage for the job. Of these four individuals, only one (the building operator) had taken a hut down before this time. The building supervisor did not designate anyone to be “in charge” of the job.

Everyone except the CRANE OPERATOR signed in on the sign-in sheet for RWP 96-FC-267 at 1500 hours. The CRANE OPERATOR signed in on Standing RWP 96-FC-005, “Entry Into Airborne Radioactivity Areas With Contamination/Radiation Areas by Trained (RWT) Personnel,” at 1500 hours. This RWP also required a full face respirator as part of the protective clothing requirements.

Everyone except the CRANE OPERATOR signed out the proper respiratory protection equipment as documented in the respirator issue log.

The CRANE OPERATOR, crane operator #2, and the building operator entered the Warm Gang Valve Corridor at section 4 via the stairway from the first level air lock (Figure 2-5). The RCI entered via the same route shortly after and turned the placard on the door to designate the Warm Gang Valve Corridor as an Airborne Radioactivity Area. The RCI stated she was to be the Airborne Radioactivity Area boundary on the north side of the work area in the Warm Gang Valve Corridor. The door entering the Warm Gang Valve Corridor from the truck well area was not posted as an Airborne Radioactivity Area. No one brought a copy of the procedure for hut removal with them.

The CRANE OPERATOR stated he went to section 12 with the building operator and crane operator #2. He left his respirator at section 12 and walked back towards section 4. He allegedly stopped and talked to the RCI telling her he was going to check the B-25.

The CRANE OPERATOR exited the Warm Gang Valve Corridor via the door at section 4 to the truck well to check if a B-25 waste container was available for all the waste generated in removing the hut. He crossed from the Contamination Area boundary in the truck well area, into the B-25 Radioactive Material Area while still in radiological protective clothing and without monitoring. The B-25 Radioactive Material Area is adjacent to, but not a part of, the Contamination Area (Figure 2-5). Radiological control requirements do not allow exiting a Contamination Area while still in protective clothing. The CRANE OPERATOR opened, closed, and tabbed one B-25 that was already full. He opened and closed another B-25 that did have sufficient room for the waste from the hut removal job.

At approximately 1450 hours a DOE Facility Representative was exiting FB-line and heard a banging noise coming from the B-25 storage area adjacent to the truckwell area. He observed an individual, dressed in radiological protective clothing, in the B-25 Radioactive Material Area. The Facility Representative attempted to obtain the individual’s attention. The person had left the area by the time the Facility Representative got to the truckwell area. The Facility Representative immediately called the control room and talked to the control room supervisor. The Facility Representative expressed his concerns about an individual being outside the Contamination Area with protective clothing on and hammering on a B-25 without wearing protective safety glasses. A Radiological Deficiency Report was not written on this event.

The CRANE OPERATOR re-entered the Warm Gang Valve Corridor from the truckwell and proceeded to section 12. The Shift Operations Manager paged the CRANE OPERATOR via the public address system to call the control room.

From the telephone records the following calls were made from the Warm Gang Valve Corridor section 14 telephone (Figure 2-5): 1501 hours to the control room for 0.2 min; 1503 hours to the control room for 0.3 min; 1504 hours to the control room for 3.9 min; 1511 hours to the control room for 4.3 min; 1515 hours to the RCO office for 1.8 min; 1527 hours to the RCO office for 2.5 min; 1533 hours the RCO office for 0.4 min; 1803 hours to the RCO office for 0.4 min.

The RCI stated she surveyed the inside of the hut before work to remove the hut was started and detected about 200,000 dpm/100 cm^2 of alpha emitting radioactivity. She also surveyed the Warm Gang Valve Corridor south of the hut and changed out the filter papers on air samplers south and north of the hut. However, no pre-job survey was documented as required by Standard Operating Procedure 221-F-52251.

The CRANE OPERATOR heard the page for him to call the control room. He called the control room from phone number 2-3505 (this could be the calls at 1501 hours, 1503 hours, or 1504 hours) and talked to the Shift Operations Manager about the Facility Representative observing the CRANE OPERATOR’s improper activities at the B-25. The CRANE OPERATOR then either handed the phone to the RCI to talk to the Shift Operations Manager or the RCI called the control room right after the CRANE OPERATOR (this could be the 1511 hour call to control room). The RCI removed her respirator to talk to the Shift Operations Manager. After the RCI talked to the SOM, she and the CRANE OPERATOR had a heated discussion about his leaving the Contamination Area to check the B-25. The RCI stated she told the CRANE OPERATOR to put on his respirator and leave the Warm Gang Valve Corridor via section 4. The RCI called the RCO office and told another RCI to survey the B-25 RMA (this could be the 1515 hours call). The CRANE OPERATOR stated he decided to leave the Warm Gang Valve Corridor via section 4 and talk to the Shift Operations Manager in person about the B-25. The CRANE OPERATOR also stated he thought he had a respirator on when he left the Warm Gang Valve Corridor. No one else remembered if he was wearing a respirator when he left the valve corridor. The CRANE OPERATOR signed out on RWP 96-FC-005 at 1530 hours.

None of the personnel interviewed could remember what was being done with the hut when the CRANE OPERATOR left the Warm Gang Valve Corridor. The CRANE OPERATOR stated that as he walked by the hut he remembers seeing crane operator #2 inside with a large area wipe in his hand as if decontaminating the hut. He also stated the CAM was not in alarm condition when he exited the Warm Gang Valve Corridor.

While these activities were underway, crane operator #2 removed a ladder from the inside of the hut with the help of the building operator. From inside the hut, crane operator #2 began cutting the lines supporting the hut from the overhead. He expected the hut to collapse from suction of the portable blower that had remained on to collect contamination. The hut did not collapse as he expected. He concluded the hut was taped to the overhead piping and decided to cut the roof of the hut away from the pipes. The procedure for removing a plastic hut did not address any of the above actions performed by crane operator #2. Crane operator #2 collapsed the hut and started to roll it up.

At some point during the hut removal, the RCI left the north side of the work area and probed the air sampler at the south end of the hut. At this point there was no Airborne Radioactivity Area boundary at the north side of the work area. She probed (on the air sampler filter paper) 40,000 dpm of alpha emitting radioactivity and performed a field calculation for the DAC, obtaining a DAC of 3900. The suspension limit on the RWP was 40 DAC. If a suspension limit on a RWP is reached, work under that RWP is required to be stopped. She called the RCO office to verify her calculations (this could be the 1527 hours call to RCO office). The RCI did not immediately require evacuation by all personnel.

Either the RCI or the building operator noticed the CAM at section 5 was in alarm. They saw the light flashing but did not hear the audible alarm. The RCI called the RCO office to inform them of the CAM alarm (this could be the call at 1533 hours to the RCO office) and told them she needed assistance. The RCI monitored crane operator #2's plastic suit and found high levels of contamination. The RCI had the building operator spray paint the outside of the crane operator #2's suit before the building operator cut crane operator #2 out of his suit. Crane operator #2 put on a respirator and they exited through the section 15 crossover to the Hot Gang Valve Corridor (Figure 2-5). They removed their protective clothing and full-face respirators at the section 4 exit from the Hot Gang Valve Corridor, exited the area, and returned to the RCO office.

The RCO supervisor, the building supervisor, the Shift Operations Manager, and the people that were in the Warm Gang Valve Corridor all met in the RCO office and discussed what happened. The RCO supervisor sent another RCI to the Warm Gang Valve Corridor via the Hot Gang Valve Corridor to survey the area for surface and airborne contamination levels and reset the CAM alarm. The RCI entered an area with unknown airborne radiological conditions wearing a full face respirator. This was potentially inadequate protection for the RCI.

Nasal and saliva smears were performed on the RCI and the building operator. These smears were negative. No nasal and saliva smears were performed on the crane operator #2 or the CRANE OPERATOR. No bioassays samples were obtained from anyone involved**.**

The RCO supervisor and Shift Operations Manager decided to send the same personnel back into the Warm Gang Valve Corridor along with the building supervisor to cover the dismantled hut with plastic. No critique or analysis to determine the source of the CAM alarm was documented. The RWP was not revised to cover this work. The pre-job brief for the second entry into the Warm Gang Valve Corridor was not documented on an attendance sheet. The building supervisor did not direct any actions in the Warm Gang Valve Corridor, but only observed.

The RCO supervisor has stated he believed the protective clothing requirements for the person covering the hut with plastic would be plastic suit and they would re-enter the Warm Gang Valve Corridor via the Hot Gang Valve Corridor.

Crane operator #2 signed in at 1730 hours on the RWP under task 1, which required a plastic suit. The CRANE OPERATOR and the building operator signed in at 1730 hours on the RWP under task 2, which required full-face air purifying respirators. The RCI and building supervisor signed in on the RWP at 1745 hours. The RCI signed in under task 3 and the building supervisor signed in under task 2. Both tasks 2 and 3 required full-face air purifying respirators. Everyone but the crane operator #2 signed out full-face air purifying respirator in the respirator issue log. No one signed out a plastic suit in the respirator issue log for the second entry into the Warm Gang Valve Corridor.

Crane operator #2, the CRANE OPERATOR, and the building operator entered the Warm Gang Valve Corridor via section 4. The RCI and building supervisor entered the Warm Gang Valve Corridor via section 4 shortly afterward. During the interviews all personnel stated they were in two pairs of protective clothing and full-face respirators.

Crane operator #2 and the CRANE OPERATOR attempted to roll the collapsed hut up inside a large sheet of plastic that had been brought in by the CRANE OPERATOR. During this attempt, the RCI, the building operator, and building supervisor were standing in section 12, just north of section 11.

Crane operator #2 and the CRANE OPERATOR were unsuccessful in the attempt and they began compressing the hut to a size of approximately 2 to 3 feet in diameter and 5 to 6 feet in length. They got the hut into a waste bag with approximately 2 to 3 feet of the hut sticking out of the bag.

While the crane operator #2 and the CRANE OPERATOR worked on bagging the hut, either the RCI or building supervisor noticed the CAM alarm light flashing. No one heard the CAM audible alarm. The RCI had the crane operator #2, the CRANE OPERATOR, and the building operator exit the Warm Gang Valve Corridor via the section 15 crossover to the Hot Gang Valve Corridor (Figure 2.5). The RCI did a field DAC estimate on the air sampler south of the work area. Her rough estimate was approximately 900 DAC. This value was not logged on a survey sheet. The RCI and building supervisor then exited via the section 15 crossover to the Hot Gang Valve Corridor.

The RCI stated she surveyed the people before they exited the Warm Gang Valve Corridor. No one else specifically remembered being surveyed by the RCI before leaving the Warm Gang Valve Corridor.

All five workers removed their protective clothing and full-face respirators at the section 4 exit from the Hot Gang Valve Corridor, exited the area, and returned to the RCO office.

Crane operator #2, the CRANE OPERATOR, and the building operator signed out on the RWP at 1810 hours. The building supervisor signed out at 1815 hours and the RCI signed out at 1820 hours. No nasal or saliva smears were performed on any of the people that were in the Warm Gang Valve Corridor when the second CAM alarm was received. Again, no bioassays were performed.

After shift change at 1900 hours, the on-coming RCO supervisor conducted a pre-job brief before going into the Warm Gang Valve Corridor, decontaminating the area, and bagging up all the waste in the area. Those in attendance were five operators and an RCI. This work was conducted under RWP 96-FC-267 Rev. 3, the same as the previous shift.

There were two entries made into the Warm Gang Valve Corridor to complete the work. The first time, at 2145 hours, four separations personnel and one RCI entered the area. Two separations people signed in on task 1, the RCI signed in on task 3, and the other two separations people put "NA" in the task number block of the sign in sheet. The second time, at 0330 hours, two separations people put "NA" in the task number block and another separations person signed in on task 1. The RCI signed in under task 3. Task 1 required a plastic suit as part of the protective clothing. None of the individuals signed in under task 1 are documented in the respirator issue log as being issued a plastic suit.

The critique for the two CAM alarms was not conducted until December 26, 1996, 5 days after the event. The only member of management at the critique was the Radiological Control & Health Physics Deputy Area Manager. The CRANE OPERATOR was not present at the critique. The Shift Operations Manager stated that "Other than the 3900 DAC the job went well."

Analysis of Hut Removal Events

An Events and Casual Factors Chart and a Barrier Analysis worksheet were developed and utilized as part of the analysis of the hut removal in the Warm Gang Valve Corridor.

Events and Casual Factors Chart (Figure 2-9)

Standard Operating Procedure 221-F-52251, "Removing a Plastic Hut," is the governing procedure for the hut removal job that took place on December 21, 1996. The procedure is a reference procedure, which means it does not have to be at the job site, but must still be followed.

The procedure requires a detailed contamination survey be conducted in and around the hut after all material is removed and the hut is decontaminated. The survey results are to be compared with the levels specified in the pre-plan meeting. There were no detailed surveys documented prior to the entry to remove the hut. Therefore, this requirement was not met. The RCI stated she surveyed around and inside the hut prior to removing it, but there is no documented evidence of that survey.

The procedure also requires all openings of the hut be taped closed. With the portable ventilation blower still in operation, to maintain a negative pressure in the hut, all support lines are to be cut. This allows the hut to collapse on itself and prevent the release of contamination from within the hut.

At the pre-job brief the procedure for hut removal was discussed by the building supervisor. However, a copy of the procedure was not taken to the job site despite the fact that of all the workers involved, only the building operator could remember participating in a hut removal before this job. The building supervisor also did not designate anyone to be in charge of this job. If someone had been in charge, that person should have been able to note the problems encountered in the hut removal and stopped the work before problems arose.
From the interviews of crane operator #2 it is evident the hut had to be partially collapsed from the inside because all of the lines supporting the hut were on the inside of the hut. Also, the ceiling of the hut was not in one piece but was constructed around several pipes in the overhead. Crane operator #2 had to cut the ceiling away from these pipes. Because some of the pipes were steam pipes, part of the plastic and tape adhered to these pipes and remained there after the hut was removed. The above actions were in violation of the procedure for hut removal.

RWP 96-FC-267 had been revised on October 26, 1996, to allow the erection of a hut in section 11 of the Warm Gang Valve Corridor. Hut removal was not listed in the Job Breakdown by Task section of the RWP. As evidenced by interviews and reviews of completed procedures, this RWP had only been approved by the RCO first line supervisor and the Shift Operations Manager. This was in violation of the WSRC Radiological Controls Manual, which requires upper level of management approval for infrequent operations. This was only the second time in 2 years that a radiological containment hut had been constructed/removed.

The CRANE OPERATOR signed the log in sheet for Standing RWP 96-F-005 at 1500 hours. This RWP allows entry into an Airborne Radioactivity Area, but does not allow specific work such as hut removal.

There is no record in the respirator issue log of the CRANE OPERATOR being issued any respiratory protection equipment for the first entry into the Warm Gang Valve Corridor. This failure to sign out respiratory protection equipment was in violation of WSRC Industrial Hygiene Manual.

When the RCI entered the Warm Gang Valve Corridor, she turned the insert on the placard on the entry door to designate an Airborne Radioactivity Area. However, the RCI did not post the entry door from the truckwell area as an Airborne Radioactivity Area. Her failure to properly post all entries into a radiologically controlled area was in violation of the Radiological Control Manual. The RCI also stated she was to be the Airborne Radioactivity Area boundary on the north side of the work area. However, when she went to the south side of the hut area to probe the air sampler, there was in effect no Airborne Radioactivity Area boundary on the north side.

When the CRANE OPERATOR exited the Contamination Area and entered a Radioactive Material Area without removing protective clothing and monitoring, this was in violation of the radiological control manual. The CRANE OPERATOR was observed in the Radioactive Material Area while still wearing protective clothing by a Facility Representative. The Facility Representative notified the Shift Operations Manager of his observations. However, the Shift Operations Manager did not write a radiological deficiency report as he should have done to ensure proper corrective actions for this event.

The RCI stated after entering the Warm Gang Valve Corridor, she performed an initial surface contamination and airborne radioactivity survey, but there is no documented survey sheet for this survey. After this survey, crane operator #2 and the building operator commenced hut removal.

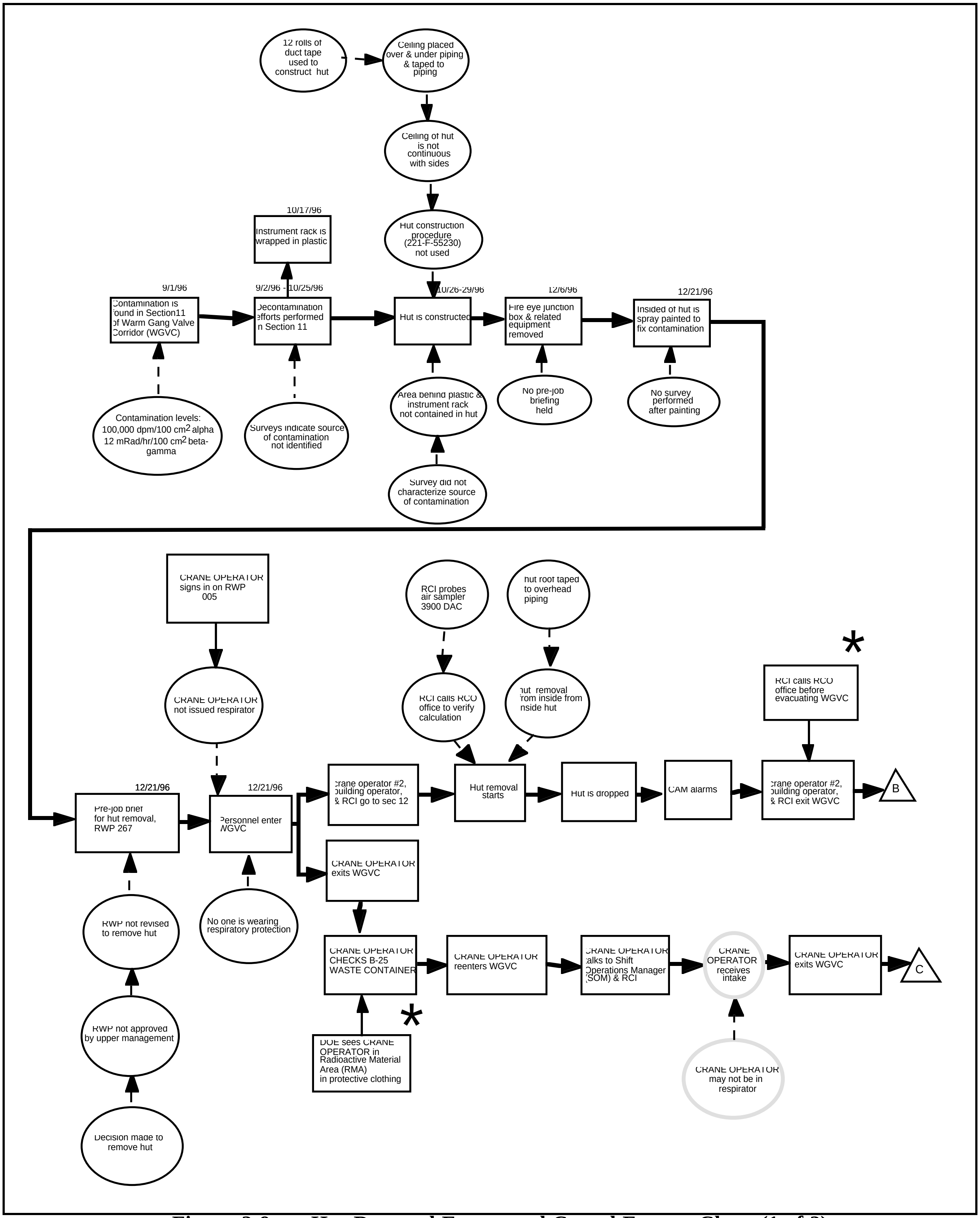


Figure 2-9 Hut Removal Events and Causal Factors Chart (1 of 2)

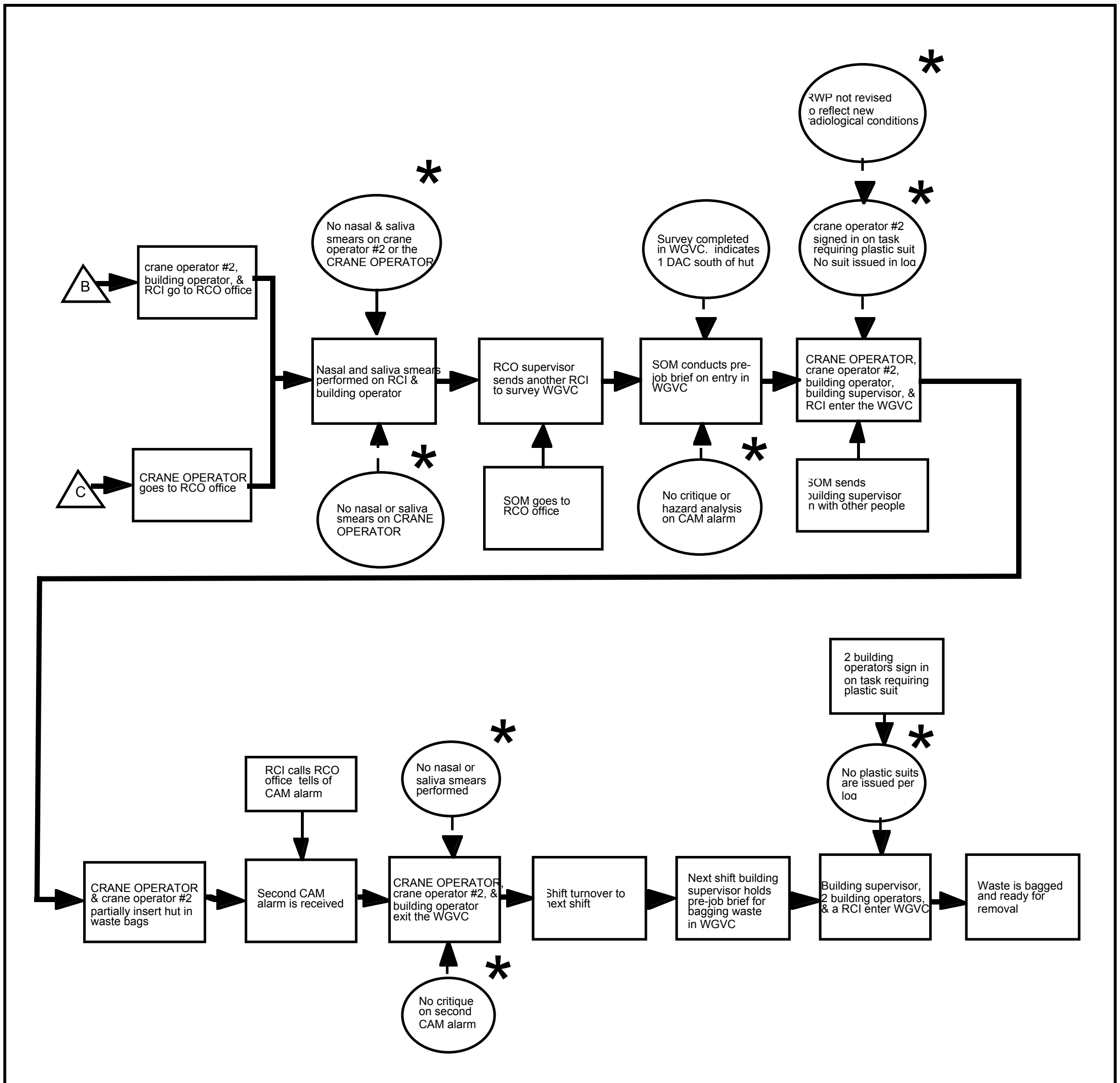


Figure 2-9 Hut Removal Events and Causal Factors Chart (2 of 2)

After the CRANE OPERATOR and the RCI talked to the Shift Operations Manager about the B-25 incident, the RCI stated she told the CRANE OPERATOR to put on his respirator and exit the Warm Gang Valve Corridor. The CRANE OPERATOR stated in his interviews he decided to exit the Warm Gang Valve Corridor and talk to the Shift Operations Manager in person. He also stated he thinks he was wearing a respirator when he exited. No one else can definitely remember if the CRANE OPERATOR was wearing a respirator when he exited the Warm Gang Valve Corridor.

No one, including the CRANE OPERATOR, remembers what the status of hut removal activities was while the CRANE OPERATOR exited the Warm Gang Valve Corridor via section 4.

During the hut removal, the RCI stated she went to the air sampler south of the hut to survey the air filter. The survey of the filter paper indicated 40,000 dpm of alpha emitting radioactivity. Based on a 20 minute sample, a 5 cubic feet per minute sample flow rate, and subtracting initial background reading she made a field estimate of 3900 DAC. The RCI stated because of the high value, she called the RCO office to verify her calculations. Based on telephone records, this call was made at 1527 hours. The RCI did not immediately stop the work and evacuate personnel. This value exceeded the airborne suspension guide limit of the RWP.

A CAM alarm on the portable CAM in section 5, which was approximately 300 feet away from the work area, was visually noticed by the RCI. The audible alarm was not heard by any of the personnel in the area. If a CAM had been placed next to the work area, the alarm would have been heard as soon as it occurred. Also, the measured activity on the CAM collection media would have been representative of the work area airborne activity.

The calculated intake of 7.2 nCi (see Appendix C) would result in an estimated CEDE of 3.0 rem. However, the airborne activity would have only been the above levels until the activity reached section 9 and would have been diluted until it reached the CAM at section 5. Assuming the CRANE OPERATOR's intake was 70 percent of the calculated intake value while he was exiting the Warm Gang Valve Corridor, the CEDE could be 2.1 rem.

The CAM at section 5 was surveyed after the first alarm by another RCI. This survey showed a calculated DAC of 1486 over a one minute period. A sudden increase observed on the strip recorder indicated a burst release instead of a continuous release.

Prior to the hut being installed, the instrument rack area in section 11 of the Warm Gang Valve Corridor was decontaminated several times and plastic was placed over the instrument rack.

After the hut was removed and the instrument rack area was decontaminated, plastic was again placed over the instrument rack to allow access to the Warm Gang Valve Corridor with minimal protective clothing and no respiratory protection. A survey of the area behind the plastic performed on April 26, 1997, indicated contamination levels of 200,000 dpm/100 cm^2 alpha and 300,000 dpm/100 cm^2 dpm beta-gamma. This increase in contamination levels indicates a source of contamination that had not been eliminated by previous decontamination efforts and work that had been done before the hut was removed.

This plastic sheeting may have been incorporated into the hut construction. Assuming the plastic sheeting covering the instrument rack was removed during the hut dismantling process, the radioactivity which accumulated behind the wall could have been suspended into the air.

The WSRC HEPA Filter Testing Group performed a quantitative aerosol test of the Warm Gang Valve Corridor, establishing 5 sample points and performing 20 second burst releases at the section 11 hut location. Based on this test, the aerosol required approximately 4 minutes to transit from section 11 to the CAM location in section 5. The aerosol at section 5 was between 6 percent and 20 percent of the concentration at section 11. Based upon this aerosol testing, it would have taken any airborne radioactivity release approximately 4 minutes to reach the CAM in section 5.

When the aerosol was released at section 11, the 20 second burst traveled southward down the corridor as an intact cloud, with little dispersion, until reaching section 9 (Exhibit 2-6). At section 9, northward facing ventilation supply ducts tended to stall the cloud, providing a hold-up and diffusion of the aerosol. The cloud of aerosol slowly leaked across the ventilation supply area and then proceeded southward to the section 4 Warm Gang Valve Corridor exhaust.

It took approximately 90 seconds for the CRANE OPERATOR to exit the Warm Gang Valve Corridor. This is based on the time it took Board Members to walk at a normal rate from section 11 to the exit at section 4 during the investigation process. The CAM at section 5 would have alarmed in less than a minute after the airborne radioactivity cloud reached the CAM. This is based on the recorded 1400 cpm on the CAM. The exact time to reach the alarm set point is unknown because the strip chart for that CAM was discarded before the investigation process started. Therefore, the CRANE OPERATOR would have had to been next to the hut removal area when the radioactivity became airborne.

After everyone exited the Warm Gang Valve Corridor due to the CAM alarm, only the building operator and the RCI had nasal and saliva smears performed on them. The RCO supervisor determined crane operator #2 did not require these smears because crane operator #2 was wearing a plastic suit. Also, smears were not performed on the CRANE OPERATOR. No bioassays were performed based upon negative nasal and saliva smears.

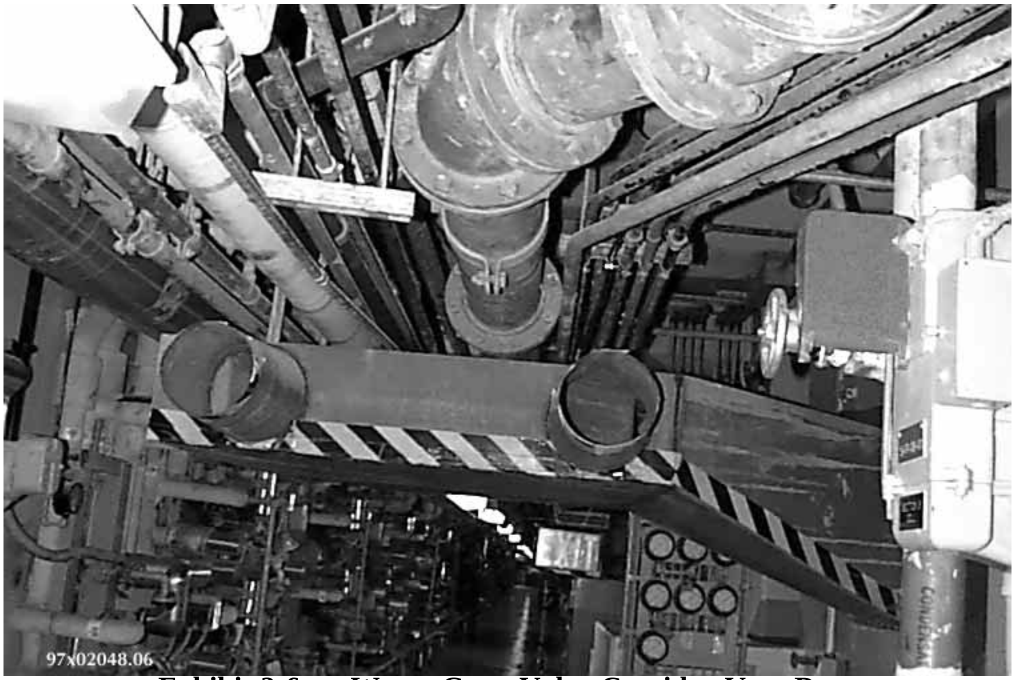


Exhibit 2-6 Warm Gang Valve Corridor Vent Duct

Based only on survey results of the Warm Gang Valve Corridor after the CAM alarm, the RCO supervisor and Shift Operations Manager decided to send the building supervisor, crane operator #2, building operator, the CRANE OPERATOR, and the RCI back into the Warm Gang Valve Corridor to bag remaining waste and the hut. These survey results indicated a maximum surface contamination level of 200,000 dpm/100 cm^2 alpha, airborne activity of approximately 1 DAC at the hut removal area, and a maximum airborne activity on the CAM of 1486 DAC. Neither a critique nor a hazard analysis was conducted at this time to accurately determine the source of the CAM alarm.

The Shift Operations Manager stated he conducted a pre-job brief for this second entry but there was no pre-job brief sign in sheet for this brief. The respiratory protection requirements and route for this entry were not adequately communicated to personnel entering the Warm Gang Valve Corridor. The RCO supervisor stated in his interviews he thought the entry was through the Hot Gang Valve Corridor, section 15 crossover, and back into the Warm Gang Valve Corridor. The RCO supervisor also stated the people bagging the hut would be in plastic suits. Crane operator #2 signed-in on the RWP under task #1, which requires a plastic suit; however, everyone entered the Warm Gang Valve Corridor via section 4 wearing respirators.

Again, shortly after starting to bag the hut, a CAM alarm in section 5 was visually noticed. Again the alarm was not audibly noticed due to the distance from the work area. The RCI had everyone but herself and the building supervisor evacuate via the section 15 crossover to the Hot Gang Valve Corridor. The RCI entered an unknown Airborne Radioactivity Area to perform a survey on the air sampler just south of the work area wearing a respirator. This put the RCI in an area that could have exceeded the protection factor of the respirator. The RCI calculated a field DAC estimate of approximately 900 DAC. This survey was not documented on any survey sheet.

After all personnel exited the Warm Gang Valve Corridor, the RCO supervisor made the decision not to have nasal and saliva smears performed. He stated this was based on the fact they were only in the area for a few minutes and the DAC level on the second alarm was lower than the DAC level on the first alarm. Again no bioassays were performed on anyone.

In the opinion of the Board, the WSRC criteria established to determine whether a special bioassay is warranted when personnel are exposed to unusual or abnormal radiological conditions was not adequate. The criteria was very general and relied heavily upon the collective judgment of radiological control management and internal dosimetrists to determine the need for a special bioassay. The board believed more definitive criteria should be established. The Board also noted that WSRC's reliance on saliva and nasal smear results to support decisions on whether special bioassay samples were needed, or to conclude whether an uptake may have occurred, is inconclusive as a negative discriminator.

Shift turnover was conducted and all of the off-going shift departed the area without conducting a critique on the second CAM alarm. The next shift RCO supervisor did not revise the RWP to reflect the changing radiological conditions (two CAM alarms), but conducted a pre-job brief and sent four separations personnel and one RCI in the Warm Gang Valve Corridor on two separate entries to bag up the hut and rest of the waste.

Two of the separations personnel signed in under task 1 of the RWP, which requires a plastic suit, but did not log out a plastic suit in the respiratory protection equipment issue log. The other two separations personnel signed in on the RWP sign in sheet but put "NA" in the task number block. These actions were in violation of site procedures.

Review of the critique minutes and attendance sheet for the critique held 5 days after the event indicated a less than adequate analysis of the event. The only member of management at the critique was the Radiological Control and Health Physics Deputy Area Manager. The CRANE OPERATOR was not at the critique.

If the CRANE OPERATOR was properly wearing a respirator while exiting the Warm Gang Valve Corridor, he would not have received a measurable intake. If the CRANE OPERATOR was not wearing a respirator, he could have received an intake close to the value of the intake assigned by the internal dosimetry group (see Appendix C for the supporting assumptions and calculations).

Barrier Analysis (see Tables 2-5 and 2-6)

In conducting the Barrier Analysis it was determined there were six barrier failures which could have resulted in the CRANE OPERATOR's intake.

The barrier that could have been directly breached, causing the intake, was failure of the CRANE OPERATOR to wear a full face respirator during the release of airborne radioactivity in the Warm Gang Valve Corridor.

The five additional control barriers breached were: failure to use a specific procedure for removing the hut; failure to revise the RWP to include the hut removal; failure of workers to stop when the hut could not be removed in accordance with the standing operating procedure; failure to place a CAM close to work area; and failure to immediately evacuate the work area with high airborne levels. Although these barriers could not have caused the intake if individually breached, the number of barriers breached indicates that problems existed in several areas.

The root causes for these barrier failures were: Job Hazard Analysis for hut removal was not performed, there was less than adequate pre-job planning for the hut removal; less than adequate pre-job briefing; less than adequate supervision of the hut removal; less than adequate enforcement of respirator-issuing procedures; less than adequate radiological control boundaries of work areas; and less than adequate RCI training.

The commonality of findings and causal factors associated with this particular PERIPHERAL work to the other scenarios gives credence to the Board's determination of causes and conclusions.

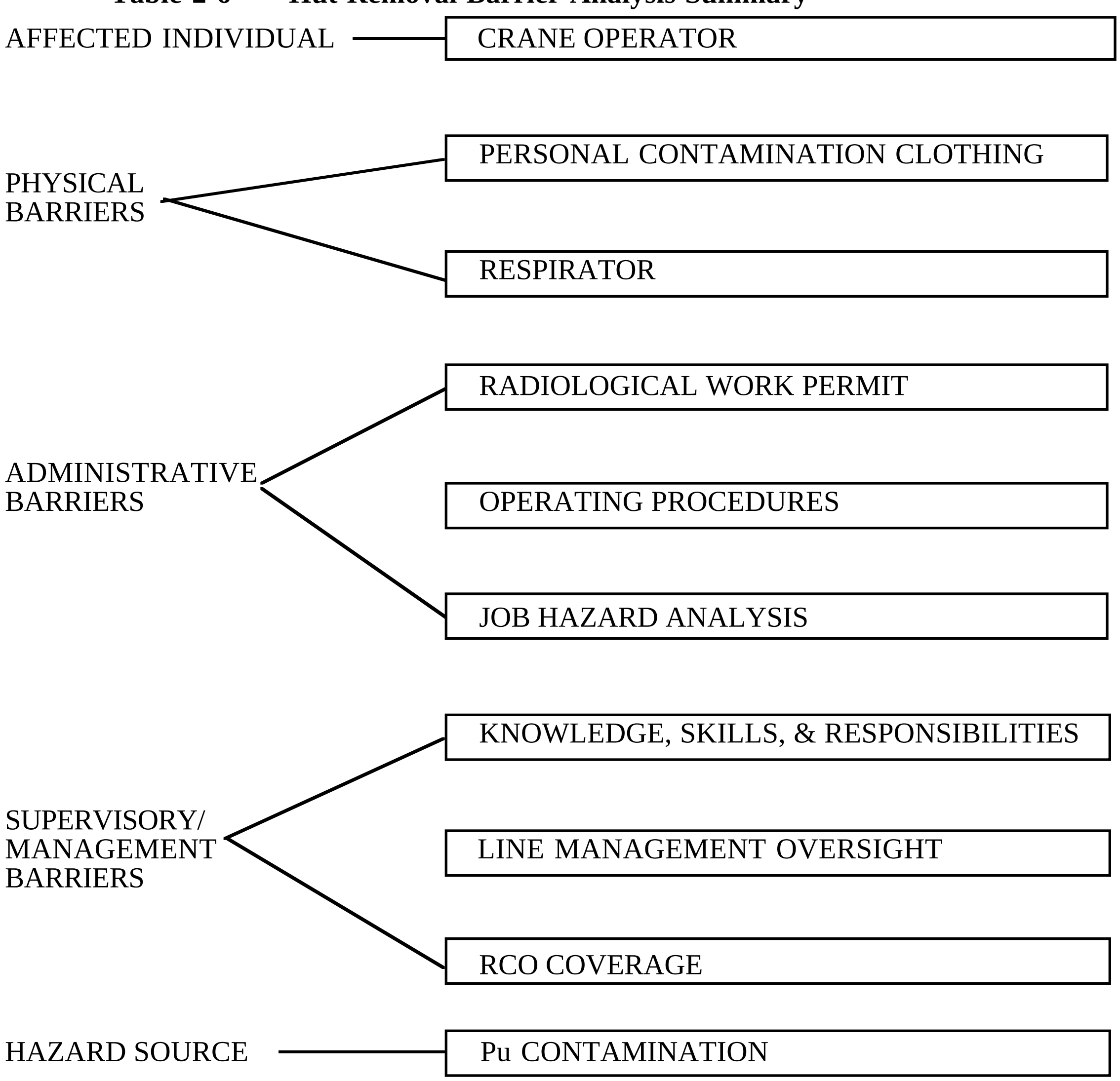
Table 2-5 Hut Removal Barrier Analysis (1 of 2)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failure	Loss or Potential Loss Event	Evaluation
Breathing airborne radioactivity	Failure to use specific procedure for removing hut	The Warm Gang Valve Corridor (WGVC) hut was not constructed in accordance with the Standard Operating Procedure for hut construction No walk down of the hut was performed prior to hut removal	Separations supervision was not knowledgeable of unique hut construction	Internal exposure greater than allowed by 10 CFR 835	**The pre-job planning was inadequate for hut removal**
	Failure of workers to stop when hut could not be removed in accordance with procedure	The Standard Operating Procedure for hut removal was not discussed in detail during pre-job brief Of the four personnel involved in hut removal only one had any prior experience in removing huts	Supervision did not personally oversee hut removal job		Supervision of hut removal job Less Than Adequate (LTA)
	Failure to revise RWP to include hut removal	The RWP had already been revised twice due to changing job tasks	Shift supervision did not review the RWP before starting job		Hazard analysis of hut removal not performed
	Failure of CRANE OPERATOR to wear full face respirator	Both times the CRANE OPERATOR entered WGVC it was not posted as an Airborne Radioactivity Area (ARA) CRANE OPERATOR thought he was not involved with job but only a waste handler. CRANE OPERATOR did not sign out respirator in issue log.	RCI did not post entries into WGVC as ARA before other workers entered CRANE OPERATOR's lack of understanding responsibilities Implementation of respirator issue procedures		Radiological control boundaries of work area LTA Pre-job brief less than adequate Enforcement of respirator issuing procedure LTA

Table 2-5 Hut Removal Barrier Analysis (2 of 2)

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failure	Loss or Potential Loss Event	Evaluation
Breathing airborne radioactivity	Failure to place CAM close to work area	No portable CAM dedicated for temporary work areas	Personnel's expectation that there would be no high levels of airborne activity	Internal exposure greater than allowed by 10 CFR 835	Hazard analysis of hut removal not performed
	Failure to immediately evacuate with high airborne levels	The RCI called the RCO office to verify her DAC calculations on air sampler	The RCI was not confident of her calculations		Training of RCO LTA

Table 2-6 Hut Removal Barrier Analysis Summary



2.3 MANAGEMENT SYSTEMS ANALYSIS

2.3.1 Self-Assessment and Third-Party Reviews

During the investigation, the Phase II Restart of F-Canyon Operational Readiness Review (January 1996), the most recent Management Evaluation (NMSP-SPS-960050, October 3, 1996), the most recent Facility Evaluation Board report (ESH-FEB-96-0727, December 6, 1997) and response (NMS-PRG-97-0492, March 31, 1997), the F-Canyon self-assessment evaluations for August 1996 through February 1997, and the Commitments Management System entries during that same period were reviewed. From these documents, the Board concluded that WSRC management should have been aware of the issues addressed in this report. The Management Evaluation found, in part, the need to increase management field presence, improve pre- and post-job briefs, and implement a housekeeping program. The Facility Evaluation Board and response also highlighted similar deficiencies and corrective actions. These actions, if implemented, had the potential to mitigate many of the Board's findings. The Board found no evidence that these corrective actions had been implemented during the period under investigation. This is further complicated by the lack of information available for the Management Evaluation. For example, an effective Radiological Deficiency Report system could have provided information relative to the status of radiological controls implementation. Similarly, if self-assessment Lines of Inquiry included both vertical and horizontal reviews, the problems with RWP versus respiratory protection equipment sign-outs could have been addressed earlier. Timely implementation of management field presence could have mitigated the problems found in all four scenarios.

2.3.2 WSRC Management Oversight

The Board reviewed signature sheets for Standing RWPs and respiratory protection equipment issuance logs for the period of interest to determine the number of times WSRC management observed work or conditions within the facility. Due to the nature of the investigation (plutonium intake of a worker), the Board confined the record review to those occasions where management entered radiological controlled areas with high levels of transferable surface contamination or airborne radioactivity. Within the context defined above, the Board found senior WSRC management (shift operations manager or above) entered infrequently.

The Board found WSRC failed to adequately implement an effective Radiological Deficiency Report program. Problems regarding compliance with RWPs, control and use of respirators, and personnel performance errors (e.g., opening of the B-25 box by the CRANE OPERATOR, materials left on cell covers, hut removal) should have been documented via radiological deficiency reports. Without documentation of such deficiencies, WSRC and DOE management have no measure of program effectiveness or performance. The lack of an effective Radiological Deficiency Report program was compounded by the failure of WSRC management to periodically review the performance of work and to inspect pre- and post-work conditions in the facility. Thus, a direct means of assessing the effectiveness of the radiological control program was not utilized.

In reviewing the available documentation, the Board found problems in the level of detail and consistency in logs and turnover sheets. The problems existed to some degree in virtually all of the records reviewed, including the Shift Operation Manager's log, Crane log, Building Supervisor's log, and RCO's turnover checklists. The extent of the problems indicate inadequate reviews were performed by facility management. This includes daily review of shift logs and operational data, as well as periodic reviews required as part of the facility management's self-assessment program.

The Board noted several examples where unusual or abnormal radiological conditions existed within portions of the facility, but management failed to analyze the significance of the available data. The primary example was the continued ingress of high levels of transferable surface contamination in the Warm Gang Valve Corridor. Management waited several months before attempting to isolate and stop the source of contamination or to use some form of containment. Other evidence of inadequate management analyses and follow up included periods of high airborne radioactivity in the canyon; calculation errors in determining airborne radioactivity levels, failures of protective equipment on the old warm crane cab; and the subsequent re-entry on the hut removal job.

2.3.3 DOE Oversight

There are four DOE Facility Representatives (FR) in Nuclear Materials Separations Division assigned to F-Area. At the time of this report one FR was fully qualified on F-Canyon and two others were in the process of qualifying. These FRs provide the day to day oversight of contractor operations in F-Canyon in accordance with the appropriate Savannah River Implementing Procedures. The DOE-SR Radiation Protection Division provides one person for matrix support to Nuclear Materials Separations Division as well as the Tritium Division and Reactor and Spent Fuel Division. This matrix person conducts radiological controls assessments in: F-Canyon, FB Line, F Outside facilities, H-Canyon, HB Line, H Outside facilities, Replacement Tritium Facility, Tritium Extraction and Storage facilities, Reactor Basins, and Receiving Basin for Offsite Fuel. This person conducts radiological control assessments on a rotating basis. He assesses F-Canyon approximately six weeks a year. During the period under investigation, the matrix support person assessed F-Canyon for a total accumulation time of approximately two weeks.

The Board conducted a review of the Standing RWP sign in sheets for those RWPs governing access to Contamination Areas and Airborne Radioactivity Areas from August 1996 through December 1996. During this period, DOE made infrequent entries within Contamination and Airborne Radioactivity Areas. Based upon review of the DOE monthly reports, DOE had opened no significant observations or findings about activities in Contamination or Airborne Radioactivity Areas, but were tracking several previously opened deficiencies. However there were several radiological control deficiencies noted during this period. These deficiencies were transmitted to the contractor via the DOE tracking and notification computer system and were not included in the DOE monthly report.

The Board concluded that DOE should have been aware of (1) the less than adequate material condition, housekeeping and improper work potential of the warm canyon; (2) the prolonged high contamination source in the Warm Gang Valve Corridor; and (3) the use of the Old Warm Crane without proper analysis.

2.3.4 Integrated Safety Management

Safety management activities can be grouped into five core safety management functions: (1) define the scope of work; (2) identify and analyze the hazards associated with the work; (3) develop and implement hazard controls; (4) perform work safely within the controls; and (5) provide feedback on adequacy of the controls and continuous improvement in defining, planning, and performing work.

These five functions provide the necessary structure for any work activity that could potentially affect the worker, public, or the environment. The formality and rigor needed to address each function varies based on the hazards involved with the work. The following is an analysis of the relationship of the Board's causal factors and findings during this investigation to each of the five core functions of integrated safety management. Again, the context of this analysis is with respect to PERIPHERAL WORK in F-Canyon radiological areas.

Define the Scope of Work

Set Expectations:
For several tasks or work activities, WSRC management failed to establish clear expectations. The most prominent example was removal of the hut from the Warm Gang Valve Corridor. The personnel involved were given only general instructions for removing the hut via a pre-job briefing, and were provided with no subsequent work site supervision or direction. Prior decontamination efforts in the Warm Gang Valve Corridor (which persisted over an extended period of time from early September until the time of this report) also reflect this problem. Personnel were frequently assigned to decontamination activities in the Warm Gang Valve Corridor with the objective to simply reduce the levels of transferable contamination present.

Prioritize Tasks and Allocate Resources:
WSRC management failed to adequately prioritize the need to determine the source or cause of elevated levels of transferable contamination which persisted for an extended period in the Warm Gang Valve Corridor. For the hut removal job (both for initial entry and subsequent re-entry after the first CAM alarm), WSRC management failed to adequately consider the inexperience of the personnel

involved. Although sufficient management experience was potentially available on the shift to have safely executed or stopped the removal efforts, the job was considered low priority or routine work. The criteria used by WSRC management to prioritize which jobs or work activities received continuous, intermittent, or no coverage by RCO personnel was not evident. Thus, decisions on resource allocation or job coverage were made by lower levels of supervision with no clearly established criteria.

Identify and Analyze Hazards

WSRC failed to adequately characterize the hazards associated with the hut installation and removal in the Warm Gang Valve Corridor. Based on the radiological survey records reviewed by the Board, WSRC did not establish an adequate baseline of the radiological conditions present in the Warm Gang Valve Corridor to support the work performed. None of the radiological surveys were extensive enough to have encompassed all of the area eventually covered by the hut.

Similar problems existed with use of the Old Warm Crane. No Job Hazards Analysis (JHA) or Preliminary Hazards Analysis was performed for operations involving use of the Old Warm Crane. As a result, the relative importance of protective equipment (HEPA filtered ventilation system and CAM) on the Old Warm Crane Cab was not recognized. The radiological surveys taken of the Old Warm Crane Cab were infrequent and of limited scope. Therefore, a poor technical basis existed for important decisions on radiological protection controls (i.e., whether or not to place the Old Warm Crane Cab on respiratory protection or “on mask”).

No JHA was performed for other activities routinely performed by CRANE OPERATORS. For example, crane operators are frequently requested to decontaminate equipment with high levels of transferable surface contamination. The operating procedure used by the facility contained only general directions and was inadequate for all radiological conditions crane operators might encounter during decontamination performance.

The Board found facility engineering personnel had limited technical information available to them (drawings, etc.) and limited knowledge of key safety equipment on the Old Warm Crane. The Board found the physical arrangement used to test the efficiency of the HEPA filters on the Old Warm Crane did not test each filter independently. This was unknown to facility engineering personnel. At the Board’s request, a penetration test was performed on the second HEPA filter, which subsequently failed. It was determined the second HEPA filter had not been replaced in approximately ten years.

The protective clothing and other materials found atop the cell covers indicated work may have been performed in an area of the Warm Canyon with high transferable surface contamination levels. The hazards associated with this condition would have warranted air-fed respiratory protection. The levels of contamination could have resulted in an airborne radioactivity environment potentially exceeding the protection factor afforded by a full face respirator. Given the fact no breathing air manifolds were located in that portion of the canyon, personnel could not have been wearing adequate respiratory protection equipment to perform work atop the cell covers.

Develop and Implement Hazard Controls

Identify Standards and Requirements:
The Board found the established requirements for retention of certain facility records to be inadequate. In particular, the Board found, consistent with DOE Order 1324.24, the record retention requirements for radiological air monitoring data on strip charts is “Destroy when purpose is served or when 3 months old, whichever is earlier.” The Board believes such strip charts should be retained as permanent records. The Board was unable to verify or determine the source of several periods of high airborne radioactivity levels without the associated strip charts. The Board encountered similar problems with the lack of strip charts used to record certain process parameters. For example, in investigating the potential for an eructation to have occurred involving tanks 11.8 and 12.5, the Board requested the strip charts showing the liquid level at the time of any chemical additions. Based on discussion with facility engineering personnel, the strip charts should have reflected any sudden level change which might be indicative of loss of contents (i.e., an eructation). However, F-Canyon maintained such strip charts for only one month. Thus, limited conclusions could be drawn for this potential given the lack of strip charts for the period under investigation.

Additionally, in the opinion of the Board, the WSRC criteria established to determine whether a special bioassay is warranted when personnel are exposed to unusual or abnormal radiological conditions was not adequate. The criteria was very general and relied heavily upon the collective judgment of radiological control management and internal dosimetrists to determine the need for a special bioassay. The Board believed more definitive criteria should be established. The Board also noted that WSRC's reliance on saliva and nasal smear results to support decisions on whether special bioassay samples were needed, or to conclude whether an uptake may have occurred, is inconclusive as a negative discriminator.

Identify and Implement Controls to Prevent/Mitigate Hazards:
The Board found several work situations where radiological evaluations by engineering personnel should have been required but were not performed. The primary example was the installation and subsequent removal of a radiological hut performed in the Warm Gang Valve Corridor. The use of primary containment features (e.g., glovebag), design of the hut, installation techniques, physical location, and proximity of self-alarming air monitoring equipment were all inadequate. Based on the air flow tests performed in the Warm Gang Valve Corridor as part of the Board's investigation, several localized anomalies existed in the general area air flow (due to supply headers, air conditioning systems, physical interference, etc.). The relevance of such information with respect to specifying the location and type of job site air monitoring equipment was not recognized by WSRC in planning the hut removal. As a result, the only self-alarming air monitoring equipment was located 300 feet from the job site.

The Board also found a job-specific RWP (96-FC-251) was referenced as governing the radiological requirements for removal of the Fireye Junction Box in the Warm Gang Valve Corridor. Several radiological surveys were performed and several pieces of respiratory protection equipment were issued listing this permit. However, this RWP was never formally issued by facility management.

The Board found a number of activities involving high radiological potential (for spread of contamination or intake by personnel) were generally characterized as "routine" by F-Canyon facility management and operating personnel. These activities included access to and operation of the cranes to support process evolutions or to perform maintenance; decontamination activities in work areas with high levels of transferable surface contamination; and repair or troubleshooting of equipment with high levels of transferable surface contamination. Work controls established for these activities frequently took the form of Standard Operating Procedures and standing RWPs in lieu of job-specific controls tailored to the hazards present. This resulted in a less than adequate safety envelope being established for the work.

The Board found a lack of surveillance and operational requirements for Old Warm Crane protective equipment. Coupled with the lack of clear radiological controls for entry and use of the Old Warm Crane Cab (posting as an Airborne Radioactivity Area, etc.), a less than adequate safety envelope existed for Old Warm Crane use.

The Board found primary containments were not used for a number of work situations where the combination of radiological and physical conditions warranted such use. The primary example was removal of the Fireye Junction Box in the Warm Gang Valve Corridor. The hut should have been the secondary means of confinement, not the primary. The WSRC Radiological Control manual (5Q) requires the use of primary containments, consistent with the DOE Radiological Control Manual and 10 CFR 835. WSRC failed to implement the use of engineered, soft-sided containments in accordance with established requirements.

Perform Work Safely Within Controls

Confirm Readiness:
The Board found numerous examples of inadequate job planning and preparedness to perform work. Problems existed in the adequacy of procedures, ALARA reviews, training (or experience) of personnel, radiological controls, lack of pre-job briefings, and clarity of expectations. The primary examples were the persistent decontamination efforts and hut removal in the Warm Gang Valve Corridor. The problems were not identified until after the work was performed, if at all. The problems reflect a weakness by WSRC management to confirm readiness prior to initiating work.

Consistent with the previous discussion, WSRC management failed to perform adequate work site pre-inspections and surveillances in order to determine the adequacy of preparatory actions. By not reviewing the job site, WSRC management failed to adequately characterize important radiological conditions. As a result, a hut was installed in the Warm Gang Valve Corridor without an adequate radiological survey, hut design, or installation procedure.

Perform Work Safely:

Through interviews with personnel involved in the hut removal work, the Board noted a consistent theme: none of the personnel could remember exactly when or what constituted the start of actual removal of the hut. No single person was assigned lead or primary responsibility for control of the work at the job site. As a result, the work was performed in an uncontrolled manner. The Board found examples of other work "routinely" performed in F-Canyon (e.g., decontamination activities in High Contamination Areas) without management presence where the potential existed for similar problems.

Through a review of facility records, the Board found numerous examples of personnel failure to verbatim comply with written procedures. Examples of these failures involved RWPs (failure to sign, incorrect entries); respirator issuance logs (failure to sign, referenced RWP inconsistent, etc.); jumper repair procedures (not completed). Fireye removal in Warm Gang Valve Corridor (non-existent RWP); leak check procedures (not completed); and the hut job (could not have been installed or removed in accordance with the procedures as written).

During the hut removal effort, facility personnel failed to properly post and control the radiological work site; failed to wear proper respiratory protection equipment (re-entry with full face respirators); failed to recognize abnormal radiological conditions and respond properly; and facility management failed to take nasal/saliva smears and bioassay samples after the second CAM alarm.

For routine use of the Old Warm Crane, facility management and personnel failed to check and maintain key equipment operable. This equipment included the ventilation system fan and the CAM.

As evidenced by the materials found atop the cell covers, personnel improperly handled and disposed of protective clothing and equipment.

Provide Feedback on the Adequacy of Controls and Continuous Improvement in Defining, Planning, and Performing Work

Collect Feedback Information:

The Board found WSRC failed to adequately implement an effective radiological deficiency report program. Problems regarding compliance with RWPs, control and use of respirators, and personnel performance errors (e.g., opening of the B-25 box by the CRANE OPERATOR, materials left on cell covers, hut removal) should have been documented via Radiological Deficiency Reports. Without documentation of such deficiencies, WSRC and DOE management have no measure of program effectiveness or performance. The lack of an effective Radiological Deficiency Report program was compounded by the failure of WSRC management to periodically review the performance of work and to inspect pre- and post-work conditions in the facility. Thus, a direct means of assessing the effectiveness of the radiological control program was not utilized.

Identify Improvement Opportunities:

The prolonged decontamination efforts in the Warm Gang Valve Corridor and the conditions associated with use of Old Warm Crane indicate a tendency by facility management to accept high levels of transferable surface contamination and airborne radioactivity as a "normal" work environment.

In reviewing the available documentation, the Board found problems in the level of detail and consistency in logs and turnover sheets. The problems existed to some degree in virtually all of the records reviewed, including the Shift Operation Manager's log, Crane log, Building Supervisor's log, and RCO's turnover checklists. The extent of the problems indicate inadequate reviews were performed by facility management. This includes daily review of shift logs and operational data, as well as periodic reviews required as part of the facility management's self-assessment program.

The Board noted several examples where unusual or abnormal radiological conditions existed within portions of the facility, but management failed to analyze the significance of the available data. The primary example was the continued ingress of high levels of transferable surface contamination in the

Warm Gang Valve Corridor. Management waited several months before attempting to isolate and stop the source of contamination or to use some form of containment. Other evidence of inadequate management analyses and follow up included periods of high airborne radioactivity in the canyon; calculation errors in determining airborne radioactivity levels, failures of protective equipment on the Old Warm Crane Cab; and the subsequent re-entry on the hut removal job.

Make Changes to Improve:
As discussed above, the Board found a general failure by facility management to improve on the use of primary radiological containments. Job hazard analyses have not been performed for all PERIPHERAL WORK activities perceived to be "routine" by facility management. Although facility management has plans to perform a Job Hazard Analysis for crane operator duties, it is unclear these plans extend to other duties crane operators are "routinely" assigned.

Oversight and Enforcement:
The Board reviewed signature sheets for Standing RWPs and respiratory protection equipment issuance logs for the period of interest to gauge the number of times WSRC and DOE management observed work or conditions within the facility. Due to the nature of the investigation (plutonium intake of a worker), the Board confined the record review to those occasions where management entered radiological controlled areas with high levels of transferable surface contamination or airborne radioactivity. Within the context defined above, the Board found senior WSRC management (shift operations manager or above) and DOE management (including the Facility Representatives) entered infrequently. These and other facts determined through the course of the investigation, indicate inadequate management surveillance of work activities

With respect to deficiencies noted during this investigation, the Board found few instances during the period under investigation where management had taken action to correct poor performance by personnel.

Summary

The Board determined that Integrated Safety Management was not properly implemented for PERIPHERAL WORK in F-Canyon radiological areas.

2.4 COMPILATION OF CAUSAL FACTORS

This compilation of causal factors is a result of commonalties identified with the four scenarios investigated by the Board (section 2.2 of this report). The following factors were determined to be common to most, if not all, of the scenarios:

- Failure to determine source of elevated contamination levels.
- Failure to adequately characterize work place radiological conditions.
- Failure to properly post and control radiological control boundaries.
- Improper use of respiratory protection equipment.
- Inadequate RWP Documentation.
- Inadequate job planning/work package preparation/pre-job briefs/ALARA review.
- Failure to ensure verbatim compliance with procedures.
- Inappropriate use of generic/reference procedures and reliance on skill of the craft to perform radiological work.
- Failure to provide, maintain and perform surveillance on equipment utilized to protect workers.
- Inadequate specification of who is in charge of job.
- Failure by management and supervision to perform adequate work site inspections and surveillances.

- Failure to perform adequate Job Hazard Analyses[2]
- Failure to provide adequate Radiological Engineering support of radiological work.
- Improper acceptance of high levels of surface contamination and airborne radioactivity as a "Normal" work environment.
- Inadequate management analyses of operating conditions.

The direct causal event remained indeterminate at the conclusion of the Board's analysis of the CRANE OPERATOR's activities. The Board identified two events associated with the CRANE OPERATOR's known activities for which the intake was plausible. These two events involved operation of the old warm crane on December 13, 1996 during a Na NO_3 addition to tank 11.8 and removal of a radiological hut in the Warm Gang Valve Corridor on December 21, 1996. The Board was unable, however, to determine the exact event which caused the CRANE OPERATOR's intake due to the fact the Board was only able to account for approximately 30 percent of the CRANE OPERATOR's activities for the period under investigation. In spite of this the Board concluded, based on known contamination levels, calculations, and commonality of problems identified in the four scenarios, that the direct cause, root cause, and contributing causes for the intake could be determined.

The direct cause for the CRANE OPERATOR's intake was determined to be the CRANE OPERATOR's failure to wear respiratory protection in a Airborne Radioactivity Area.

The root cause of the intake (the fundamental cause that, if eliminated or modified, would prevent recurrence of this and similar intakes) was determined to be a lack of discipline in fully implementing radiological controls and requirements for PERIPHERAL WORK in radiological areas.

The Board also determined there were three contributing causes (causes that increased the likelihood of the intake without individually causing the intake, and are important enough to be recognized as needing corrective action). The first contributing cause was determined to be lack of operations supervision and management oversight for PERIPHERAL WORK. Secondly, there was a lack of radiological controls supervision and management oversight for PERIPHERAL WORK. Third, there were inadequate management analyses of operational and radiological conditions associated with PERIPHERAL WORK.

[2] The Board determined that this issue had been previously identified by WSRC and that a corrective action plan was being implemented (WSRC memorandum, S.J. Howell to T.C. Robinson, dated April 1, 1997). Many of the applicable work activities analyzed during this investigation were scheduled to have JHAs accomplished later this year. The Board also noted, however, that a JHA had not been scheduled for Old Warm Crane operation.

3.0 CONCLUSIONS AND JUDGMENTS OF NEED

Conclusions are a synopsis of the facts and analytical results that the Board considered especially significant. Judgments of need are managerial controls and safety measures believed necessary to prevent or mitigate the probability or severity of a recurrence. They flow from the conclusions and causal factors and are directed at guiding managers in developing follow-up actions. The Board's conclusions and judgments of need are presented in Table 3-1.

Table 3-1 Conclusions and Judgments of Need

CONCLUSIONS	JUDGMENTS OF NEED (Each Identified Need is for WSRC Action)
WSRC failure to adequately implement radiological controls and requirements for PERIPHERAL WORK activities.	Improve implementation and enforcement of Radiological Conduct of Operations. Develop and implement a program which analyzes all facility activities for proper engineered radiological controls with reliance on engineered containments and ventilation systems. Improve enforcement of posting and control of radiological areas sections of the Radiological Control Manual.
WSRC failure to provide an adequate level of operations supervision and management oversight for PERIPHERAL WORK.	Increase involvement, surveillance and performance based assessments of PERIPHERAL WORK by operations supervision and management. Improve enforcement of Conduct of Operations. Improve enforcement of procedural compliance requirements of Conduct of Operations. Improve operating procedures to reflect specific facility operations and evaluate minimizing reference procedures. Ensure that a person has been designated to be in charge for all work activities. Analyze operations of the Old Warm Crane and improve the reliable operability of associated protective equipment, if the crane is to be used.
WSRC failure to provide an adequate level of radiological controls supervision and management oversight for PERIPHERAL WORK activities.	Evaluate all accessible canyon areas for potential reduction of contamination/radiation levels. Increase involvement, surveillance, and performance based assessment of PERIPHERAL WORK by radiological supervision and management.
WSRC failure to provide adequate management analyses of operational and radiological conditions associated with PERIPHERAL WORK activities.	Improve implementation of the Integrated Safety Management System by including PERIPHERAL WORK. Improve management and supervisory review and analysis of operational and radiological conditions for PERIPHERAL WORK (including procedures, logs, records, checklists and radiological surveys).

4.0 BOARD SIGNATURES

Frank R. McCoy III, Board Chairperson
U.S. Department of Energy
Savannah River Operations Office

Date: 7/7/97

R. T. Brock, Board Member
U.S. Department of Energy
Savannah River Operations Office

Date: 7/7/97

Richard L. Huskin, Board Member
U.S. Department of Energy
Savannah River Operations Office

Date: 7/7/97

Mark A. Smith, Board Member
U.S. Department of Energy
Savannah River Operations Office

Date: 7/7/97

T. Zack Smith, Board Member
U.S. Department of Energy
Savannah River Operations Office

Date: 7/7/97

Larry W. White, Board Member
DOE Accident Investigator
U.S. Department of Energy
Savannah River Operations Office

Date: 7/7/97

5.0 BOARD MEMBERS, ADVISORS, AND STAFF

Chairperson	Frank R. McCoy, III, DOE Savannah River
Member	R. T. Brock, DOE Savannah River
Member	Richard L. Huskin, DOE Savannah River
Member	Mark A. Smith, DOE Savannah River
Member	T. Zack Smith, DOE Savannah River
Member	Larry W. White, DOE Savannah River
Advisor	Michael J. Blackwood, WSRC
Advisor	Kevin J. Collins, WSRC
Advisor	Janis Gatlin, WSRC
Advisor	Jack H. Riley, Coopers & Lybrand LLP
Advisor	Ronald L. Kathren, Washington State University
Technical Writer	Lauren McDermott, DOE Savannah River
Report Publisher	John Strack, WSRC
Administrative Support	Judy Hicks, DOE Savannah River
	Lynda Autry, DOE Savannah River

APPENDIX A

TYPE B
ACCIDENT INVESTIGATION BOARD
APPOINTMENT MEMORANDUM

DOE F 1325.8 (8-89)

United States Government

Department of Energy (DOE)

Savannah River Operations Office (SR)

memorandum

DATE: MAY 0 1 1997

REPLY TO ATTN OF: NMSD (D. J. Dearolph, 952-4478)

SUBJECT: Type B Accident Investigation Board

TO: Frank R. McCoy, Assistant Manager for High Level Waste
Richard L. Huskin, Radiation Protection Division, AMHS&TS
Mark A. Smith, Operational Programs Office, AMHS&TS
R. T. Brock, Engineering and Analysis Division, AMHS&TS
Larry W. White, Operations Division, AMHLW
T. Zack Smith, Operations Division, AMHLW

I hereby establish a Type B Accident Investigation Board to investigate the circumstances related to the personal assimilation event which occurred at the F-Canyon and was reported on April 29, 1997. I have determined it meets the requirements established for a Type B accident investigation in DOE Order 225.1, "Accident Investigations," dated April 26, 1996.

I appoint Frank McCoy as the accident board chairperson. The board members will be Richard L. Huskin, Mark A. Smith, Larry White, T. Zack Smith and R. T. Brock. The board will be assisted by advisors and consultants and other support personnel as determined by the chairperson.

The scope of the board's investigation will include, but is not limited to: identifying all relevant facts; analyzing the facts to determine the direct, contributing, and root causes of the accident; developing conclusions; and determining the judgments of need that, when implemented, should prevent the recurrence of the accident. The investigation will be conducted in accordance with DOE Order 225.1 and will specifically address the role of DOE and contractor organizations and management systems as they may have contributed to the accident. The scope will also include an analysis and evaluation of the radiological practices and controls used to provide personnel protection and the application of lessons learned from similar accidents within the Department.

The board will provide my office with periodic reports on the status of the investigation but will not include any conclusions until an analysis of all the causal factors has been completed. Draft copies of the factual portion of the investigation report will be submitted to the Assistant Manager for Nuclear Material and Facility Stabilization and the Vice President for Nuclear Materials Stabilization and Storage for a factual accuracy review prior to issuance of the final report.

The report should be provided to me within 30 days from the date of this memorandum. Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

Please contact me if you or your staff have any questions.

Mario P. Fiori
Manager

NMSD:DJD:cc

APPENDIX B

TYPE B
ACCIDENT INVESTIGATION BOARD
EXTENSION MEMORANDUM

DOE F 1325 8

United States Government | Department of Energy (DOE)

memorandum

Savannah River Operations Office (SR)

DATE: May 30, 1997

REPLY TO ATTN OF: Type B Accident Investigation Board Chairperson (F.R. McCoy, (803) 952-2518)

SUBJECT: Extension of F-Canyon Type B Accident Investigation Schedule

TO: Mario P. Fiori, Manager

Your memorandum, dated May 1, 1997, established the Type B Accident Investigation Board and requested that the investigation report be provided to you within 30 days from the date of the memorandum. I am requesting that the activities of the Accident Investigation Board be extended to June 20, 1997, based on the following facts.

The Type B Accident Investigation Board has been required to review and analyze, more than three months after the fact, an indeterminate event(s) that occurred at some point over an unusually large time frame (August 1996 - February 1997) and resulted in an F-Canyon crane operator's assimilation. This is not typical of most accident investigations in which an investigation is able to begin within days of the accident. The Board's investigation has also experienced difficulties due to incomplete data and record retention problems. These conditions have caused the Board to take longer to identify all the relevant facts.

To date, the Board has not been able to positively identify the exact causal event(s) for the assimilation. The Board has, however, identified four (4) separate sequence of events with high potential for this assimilation. The Board is now in the process of further analysis of these scenarios to fully characterize them. The Board's activities next week will also include accident analysis, events and causal factor analysis, performance of root cause analysis, and identification of direct and contributing causes. Initial preparation of the report should also begin late next week. After completing the accident analysis activities, the Board will determine its conclusions and develop judgments of needs for inclusion into the report. I currently expect to submit our report for your review by June 20, 1997.

Questions from you or your staff may be directed to me at (803) 952-2518.

Frank R. McCoy, III, Chairperson
DOE Type B Accident Investigation

AMHLW:MAS:joh

cc: A. Alm (EM-1), HQ
T. O'Toole (EH-1), HQ
J. Ford (EM-63), HQ
D. Huizenga, (EM-60), HQ
D. Vernon (EH-21), HQ

APPENDIX C

CALCULATIONS SUPPORTING SCENARIOS WITH POTENTIAL FOR HIGH INTAKE

1.0 Calculations Supporting "Cell Cover -To -Crane Cab" Scenario

Calculation is based on a scenario that a worker splashed himself with process liquid while regasketing a Jumper on cell covers. The liquid evaporated leaving high levels of alpha contamination on the sleeve of the worker's outer coveralls. The worker entered the Old Warm Crane Cab and removed his Full-Face Respirator. As the worker performed his duties in the crane cab, the contamination dried. The worker's arm motions caused the contamination to go airborne. The worker inhaled the resuspended material. The resuspension and intake fractions were intentionally chosen to be very high to test the limits of the scenario.

(Calculating CEDE from estimated Intake in Old Warm Crane Cab)

Assumptions:

Radioisotope = **Pu^{239}**
Volume of Process Liquid Spilled = **5 ml**
Specific Activity of Pu^{239} in Process Liquid = **1×10^6 dpm/ml**
Resuspension Fraction = **0.01**
Fraction of Airborne Pu^{239} Inhaled = **1.0**
Conversion Factor for dpm to nCi = **4.5×10^{-4} nCi/dpm**
Assumed uniform activity distribution

Total Activity on Coveralls = (Volume of Sample) * (Specific Activity) * (Conversion Factor for dpm to nCi)

= **(5 ml) * (1×10^6 dpm/ml) * (4.5×10^{-4} nCi/dpm)**

= 2.25×10^3 nCi

Total Activity Released to Air = (Activity on Coveralls) * (RF)

= **(2.25×10^3 nCi) * (0.01)**

= 22.5 nCi

Intake = (Activity Released to Air) * (Fraction of Airborne Pu^{239} Inhaled) *

= (22.5 nCi) * (1.0)

Intake = 22.5 nCi of Pu^{239}

Estimated CEDE = **(Intake) * (CF of Intake to CEDE)**

= **(22.5 nCi) * (0.420 rem/nCi)**

Estimated CEDE = 9.5 rem

2.0 Calculation Supporting Old Warm Crane Cab Scenarios

2.1 Contamination in Crane Cab Scenario

Calculation is based on a scenario that a worker contaminated his coveralls while handling contaminated equipment. The worker entered the Old Warm Crane Cab and removed his Full-Face Respirator. The worker performed his duties in the crane cab and his movements caused the contamination to go airborne. The worker inhaled the resuspended material.

(Calculating CEDE from estimated Intake expressed in nanocuries)

Assumptions:

Radioisotope = **Pu^{239}**
Levels of Transferable Contamination on Coveralls = **1×10^6 dpm/100 cm^2**
Size of Contaminated Area on Coveralls = **2 ft^2**
Resuspension Fraction = **0.01**
Estimated Free Volume of Crane Cab = **640 ft^3 (8' x 8' x 10')**
Breathing Rate of Standard Man = **1.25×10^6 cm^3/hr.**
Duration of Exposure = **4 hours**
Assumed uniform activity distribution

Conversion Factors:

DAC Value for Pu^{239} = **2×10^{-12} μCi/cm^3**
Conversion Factor (CF) for dpm to μCi = **4.5×10^{-7} μCi/dpm**
CF for ft^3 to cm^3 = **2.8×10^4 cm^3/ft^3**
CF for ft^2 to cm^2 = **929 cm^2/ft^2**
CF for μCi to nCi = **10^3 nCi/μCi**
CF for nCi Intake to rem CEDE = **0.420 rem/nCi**

Total Activity on Coveralls = (Contamination Levels) * (Area) * (CF, ft^2 to cm^2)

= **(1×10^6 dpm/100 cm^2) * (2 ft^2) * (929 cm^2/ ft^2)**

= 1.86×10^7 dpm

Airborne Activity in Cab = (Total Activity on coveralls) * (CF, dpm to μCi) * (RF) * (Volume of Cab)$^{-1}$ * (CF, ft^3 to cm^3)$^{-1}$

= **(1.86×10^7 dpm) * (4.5×10^{-7} μCi/dpm) * (0.01) * (640 ft^3)$^{-1}$ * (2.8×10^4 cm^3/ft^3)$^{-1}$**

= 4.67×10^{-9} μCi/ cm^3

Intake = (Airborne Activity in Cab) * (CF, μCi to nCi) * (Time Exposed) * (Breathing Rate of Standard Man)

= **(4.67×10^{-9} μCi/ cm^3) * (10^3 nCi/μCi) * (4 hrs) * (1.25×10^6 cm^3/hr.)**

= 23.4 nCi

Estimated CEDE = (Intake) * (CF, Intake to CEDE)

= **(23.4 nCi) * (0.420 rem/nCi)**

Estimated CEDE = 9.8 rem

2.2 Canyon Event Scenario

Calculation is based on a scenario that an event in the process area of the Warm Canyon releases sufficient radioactive material to expose a worker in the Old Warm Canyon Crane Cab to significant quantities of material. The source term is based on the measured radioactivity on filter paper samples taken from the unfiltered canyon air exhaust stream for the period December 12-16, 1996 (425 µCi) and is assumed to be approximately one-half that amount (200 µCi). The cab ventilation system is inoperable (Dravo fan found out of service on January 8, 1997). The motors for the air sampler and constant air monitor (CAM) within the cab are operable. The CAM does not alarm. The worker is without respiratory protection in the crane cab. The worker is exposed to a high airborne radioactivity environment for ten (10) minutes.

(Calculating CEDE from estimated Intake expressed in nanocuries)

Assumptions:

Radioisotope = **Pu^{239}**
Activity Released = **200 µCi**
Estimated Volume of Contaminated Cloud = **3,000 ft^3 (30'H x 10'W x 10'L)**
Breathing Rate of Standard Man = **1.25×10^6 cm^3/hr.**
Duration of Exposure = **0.16 hr**
Intake Rate of Air Sampler in Crane Cab = **4 cfm**
Intake Rate of Continuous Air Monitor in Crane Cab = **40 cfm**
Estimated Free Volume of Crane Cab = **640 ft^3 (8' x 8' x 10')**
Assumed uniform activity distribution

Conversion Factors:

CF for ft^3 to cm^3 = **2.8×10^4 cm^3/ft^3**
CF for µCi to nCi = **10^3 nCi/µCi**
CF for nCi Intake to rem CEDE = **0.420 rem/nCi**

Initial Airborne Activity (Over Cell) = (Activity Released) * (Volume of Contaminated Cloud)$^{-1}$ * (CF for ft^3 to cm^3)$^{-1}$

$$= (200\ \mu Ci) * (3{,}000\ ft^3)^{-1} * (2.8 \times 10^4\ cm^3/ft^3)^{-1}$$

$$\boxed{= 2.4 \times 10^{-6}\ \mu Ci/cm^3}$$

Air exchange constant for crane cab = [(Intake rate of air sampler) + (Intake rate of CAM)] * (Volume of Crane Cab)$^{-1}$

$$= [(4\ ft^3/min) + (40\ ft^3/min)] * (640\ ft^3)^{-1}$$

$$\boxed{= 0.069\ /min}$$

Initial airborne activity in cab (after 1 minute) = Rate of air exchange $(1 - e^{-\lambda t})$ * (initial airborne activity over cell)

$$= (1 - e^{-0.069/min \times 1\ min}) * 2.4 \times 10^{-6}\ \mu Ci/cm^3$$

$$\boxed{= 1.6 \times 10^{-7}\ \mu Ci/cm^3}$$

Residual airborne activity in cab (after 10 minutes) = Rate of air exchange $(1 - e^{-\lambda t})$ * (initial airborne activity in cab)

$$= (e^{-0.069/min \times 9\ min}) * (1.6 \times 10^{-7}\ \mu Ci/cm^3)$$

$= 8.6 \times 10^{-8}$ µCi/cm^3

Intake (1st minute) = (Airborne Activity) * (CF, µCi to nCi) * (Time Exposed) * (Standard Breathing Rate)

= $(1.6 \times 10^{-7}$ µCi/ cm^3) * (10^3 nCi/µCi) * (0.017 Hr) * (1.25×10^6 cm^3/Hr.)

= 3 nCi

Intake (next 9 minutes) = (Airborne Activity) * (CF, µCi to nCi) * (Time Exposed) * (Standard Breathing Rate)

= $(8.6 \times 10^{-8}$ µCi/ cm^3) * (10^3 nCi/µCi) * (0.153 Hr) * (1.25×10^6 cm^3/Hr.)

= 16 nCi

Estimated CEDE = (Intake) * (CF of Intake to CEDE)

= (19 nCi) * (0.420 rem/nCi)

Estimated CEDE = 8 rem

*Note:
Radioactivity collected on air sampler filter paper = [Initial radioactivity * sample time * sample rate] + [Residual radioactivity * sample time * sample rate]

= [1.6×10^{-7} µCi/cm^3 * 1 min * 4 ft^3/min * 2.8×10^4 cm^3/ft^3] + [8.6×10^{-8} µCi/cm^3 * 9 min * 4 ft^3/min * 2.8×10^4 cm^3/ft^3]

= 0.105 µCi

= 0.105 µCi * 2.22×10^6 dpm/µCi

= 233,100 dpm

This correlates well with the amount of radioactivity measured on the filter paper for the period December 5, 1996 through February 10, 1997. When removed on February 10, 1997, the contamination levels of the filter paper measured 200,000 dpm (alpha).

3.0 Calculation Supporting The Warm Gang Valve Corridor Decontamination Activities Scenario

Calculation is based on a scenario that as a worker performed decontamination activities in the Warm Gang Valve Corridor without a respirator. A sufficient quantity of radioactive material was caused to go airborne by the worker's actions.

(Calculating CEDE from estimated Intake expressed in nanocuries)

Assumptions:

Radioisotope = **Pu^{239}**
Area of decon wipes = **2 ft^2**
Alpha contamination levels on components = **200,000 dpm/100 cm^2**
Resuspension Fraction = **0.01**
Estimated Volume of Air Contaminated = **1 m^3 (1 x 10^6 cm^3)**
Duration of Exposure = **0.3 Hours**
Assumed uniform activity distribution

Conversion Factors:

DAC Value for Pu^{239} = **2 x 10^{-12} μCi/cm^3**
Conversion Factor (CF) for dpm to μCi = **4.5 x 10^{-7} μCi/dpm**
CF for ft^3 to cm^3 = **2.8 x 10^4 cm^3/ft^3**
CF for ft^2 to cm^2 = **929 cm^2/ft^2**
CF for μCi to nCi = **10^3 nCi/μCi**
CF for nCi Intake to rem CEDE = **0.420 rem/nCi**

Total Activity on Decon Materials = (Contamination Levels) * (CF, dpm to μCi) * (Area of Decon Wipes) * (Number of Wipes) * (CF for ft^2 to cm^2)

= **(2 x 10^5 dpm/100 cm^2) * (4.5 x 10^{-7} μCi/dpm) * (2 ft^2) * (10) * (929 cm^2/ft^2)**

= 16.7 μCi

Total Activity Released to Air = (Total Activity on Decon Materials) * (RF)

= **(16.7 μCi) * (0.01)**

= 0.17 μCi

Airborne Activity = (Activity Released) * (Volume of Air Contaminated)$^{-1}$

= **(0.17 μCi) * (1 x 10^6 cm^3)$^{-1}$**

= 1.7 x 10^{-7} μCi/ cm^3

Intake = (Airborne Activity) * (CF, mCi to nCi) * (Time Exposed) * (Standard Breathing Rate)

= **(1.7 x 10^{-7} μCi/ cm^3) * (10^3 nCi/μCi) * (0.3 Hrs) * (1.25 x 10^6 cm^3/Hr.)**

Intake = 63.8 nCi

Estimated CEDE = (Intake) * (CF of Intake to CEDE)

= **(63.8 nCi) * (0.420 rem/nCi)**

Estimated CEDE = 26.8 rem

4.0 Calculation Supporting the Hut Removal Scenario (Section 2.2.4)

Calculation is based on a scenario that as a worker passes a plastic contamination containment structure, another worker pulls the plastic sheeting from a wall causing significant quantity of radioactive material to go airborne. The first worker is not wearing a respirator and is momentarily engulfed by a cloud of radioactive material.

(Calculating CEDE from estimated Intake expressed in nanocuries)

Assumptions:

Radioisotope = **Pu^{239}**
Area of plastic sheeting = **5 m^2 (5 x 10^4 cm^2)**
Alpha contamination levels on plastic sheeting = **200,000 dpm/100 cm^2**
Resuspension Fraction = **0.01**
Estimated Volume of Air Contaminated = **2 m^3 (2 x 10^6 cm^3)**
Duration of Exposure = **1.5 minutes (0.025 Hrs)**
Assumed uniform activity distribution

Conversion Factors:

DAC Value for Pu^{239} = **2 x 10^{-12} μCi/cm^3**
Conversion Factor (CF) for dpm to μCi = **4.5 x 10^{-7} μCi/dpm**
CF for ft^3 to cm^3 = **2.8 x 10^4 cm^3/ft^3**
CF for cm^2 to ft^2 = **929 cm^2/ft^2**
CF for μCi to nCi = **10^3 nCi/μCi**
CF for nCi Intake to rem CEDE = **0.420 rem/nCi**

Total Activity on Plastic = (Contamination Levels) * (Area) * (CF, dpm to μCi)

= **(2 x 10^5 dpm/100 cm^2) * (5 x 10^4 cm^2) * (4.5 x 10^{-7} μCi/dpm)**

= 45 μCi

Total Activity Released to Air = (Total Activity on Plastic) * (RF)

= **(45 μCi) * (0.01)**

= 0.45 μCi

Airborne Activity = (Activity Released) * (Volume of Air Contaminated)$^{-1}$

= **(0.45 μCi) * (2 x 10^6 cm^3)$^{-1}$**

= 2.3 x 10^{-7} μCi/ cm^3

Intake = (Airborne Activity) * (CF, μCi to nCi) * (Time Exposed) * (Standard Breathing Rate)

= **(2.3 x 10^{-7} μCi/ cm^3) * (10^3 nCi/μCi) * (0.025 Hrs) * (1.25 x 10^6 cm^3/Hr.)**

= 7.2 nCi

Estimated CEDE = (Intake) * (CF of Intake to CEDE)

= **(7.2 nCi) * (0.420 rem/nCi)**

Estimated CEDE = 3.0 rem

APPENDIX D

Relationship of Improper Work Activities Reported on May 22, 1997, to the Investigation

On May 13, 1997, while performing a walkdown of the Old Warm Canyon, the Board discovered tools and protective clothing on top of the section 18 cell covers, section 18 stairwell landing, section 18 platform, and the maintenance bridge in the Warm Canyon. Because of the worker safety implications of these discoveries, WSRC management was notified. Subsequently, WSRC management conducted work site investigations and extensive interviews of facility personnel to determine when, how, and why the tools and protective clothing were located there. Although none of the personnel interviewed substantiated improper work on the warm canyon section 18 cell covers, platform or maintenance bridge, one employee alleged instances of improper actions which were substantiated and which involved, in part, the F-Canyon Operation and Operations Support Managers and one Operations Supervisor. The following three alleged concerns were determined by WSRC to be valid issues:

- Improper documentation by a supervisor of procedure prerequisites with the knowledge of his immediate acting manager.
- Failure to properly complete a procedure valving evolution by the same supervisor and subsequent discarding of the original procedure.
- Failure of a second manager to obtain required engineering approvals of a temporary modification.

The WSRC investigative team determined these instances where management acted outside of established policies and procedures were limited to three individuals who, upon identification, were removed from their positions. One individual resigned and two were subsequently fired.

The Board determined the events described above did not involve the CRANE OPERATOR's intake because he was not identified with these activities. The first two occurred after the CRANE OPERATOR had submitted his bioassay in February 1997 and had been restricted from entering any radiological areas. The third event involved a supervisor and a different crane operator. The Board's determination was confirmed by the review of the official WSRC interview transcripts and the timeline.