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FEPS Analysis for the West Valley Site

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Prepared by

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ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
CFR	Code of Federal Regulations
CLSM	controlled low-strength material
CSM	conceptual site model
DOE	(United States) Department of Energy
EIS	Environmental Impact Statement
EPA	(United States) Environmental Protection Agency
FEIS	Final Environmental Impact Statement
FEP	features, events, and processes
FEPS	features, events, processes, and scenarios
HLW	high-level radioactive waste
IAEA	International Atomic Energy Agency
IC	institutional control
LANL	Los Alamos National Laboratory
LLW	low-level radioactive waste
LTR	License Termination Rule
MLLW	mixed hazardous and low-level radioactive waste
MPPB	Main Plant Process Building
NDA	(United States) Nuclear Regulatory Commission-licensed Disposal Area
NEPA	National Environmental Policy Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NFS	Nuclear Fuel Services
NPR	New Production Reactor
NRC	(United States) Nuclear Regulatory Commission
NYCRR	New York Codes Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
NYSERDA	New York State Energy Research and Development Authority
PA	performance assessment
PAWG	Performance Assessment Working Group
PPA	probabilistic performance assessment
RCRA	Resource Conservation and Recovery Act
RH	remote-handled (radioactive waste)
ROI	region of interest
SDA	(New York) State-licensed Disposal Area
SEIS	Supplemental Environmental Impact Statement
Site	WVDP and WNYNSC
SNI	Seneca Nation of Indians
SNL	Sandia National Laboratories
TED	total effective dose
TRU	transuranic waste
UNF	used nuclear fuel
USDA	United States Department of Agriculture
WIPP	Waste Isolation Pilot Plant
WIR	waste incidental to reprocessing
WNYNSC	Western New York Nuclear Service Center

WTF	Waste Tank Farm
WVDP	West Valley Demonstration Project

1.0 Introduction

The New York State Energy Research and Development Authority (NYSERDA) is the owner of the Western New York Nuclear Service Center (WNYNSC), a 1,351-ha (3,338-ac) site located approximately 48 km (30 mi) south of Buffalo, New York. The WNYNSC was established in 1961 as the site of a commercial spent nuclear fuel reprocessing and radioactive waste disposal facility. Nuclear Fuel Services, Inc. (NFS) built and operated the spent fuel reprocessing plant and waste disposal facilities, processing 640 Mg (metric tons, or 705 short tons) of spent nuclear fuel from 1966 to 1972 under an Atomic Energy Commission license. Nuclear fuel reprocessing operations ended in 1972 and never reopened, leaving behind radioactive and chemical wastes.

The NFS reprocessing operations and subsequent plant remediation activities generated radioactive and hazardous chemical wastes. Liquid radioactive waste generated during fuel reprocessing was transferred to tanks 8D-2 and 8D-4 in the Waste Tank Farm. Solid radioactive reprocessing waste was disposed in what is now known as the Nuclear Regulatory Commission (NRC)-Licensed Disposal Area (NDA). Radioactive wastes generated by WVDP decontamination and decommissioning activities were disposed in the NDA between 1982 and 1986. Radioactive and chemical wastes were also disposed in the State-Licensed Disposal Area (SDA) from 1963 until 1975. As a regional disposal facility, the SDA received waste from off-site locations, as well as waste generated by the NFS nuclear fuel reprocessing operations.

Much of the radioactive and hazardous chemical contamination at the West Valley Site (consisting of the WVDP and WNYNSC) is not the result of intentional disposal, but is the result of spills and releases during operations. These include the following:

- An on-site surface contamination area along the Rail Spur and other areas of surface contamination.
- A plume of contaminants migrating in North Plateau groundwater.
- An off-site release of cesium-137 (^{137}Cs) known as the "Cesium Prong."
- Stream sediments contaminated as a result of past discharges during operations.

While these are not technically disposed wastes, they are *de facto* wastes, in that they are sources of contamination that will contribute to future risks to people and the environment.

While some facilities and wastes at the Site have been clearly identified for removal during Phase 1 decommissioning, Phase 2 decommissioning decisions need to be made for those facilities remaining at the WNYNSC after the completion of Phase 1 decommissioning. The National Environmental Policy Act (NEPA) provides the overarching process for decision making. Key to this process is the development of a site-specific Environmental Impact Statement (EIS), in which alternatives are evaluated in the context of environmental, social, and economic objectives. A Final EIS (FEIS) was prepared for the Site in 2010 (DOE 2010a, 2010b, 2010c). A Supplemental Environmental Impact Statement (SEIS) will be prepared to support Phase 2 decision making for those facilities remaining at the Site following Phase 1 decommissioning. One important tool that is needed in order to inform the decision making process is a detailed computational model of the Site that will evaluate potential future consequences for human health and ecological receptors (i.e., plants and animals that may be at risk from Site releases).

Neptune and Company, Inc. (Neptune) has been contracted to develop a Probabilistic Performance Assessment (PPA) Model for the Site in order to provide support for Phase 2 decision making in the context of uncertainty. The goal is to model the present and future Site in a manner that is as transparent, defensible, and robust as possible. This West Valley PPA Model is intended to evaluate the long-term "performance" of the Site, in which contamination from past operations that is being transported into the environment is assessed, along with potential adverse consequences for human and ecological health. The West Valley PPA Model will be able to evaluate the effectiveness of potential remedial actions, including different strategies for contaminant removal, in terms of future consequences. Uncertainty will be assessed for the following, to the degree possible:

- The current state of knowledge regarding the nature and amounts of the wastes.
- The features, events, processes, and scenarios (FEPS) that govern fate and transport of contaminants and exposure of humans and ecological receptors to these contaminants.
- The risks associated with exposures to radioactive and chemical contamination.
- How these risks may be modified by different remediation/management alternatives.

The focus of this report is the evaluation of the FEPS that are important and relevant for the Site.

The West Valley PPA Model will provide additional information to regulators and the public, beyond that of the FEIS and associated assessments, in order to inform the SEIS that will be used to make informed and defensible decisions at the Site. The basic decision context involves whether particular waste forms and contaminated media should remain or be stored at the Site, or transported and disposed elsewhere (e.g., disposal facilities in the US West). An initial step carefully defines FEPS that can influence future radiation and chemical risks to humans and the ecological receptors. The FEPS process then assists in developing the detailed site-specific Conceptual Site Model (CSM), which represents potentially important mechanisms and processes by which human and ecological receptors will experience risks associated with wastes over long periods of time (e.g., thousands of years after closure). The CSM in turn is the foundation for the development of the quantitative West Valley PPA Model, which will provide estimates of potential future risks under different exposure scenarios and remediation alternatives.

The present FEPS and CSM are focused strictly on the West Valley PPA Model. Any other analyses (e.g., costs, transportation risks, etc.) that are needed to support the SEIS will involve a similar process. Note that the terms "repository" and "disposal facility" are employed throughout this document, as the FEPS and CSM procedures have been developed for facilities that are designed for radioactive waste disposal. There are various options for remediation of the Site, including in-place closure and removal of some or all chemical and radioactive wastes. Regardless, any retained FEPS that apply to a "repository" or "disposal facility" are assumed to also apply to the Site. Any exceptions are noted.

2.0 Regulatory Considerations, Guidance, and Supporting Information

2.1 Overall Context

The regulatory context for the Site is described in detail in the *Conceptual Site Model for the West Valley Site* report (Neptune 2016). Applicable regulations and guidance are reviewed in this section in order to specify the appropriate boundaries for identifying and screening FEPS. These include the metrics by which the performance of the Site is to be measured, the spatial and temporal constraints for computer modeling, and the modeling domain within the overall decision-making landscape for the fate of wastes currently stored or disposed at the Site.

The Site has different characteristics and a different regulatory structure from that of typical radioactive waste disposal facilities. A complex overlay of regulatory responsibilities and jurisdictions must be addressed, due to its history as a commercial/government venture and its range of waste types. These include high-level radioactive waste (HLW), waste incidental to reprocessing (WIR), a wide variety of low-level radioactive wastes (LLW) including mixed hazardous and LLW (MLLW), nonradioactive chemical hazardous waste, transuranic waste (TRU), and used nuclear fuel (UNF, also known as spent nuclear fuel).

In 1980, the US Congress passed the WVDP Act as Public Law 96-368 (United States Code 1980), directing DOE to conduct a demonstration project for solidification of HLW at the Site. The WVDP Act also directed DOE to transport the solidified HLW as soon as feasible to an appropriate Federal repository for disposal; to dispose of LLW and TRU that is produced in the process of solidifying HLW; and to decontaminate and decommission the tanks, facilities, material, and hardware used in the solidification of the HLW.

DOE is the lead Federal agency for decision making under the WVDP Act. NYSERDA shares in this role, and it monitors and maintains the SDA and other areas of the WNYNSC not being used by DOE for its WVDP activities. The NRC is charged with developing decommissioning criteria for the NRC-licensed portions of the West Valley Site, and it has responsibility under the WVDP Act for review and consultation with DOE and the State, and for monitoring activities.

A formal evaluation of environmental considerations is required by NEPA, because the WVDP is a proposed Federal action with appreciable potential impacts. In order to consider the consequences of the proposed action(s), DOE and NYSERDA developed the FEIS (DOE 2010a, 2010b, 2010c). The alternatives presented in the FEIS developed by DOE and NYSERDA were being evaluated by the NRC, the US Environmental Protection Agency (EPA), the New York State Department of Environmental Conservation (NYSDEC), and the New York State Department of Health (NYSDOH). EPA also has responsibility for radiation protection standards under 40 CFR 191 (CFR 1985, 1993) and radioactive air emissions monitoring and regulation under the National Emissions Standards for Hazardous Air Pollutants (NESHAPS) (40 CFR 61.93, Subparts H and Q) (CFR 2014a).

In addition to radioactive wastes, there are also hazardous nonradioactive chemicals and MLLW that are being managed in accordance with EPA's Resource Conservation and Recovery Act (RCRA) Subtitle C Hazardous Waste Management Program (40 CFR 260–279, CFR (2014b)) and the State's equivalent (Part 373/RCRA regulations: 6 NYCRR 370–374 and 376, Westlaw (2016)).

2.2 Summary of Regulatory and Temporal Scope Issues

The overarching regulatory framework for the West Valley PPA Model is the NRC *Final Policy Statement* (NRC 2002). In this, the NRC announced its decision to apply its *License Termination Rule* (LTR) (10 CFR 20, Subpart E) (CFR 2014c) as the decommissioning goal for the entire NRC-licensed site. In addition, the NRC *Final Policy Statement* provided specific criteria for classification of Waste Incidental to Reprocessing (WIR) that might be present after decommissioning activities. While the NRC does not have regulatory authority over the SDA, NYSERDA has agreed to apply the LTR criteria described by NRC (2002) for evaluating the SDA (http://www.nrc.gov/reading-rm/doc-collections/commission/policy/67fr5003.html).

The following criteria therefore generally apply at the Site:

- Annual total effective dose (TED) to the average member of the critical group does not exceed 25 mrem and is as low as reasonably achievable (ALARA) for unrestricted use.
- Annual TED to the average member of the critical group does not exceed 25 mrem and ALARA, for restricted use, with institutional control (IC) in place.
- Annual TED to the average member of the critical group does not exceed either 100 or 500 mrem and is ALARA, assuming IC fails.
- When calculating TED to the average member of the critical group the "licensee shall determine the peak annual TED expected within the first 1000 years after decommissioning."
- Peak dose should be calculated to determine whether this might occur after 1000 years, with the intent of defining the consequences and impacts on potential long-term management of residual radioactivity at the Site.

An additional (i.e., not part of the LTR criterion) applies:

- Evaluation of net public and environmental harm, as required by DOE Order 458.1, *Radiation Protection of the Public and the Environment* (DOE 2011).

There are numerous other potential criteria, described in the *Conceptual Site Model for the West Valley Site* report (Neptune 2016), that may apply, but the criteria above provide general guidance for the FEPS screening process. DOE and NYSERDA have directed that the West Valley PPA Model's time frame begin in 2020, which is the expected decision date by DOE and NYSERDA for a Phase 2 decommissioning decision for those facilities remaining at the WVDP and WNYNSC following the completion of Phase 1 decommissioning. This will require estimates of the nature and extent of residual contamination as of 2020. They have also indicated that potential operational worker and public exposures and doses prior to this date are out of the Model's scope, but that potential operational worker and public doses after this date (as part of Phase 2 decommissioning) are within the Model's scope. The radionuclide and chemical toxicant inventories present at the end of Phase 1 decommissioning are to be evaluated for the entire performance period. Vitrified wastes are not to be evaluated, as they are slated for removal and disposal in a geologic repository. Alternative strategies to be evaluated include site-wide removal of wastes, a closure with all wastes in place, partial removal of wastes, and "no-action" for those

facilities and wastes remaining following the completion of Phase 1 decommissioning. DOE and NYSERDA have also defined the following scope issues for the West Valley PPA Model:

- An 80-km (50-mi) radius around the Site, in the context of land uses and the "region of interest" (ROI), is applicable, consistent with the FEIS. While such a radius was largely intended to reflect potential air emissions (under NEPA, in the context of EISs), issues distant from the Site such as municipal drinking water intakes from Lake Erie are also potentially important. Therefore, the relevance of this particular radius to the West Valley PPA will be evaluated during model development.
- Evaluation of both human and ecological (aquatic and terrestrial animals and plants) risks will be determined, consistent with DOE O 458.1 (DOE 2011).

2.3 Environmental Setting and Inventory

2.3.1 Introduction

Consideration of the environmental setting characteristics of the waste disposal and storage areas, and radiological and chemical inventory of the Site, are important for identifying and screening FEPS.

2.3.2 Setting and Land Use

The Site is located in the formerly glaciated Allegheny Plateau region of the Appalachian Plateau physiographic province in western New York State. To the north and west this province is bounded by the Central Lowland province along the shores of Lake Erie and Lake Ontario. The Allegheny Plateau is characterized by rolling hills, wide valleys, and low mountains. The terrain of the region has been smoothed by continental glaciers resulting in rounded hilltops and broad stream valleys. Soils are shallow and drainage is generally poor. The plateau is dissected by numerous streams and is subject to erosion. The Site is located on a glacial till complex that forms the floor of the valley of Buttermilk Creek (DOE 2010a; LaFleur 1979). Buttermilk Creek and its tributaries have shaped the landscape in the vicinity of the Site with streams that have downcut into bedrock and surrounding topography, creating ravines and uplands (DOE 2010a). Buttermilk Creek flows for three miles to the north-northwest from the Site, where it joins Cattaraugus Creek.

In terms of land use, the overall setting in Cattaraugus County includes cropland, pasture, woodlands, and residential properties. Major land uses include the following (DOE 2010a):

- Residential (29.3 percent)
- Wild, forested, or conservation lands, plus public parks (22.8 percent)
- Vacant land (unspecified former use; 22.4 percent)
- Agriculture (19.2 percent)
- Community services, recreation and entertainment, public services, industrial, commercial, or unknown (6.3 percent)

Land use in the immediate vicinity of the Site is predominantly agricultural. The number of Cattaraugus County farms in 2012 was over 1000, with a total area of almost 80,000 ha (197,000 ac). Major crops in terms of land usage include forage (hay, grass, etc.), corn for silage

and grain, soybeans, and "woody crops" (e.g., Christmas trees). Major cash products include milk from cows, beef, and grains/beans. There are over 30,000 cattle, 33,000 bee colonies, 3000 chickens, and 1500 sheep in the county (USDA 2012).

The Hamlet of West Valley (in the Town of Ashford) is characterized by residential and commercial land uses. The larger Village of Springville, 14 km (9 mi) from the Site in Erie County, includes residential, commercial, and industrial land uses. Urban land use increases north of the Site toward Buffalo and northwest along the Lake Erie shoreline. Recreational land use increases to the south toward Allegany State Park and west toward Lake Erie (DOE 2010a).

Extractive industries are a major land use in Cattaraugus County. There are 195 permitted, non-permitted, and reclaimed sand/gravel mines in the County, up to 40 ha (100 ac) in extent and 20 m (70 ft) deep. There are also clay and peat mines (New York State 2016a, 2016b), and over 2300 currently producing oil and/or gas wells in the county (Drilling Edge 2016).

State parks near the Site include Allegany State Park to the south, and two parks on Lake Erie to the northwest. There are 18 separate State Forests, and two State Wildlife Management Areas in Cattaraugus County. In addition, there are numerous Cattaraugus County Parks, as well as municipal parks. There are hiking and snowmobile trails that pass near the Site. The Zoar Valley State Multiple Use Area is a popular area on Cattaraugus Creek northwest of the Site that is used for fishing, hunting, hiking, white-water rafting, and wildlife/scenic viewing.

If the region of interest (ROI) is expanded to Erie County, the degree of urban/suburban development and associated land uses dramatically increases. The population density of Erie County is approximately 340 persons per km^2 (880 persons per mi^2). Over one million people live within the 80-km radius ROI. Lake Erie provides a wide variety of lake-related uses (recreation, commercial fishing, etc.).

Therefore, essentially most types of land uses that are conceivable in an Eastern US mixed rural/urban area are potentially applicable for defining future land use and receptor scenarios at the Site and in surrounding areas. It is entirely possible, for example, that a future land use of the Site itself could be as a town, a gravel pit, or a farm, or all of the above depending on the time frame.

2.3.3 Inventory

A detailed inventory of wastes is not available at this time. However, preliminary review of the FEIS (DOE 2010a) indicates that the following radionuclides may be present in any inventory:

> ^{3}H, ^{14}C, ^{60}Co, ^{63}Ni, ^{90}Sr, ^{90}Y, ^{99}Tc, ^{129}I, ^{137}Cs, ^{226}Ra, ^{233}U, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{243}Cm, and ^{244}Cm.

Non-radionuclide chemicals in any inventory may include the following general classes of compounds:

> Numerous toxic metals, asbestos, phthalates, phenolic compounds, alcohols, halogenated and nonhalogenated solvents, petroleum fuel constituents, refrigerants, and polychlorinated biphenyls (PCBs).

This inventory will be revised as further information becomes available.

2.3.4 Disposal System

The following discussion is abstracted from a New York State Department of Environmental Conservation summary of the Site (NYSDEC 2008). Considerably more detail is provided in Neptune's *Conceptual Site Model for the West Valley Site* report (Neptune 2016).

Approximately 81 ha (200 ac) of the Site contain the remains of radioactive waste disposal and nuclear fuel reprocessing operations, which began in the early 1960s. NFS conducted reprocessing between 1966 and 1972, storing the resulting liquid HLW in two underground tanks on site. In addition, NFS operated two on-site disposal areas from 1963 to 1981. The SDA accepted mostly LLW from both commercial and federal facilities for disposal in shallow trenches. The NDA accepted higher activity waste generated during reprocessing that was not allowed in the SDA. The NDA also contains LLW from DOE decontamination activities from 1982 to 1986. This disposal system is not inherently stable. For example, in 1975, water infiltrated through the SDA earthen cover and seeped in through the subsurface, collected in the SDA trenches, and caused SDA Trenches 4 and 5 to overflow. NFS pumped out the accumulated leachate, treated it to reduce contamination, and then released it to adjacent streams.

The SDA is a series of unlined, shallow trenches containing 68,000 m^3 (2.4 million ft^3) of LLW from the government and various medical, commercial, and industrial sources. Much of the waste in the SDA was disposed of in drums, cardboard boxes, and wooden crates that have likely since deteriorated.

The NDA contains approximately 10,000 m^3 (360,000 ft^3) of higher activity waste that was unacceptable for disposal in the SDA, including three drums containing ruptured irradiated New Production Reactor (NPR) fuel assemblies. Similar to the SDA, the NDA is subject to erosion and is unlined. In the 1980s, several disposal "holes" at the NDA filled with water and displaced into the groundwater a liquid mixture of waste n-dodecane and tributyl phosphate that was used in the NFS solvent extraction process of its fuel reprocessing operation. This waste solvent mixture was mixed with absorbent material in 1,000 gallon tanks and disposed in several holes in the NDA. The NDA Interceptor Trench was installed in 1990 by the DOE to collect and to monitor for potential releases of these liquid wastes. Several disposal holes containing packaged n-dodecane and tributyl phosphate were removed from the NDA (Blickwedehl et al. 1987). Although n-dodecane and tributyl phosphate were found as free product in the NDA (Blickwedehl et al. 1987), the NDA interceptor trench has not yet collected any liquid used in the process.

The WTF contains four underground storage tanks (8D-1, 8D-2, 8D-3, and 8D-4) located in concrete vaults that provide secondary containment. Tanks 8D-2 and 8D-4 were used to store liquid HLW generated during NFS fuel reprocessing operations. Tanks 8D-1 and 8D-3 were intended as spare tanks during reprocessing but did not receive liquid HLW. The HLW stored in Tanks 8D-2 and 8D-4 was removed and vitrified in borosilicate glass by the DOE during the WVDP Vitrification Project from 1996–2002. Tanks 8D-1, 8D-2, and 8D-3 are dry and tank 8D-4 contains approximately 20 m^3 (5,000 gal) of liquid. Tanks 8D-1, 8D-2, and 8D-4 still contain more than 14 m^3 (500 ft^3) of residual radioactive solids, and substantial contaminated material adhered to the interior surfaces of the tanks. The tanks are located in an area where the water table is high and the soils are highly permeable.

2.3.5 Other Contamination

As of this writing, the liquid HLW, aside from the residue that remains in underground tanks, has been solidified by vitrification in borosilicate glass. Although this waste must be disposed in a geologic repository, no current off-site disposal option for the vitrified HLW exists. In an ongoing activity, this vitrified waste is being relocated to an on-site outdoor storage pad, where it will be stored in shielded casks so that deactivation activities can proceed inside the Main Plant Process Building (MPPB). Thus the vitrified waste has remained on site. Note that the MPPB is itself a contaminated structure (underlain by a plume of radioactive groundwater, described below). A substantial amount of LLW has been disposed off site. In 1993, a plume of radioactive groundwater was discovered containing ^{90}Sr, its decay progeny yttrium-90 (^{90}Y), and other contaminants. The majority of this radioactivity originated from a leak within the acid recovery system in the MPPB during NFS operations, and continues to migrate today. A ventilation system filter failure at the MPPB during NFS operations deposited ^{137}Cs on surface soils to the north-northwest of the MPPB over a distance of more than a mile. This is colloquially known as the "Cesium Prong."

Numerous other buildings and facilities will also require decontamination and dismantling once they are no longer needed for decommissioning activities. Those facilities included in the West Valley PPA Model are described in the *Conceptual Site Model for the West Valley Site* (Neptune 2016).

3.0 Definitions of FEPS

The concept of FEPS has existed for decades (IAEA 1977, 1983), although early discussions of this subject did not use the terms FEP or FEPS. The purpose of identifying FEPS is stated by the International Atomic Energy Agency (IAEA) in the context of what they termed "scenario analysis" (IAEA 1983):

> ...scenario analysis involves the identification and quantitative definition of phenomena [that] could initiate and/or influence the release and transport of radionuclides from the source to [humans], and may also include the estimation of the probabilities of occurrence of these phenomena.

The IAEA further developed this concept in a subsequent document (IAEA 1985), in the preamble to their Table II, entitled "Phenomena potentially relevant to release and transport scenarios for waste repositories." In the following excerpt, their use of the term "scenario" essentially encompasses all FEPS. The more narrow use of "scenario" here relates to the category of "human activities" identified at the end of the quote.

> ...a scenario is defined as a quantified description of a waste disposal system, including its environment and how this will change with time. Scenarios depend on the system characteristics and on events and processes [that] could either initiate release of radionuclides from waste, and cause their transport through the geosphere and the biosphere to humans, or influence release and transport rates. The choice of appropriate scenarios is very important and strongly influences subsequent analysis of the waste disposal system. The first step in identifying which of the many phenomena are relevant to a safety or performance analysis is to establish a check-list. For this purpose it is usual to divide

> phenomena into the following categories: (a) natural processes and events, (b) human activities, and (c) effects of the waste and the repository.

CFR Title 40 Part 191 (CFR 1993), promulgated by EPA, provides a useful and general definition for the scope of a PA analysis of a radiological disposal facility (note that "facility" is used in this report, but this is synonymous with "repository"). Note that the focus of Part 191 is geologic disposal of waste (disposal in deep rock formations, such as the Yucca Mountain Project in Nevada or the WIPP in New Mexico), thus it is not directly applicable to waste at the Site.

Features, events, and processes (FEP) have been defined in NRC (2003) in relation to the Yucca Mountain Project:

> ***Feature***: An object, structure, or condition that has a potential to affect system performance. Features are not characteristics of the components of the system, but an identification of the components themselves.
>
> ***Event***: A natural or human-caused phenomenon that has a potential to affect system performance and that occurs during an interval that is short compared to the period of performance.
>
> ***Process***: A natural or human-caused phenomenon that has a potential to affect system performance and that occurs during all or a significant part of the period of performance.

In addition to these definitions from NRC (2003), it is useful to add Scenarios to FEP to result in "FEPS":

> ***Scenario***: An assumption related to human actions and behaviors in the context of societal conditions that is expected to be applicable at the site location after closure.

Cranwell et al. (1982) provide a different definition of "Scenario" that is useful:

> ...the hypothetical occurrence of these events, features, and processes, either singly or in combination.

4.0 Identification of Relevant FEPS

4.1 Introduction

Identification of FEPS for consideration in the Site CSM and the West Valley PPA Model is an iterative process that begins with compiling an exhaustive list of candidate FEPS that could affect the long-term performance of and risks from any potential waste disposal facility. As an initial step, all potentially relevant FEPS from a variety of reference sources are collected. By starting with an extensive list of FEPS that are general in scope, those that apply to any given site will likely be captured, and can be screened to provide a basis for the CSM.

Additionally, there are FEPS that have been defined using expert judgment and experience with PAs for multiple sites. Historical PAs for deep geologic disposal facilities largely focused on hydrogeologic FEPS for obvious reasons. These early PAs also employed highly generalized

assumptions regarding exposed populations and other important FEPS. As PAs have evolved, they have become more site specific and detailed. Thus, the list of potentially important FEPS has grown.

This initial compilation of FEPS leads to redundancy across the original sources. Redundancy is addressed by the modification of the candidate list of FEPS via normalization (e.g., removal of redundant FEPS). This section describes the FEPS identification and normalization processes.

4.2 Compilation of FEPS

The initial list of FEPS pertaining to disposal of radioactive wastes in general is compiled from several scenario development documents published for other radioactive waste disposal facilities, including those for the Yucca Mountain Project, the Waste Isolation Pilot Plant (WIPP), and radioactive waste projects in Belgium, Switzerland, Finland, and Sweden. An important literature source for FEPS analysis is a compilation by Guzowski and Newman (1993), superseded by SNL (2008). Guzowski and Newman compiled over 700 FEPS from a review of scenario documentation from radioactive waste facilities around the world. An additional comprehensive listing of international FEPS is represented by the Nuclear Energy Agency database (NEA 2000). In this initial compilation step, over 1,300 FEPS are identified from the literature and site-specific considerations. Other FEPS have been added over time, per above. Note that the facilities considered in these source documents have substantially different geological, environmental, and regulatory settings from those of the West Valley Site. Accordingly, this initial list from external sources has been modified with additional Site FEPS that have been identified from the FEIS or other site-specific documentation, and from general knowledge of the Site and surroundings.

Initial FEPS compiled from all sources are listed in Table 1 in the Appendix of this report.

4.3 Normalization of FEPS

Subsequent to the initial compilation of FEPS, steps were taken to reduce redundancy. As shown in Table 1, FEPS were sorted by topic and duplicates deleted. FEPS definitions that are different only in wording and not in meaning (e.g., “climate change” versus “change in climate”) are normalized to capture a single primary FEPS for a series of identical or closely related concepts. To facilitate reduction in redundancy, initial FEPS are grouped by topic (e.g., “waste,” “geochemistry,” “human exposure,” etc.) and evaluated for possible normalization. Where possible, FEPS are normalized to a standard terminology. In certain cases, subtle differences were intended by the original compilers, and these are retained as separate normalized FEPS.

4.4 Classification of FEPS

Each normalized FEPS is considered for its similarity to other FEPS so that they can be grouped into fewer classes, making the review of the list more tractable. Normalized FEPS are organized into high-level Topics and intermediate-level Subtopics. The classification is principally an organizational tool for the FEPS analysis, although the Topics and Subtopics relate to

components of the Site CSM. The FEPS Topics used for a high-level grouping of the initial and normalized FEPS are as follows:

Regulatory context:

- Institutional Control (IC)
- Regulatory issues

Engineered systems:

- Engineering
- Waste

Environmental systems:

- Atmosphere
- Biology
- Erosion
- Gas phase transport
- Geochemistry
- Geology
- Geophysics
- Glaciology
- Hydrogeology
- Hydrology
- Marine issues
- Material properties

Exposure and activities:

- Human exposure
- Ecological exposure
- Inadvertent human intrusion
- IC
- Intentional human intrusion
- Land use

Miscellaneous FEPS:

- Miscellaneous
- Modeling

The specific Subtopics organized under these Topics are identified in Table 1 of the Appendix of this report. The initial and normalized FEPS, and associated references, are shown in Table 1 within the structure of Topics and Subtopics.

4.5 Screening Boundaries and Criteria

The screening of FEPS requires an explicit set of assumptions regarding the boundaries of what is relevant for modeling the performance of the Site. This can include assumptions regarding the spatial and temporal boundaries of the modeled environment, boundaries on the nature of future

exposure scenarios and events to be considered, and other similar assumptions. Regulatory boundaries were discussed above.

The following boundaries regarding the scope of the West Valley PPA Model were therefore applied as a basis for screening FEPS:

- The West Valley PPA Model considers the performance of the West Valley Site.
- The time frame will begin in 2020, which is the expected DOE and NYSERDA decision date for a Phase 2 decommissioning decision for those facilities remaining at the WVDP and WNYNSC following Phase 1 decommissioning. Potential operational worker and public exposures and doses prior to this date are out of the Model's scope, but potential operational worker and public doses after this date (as part of Phase 2 decommissioning) are within the Model's scope.
- The radionuclide and chemical toxicant inventories and environmental concentrations present at the end of Phase 1 decommissioning are to be evaluated for the entire performance period. Vitrified HLW are not to be evaluated, as they are slated for removal and disposal in a geologic repository.
- Alternative strategies to be evaluated include site-wide removal of wastes, a closure with all wastes in place, partial removal of wastes, and "no-action" for those facilities and wastes remaining following the completion of Phase 1 decommissioning.
- An 80-km (50-mi) radius around the Site, in the context of land uses and the "region of interest" (ROI), is applicable, consistent with the FEIS. While such a radius was largely intended to reflect potential air emissions (under NEPA, in the context of EISs), issues distant from the Site such as municipal drinking water intakes from Lake Erie are also potentially important. Therefore, the relevance of this particular radius to the West Valley PPA will be evaluated during model development.
- Land-use, societal, and behavioral assumptions relative to potential human and ecological exposures post-closure are based on historical and current conditions, and the likely and foreseeable future based upon these conditions.
- The consequences of intentional human intrusion into contaminated materials (e.g., intentionally removing radioactive or hazardous substances) are not directly evaluated. It is impossible to predict the circumstances and consequences of such intentional intrusion.
- The consequences of inadvertent human intrusion into contaminated materials are evaluated.

There are also assumptions regarding the scope of the West Valley PPA Model that are relevant to inclusion of FEPS for the Site, and that have been considered in recent PAs for this and other sites. The intention is to include all FEPS that may potentially be relevant to the Model, recognizing that the scope may evolve as the modeling framework is developed and regulator/stakeholder discussions take place:

- Risks related to both radiological and non-radiological toxic components of disposed wastes are considered.
- Effects endpoints other than radiological dose, such as cancer risk incidence, are considered.
- An ALARA assessment is performed, addressing population-level (collective or cumulative) doses and risks.

- Modeling is performed to a time of peak radiation effects (dose and risk) associated with wastes and environmental radioactivity.
- Possible effects related to human-induced climate change (based upon the most current available science), such as impacts on the performance of an engineered cover, are addressed in the modeling of system performance.
- Risks pertaining to populations of ecological receptors are assessed.
- Perpetual IC, limiting potential future exposures on the disposal site, is not assumed. There is no historical or practical reason to assume that IC will continue over tens, hundreds, or thousands of years. Therefore, for modeling purposes, no practical distinction is made between a future member of the public and an inadvertent intruder.

At a high level, the rationale for not evaluating specific FEPS in the CSM is typically related to one of the following exclusion criteria:

- The FEPS are not relevant to the specific types of contaminated materials present at the Site.
- The FEPS are not relevant to the waste disposal methods employed or remedial alternatives planned.
- The FEPS are not relevant to the environment where the Site is located.
- The FEPS are judged to have a zero or near-zero probability of occurrence at the Site within the modeling time frame.
- The FEPS are judged to have a negligible impact on the modeling of contaminant release, transport, and/or toxic effects within the modeling time frame.
- The FEPS are implicitly captured in the variability and/or uncertainty implicit in a West Valley PPA Model stochastic input variable.

A benefit of this formal FEPS screening is the high degree of transparency gained by having all FEPS included or excluded from the West Valley Site CSM organized by topic and easily available for review. Subjective expert judgment is acknowledged in applying these criteria to any individual FEPS in the screening process. FEPS that pertain specifically to deep geological repositories (e.g., the Yucca Mountain Project) are examples of where the degree of subjectivity in exclusion from the Site CSM is relatively small. Conversely, professional judgment related to the combined probability and consequences of disruptive or climate change events may involve more subjective judgment.

The retention or rejection of FEPS and associated rationale is documented in order to identify the specific FEPS to be incorporated in the CSM. The product of this screening procedure is the identification of those FEPS that, either alone or in conjunction with others, could affect the performance of the Site. Some FEPS are identified with "?" and are "pending review" because either 1) additional research in constructing the CSM will aid in determining whether a given FEPS should be retained, or 2) a final determination will be made following the completion of a sensitivity analysis of the West Valley PPA Model. The sensitivity analysis will identify which components of or inputs to the model are most influential on results, and thus on decisions at the Site.

Note that some FEPS that are defined as relating specifically to radionuclides may also apply to toxic but nonradioactive chemical components of waste. Rather than increasing the number of

FEPS to accommodate both radioactive and nonradioactive toxicants, or modifying original nomenclature, it is generally assumed here that FEPS identified as being relevant to radionuclides may also be applicable to nonradioactive toxicants. However, FEPS that are specific to nonradioactive toxicants alone (such as dermal absorption) are clearly identified.

5.0 Screening of Results

5.1 Introduction

This section provides details related to the screening of normalized FEPS for the West Valley PPA Model. A summary of the results of the screening is captured in Table 2 in the Appendix. FEPS that are retained via the screening and included in the CSM are documented and discussed in further detail within the CSM Report (Neptune 2016).

In the following subsections, FEPS are identified in bulleted lists with explanatory text following. Those listed with a "+" sign are retained and included in the CSM, and those with a "–" sign are excluded from further consideration. A relatively small number of FEPS are marked with a "?" indicating that their inclusion/exclusion status for the CSM is pending for the reasons stated above. This is a provisional status that will be updated in a future version of this report.

5.2 Results of Screening

5.2.1 Regulatory Context

5.2.1.1 Institutional Control

5.2.1.1.1 Institutional Control FEPS

+ active institutional control
+ post-closure surface activities
+ loss of institutional control
+ passive institutional control
+ loss of records
+ records and markers

All aspects of active IC are retained, including post-closure surface activities that are performed during the active IC period. Passive IC is retained, and is assumed to have some degree of effectiveness that deteriorates over some period of time following the loss of active IC. The loss of both active and passive IC is retained. This follows the passive IC period, at a time when passive controls such as fences, records, and markers are lost.

5.2.1.1.2 Monitoring

+ post-closure monitoring

Monitoring of the disposal site is part of active IC, and includes surface activities and subsurface monitoring. Once active IC is lost, monitoring also ceases. Monitoring is retained in the context of exposure of maintenance and monitoring workers on the Site during the IC period.

5.2.1.2 Regulatory Issues

+ regulatory issues

These are retained and help to scope the entire analysis. See the discussion in Section 2.0.

5.2.2 Engineered Systems

5.2.2.1 Engineering

5.2.2.1.1 Construction and Material Defects

– closure failure
+ faulty backfill placement
+ inadequate backfill compaction, voidage
+ poor quality construction
+ defect in backfill
+ waste canister defects

The Site Engineered Barriers Working Group recognizes that all engineered features will have some degree of "construction failure." If construction errors are to be retained in analysis, a means of doing so within the mathematical framework of the Model and its probabilistic inputs will need to be developed. Inadequate backfill compaction leads to subsidence of the waste disposal facility, and is considered separately in Section 5.2.2.1.7.

The issue of waste canister defects is considered implicitly within the context of general waste containment (see Section 5.2.2.2.6).

5.2.2.1.2 Drip Shield FEPS

– drip shield failure modes
– hydrostatic pressure on drip shield
– thermal sensitization of drip shields

All FEPS within this subtopic are excluded, as these are specific to the drip shields proposed for use in the deep geologic Yucca Mountain Project engineered system, and are not relevant outside that system.

5.2.2.1.3 Engineered Features

+ degradation of engineered features
+ hydrostatic pressure on canister
+ seal performance

All engineered features will experience performance degradation, and thus are retained.

As all of the contamination at the Site is near the ground surface (within 30 m, or 100 ft, of the ground surface), and most "canisters" and other containers have degraded, they may experience only atmospheric pressure and remain in an unsaturated condition, with no additional hydrostatic pressure. However, hydrostatic pressure is an important FEPS at the Site, as several trenches and disposal holes have filled with water to the point of overflowing, and hydrostatic pressure may contribute to further degradation of engineered features. Thus, it is retained.

5.2.2.1.4 Mechanical Failure

+ failure of waste packages
– floor buckling
+ mechanical failure of backfill
+ mechanical failure of repository
+ seal failure

The eventual failure of waste packages and sealed containment structures is relevant to the Site, and is retained. Floor buckling is specific to mined geologic repositories such as WIPP, and is thus excluded for shallow-buried wastes at the Site. Mechanical failure of containment structures in general is expected as erosion causes mass movement of the Site and its contaminants.

5.2.2.1.5 Operational Activities/Operational Errors

+ ground disturbance
+ pavement
+ phased operations
– remediation
+ repository flooding during operation
– repository ventilation
+ schedule and planning
+ unsuccessful attempt of site improvement
– accidents during operation
+ waste disposal error

The effects of ground disturbance (including pavement) and repository flooding (in this case introduction of water into containment structures during operations), whether intentional or unintentional, may have consequences in the near term following closure, so these are retained.

The effects of phased operations, scheduling, and planning are considered in the timing of waste inventory placement and are retained.

Active repository ventilation is not required, as the Site involves near-surface disposal rather than deep-mined geologic facilities. Thus, this is excluded.

Accidents during operation are not part of the scope of the West Valley PPA Model, and are excluded *per se*, though the results of such accidents, such as the Cesium Prong, are accounted for. Future activities for remediation or Site improvement are considered as part of phased remediation, and are retained.

Waste disposal, erroneous or not, is included in the state of the Site at the time of closure, and thus is retained.

5.2.2.1.6 Repository Design/Waste Configuration

– design modification
– faulty design
– poorly designed repository
+ repository design and construction
+ retrievability
+ disposal pits

+ disposal shafts
+ faulty waste placement
+ waste placement

Poor or modified disposal facility designs *per se* are not important to the West Valley PPA Model—rather, the state of the Site at the beginning of the Model's time scale is important. The as-built construction of containment structures, and the concept of retrievability, are retained. This also includes the placement of wastes in the structures. Whether waste placement is "faulty" or not is irrelevant—the Model considers disposed waste in its present and final configuration.

5.2.2.1.7 Subsidence

– repository convergence
+ subsidence in the waste zone

The concept of repository convergence is specific to deep-mined geologic repositories and does not apply at the Site, and is excluded. Subsidence in the waste zone, however, is of concern in shallow land disposal, so is retained.

5.2.2.2 Waste

5.2.2.2.1 Materials Co-Disposed with Waste

+ co-disposal of nonradioactive waste
+ co-disposal of radioactive waste
+ co-disposal of reactive wastes
+ inadvertent inclusion of undesirable materials

The West Valley PPA Model evaluates the risks posed by both radioactive and nonradioactive chemical contaminants, so both are retained. In addition, recent events related to nonradioactive materials co-disposed with Los Alamos National Laboratory (LANL) waste in the WIPP facility in New Mexico that resulted in exothermic reactions have emphasized the need for consideration of potentially deleterious effects of co-disposal of incompatible wastes (see "exothermic reactions in the repository" in Section 5.2.5.1.8). Elemental sodium disposed at a closed US Ecology site in Beatty, Nevada has been implicated in pyrophoric reactions in that facility (see "pyrophoric waste event" in Section 5.2.2.2.3). Thus, this is retained.

5.2.2.2.2 Nuclear Processes in Waste

? criticality
? criticality, in waste
? nuclear activation

Fissile materials were disposed in the NDA. Typically, packing and orientation of wastes containing fissile material is assumed to preclude the possibility of criticality. It is unknown at this time whether criticality and neutron activation would be expected in these wastes. These FEPS are pending inventory review. Criticality outside the waste, due to, for example, reconcentration of fissionable radionuclides, is considered in Sections 5.2.5.1.6 and 5.2.5.1.7.

5.2.2.2.3 Source Release

– glass waste form cracking
– glass waste form degradation
– glass waste form recrystallization
+ heterogeneity of waste forms (chemical, physical)
? I, Cs-migration to fuel surface
+ induced chemical change (solubility sorption, species equilibrium, mineralization)
+ interactions of waste and repository materials with host materials
? pyrophoric waste event
+ radon emanation from waste
+ waste/rock interaction

The liquid HLW stored in Tanks 8D-2 and 8D-4 has been vitrified (i.e., converted into a glass-like form), and is slated for disposal in a geologic facility. The scope of the West Valley PPA Model does not include these wastes, so these glass waste forms are excluded. Although nuclear fuel was disposed at the NDA, I and Cs migration is pending inventory review.

Heterogeneity of waste forms and induced chemical changes are retained.

It is unknown at this time whether a pyrophoric event would occur in the types of wastes at the Site, and thus this is pending further investigation. The NPR fuel reprocessed by NFS had zircalloy cladding, which is pyrophoric, and there were several instances of cladding fires during NFS operations. However, pyrophoricity is reduced with oxidation of the hulls, and NFS implemented a NaOH wash of the leached hulls prior to burial.

Many contaminants contain radon parents, so radon emanation is a process that is retained. Chemical interactions with the repository materials (e.g., backfill) and with host materials (e.g., glacial till) are retained.

5.2.2.2.4 Waste Characterization

+ radioactive source in waste
+ unanticipated waste composition
+ waste characterization

Much of the waste at the Site is radioactive, and this waste is retained. Any discrete radioactive sources, meaning specially packaged sources for industrial, scientific, medical, or other diagnostic use, should be included in the waste inventory and are retained. Unanticipated waste composition would be accounted for in larger uncertainties assessed as part of waste characterization, and thus is retained.

5.2.2.2.5 Waste Chemistry

+ chemical effects of void space in waste package
+ chemical liquid waste disposal
+ geochemical processes in waste
+ interactions with corrosion products and waste
+ introduced complexing agents and cellulosics
+ solubility within fuel matrix

Basic geochemical processes (e.g. phase partitioning, solubility limits) will be accounted for in porous media within the Model, including waste materials, and are retained. Void spaces within the disposed wastes are expected to contribute to subsidence (see Section 5.2.2.1.7) and are otherwise accounted for within the concept of porosity, and are retained. The incorporation of cellulosic materials may be retained, but this is pending further review. Complexing agents such as Radiacwash have been used on site to support NFS and WVDP decontamination efforts (WVNS 1994).

Liquid and corrosive waste components are possible at the Site, and thus are retained.

Because nuclear fuel residues are disposed at the Site, FEPS related to a "fuel matrix" are included.

5.2.2.2.6 Waste Containment

+ change in hydrostatic pressure on container
+ corrosion
+ corrosion of containers
– corrosion of copper waste canisters
– creep in copper waste containers
+ damaged or deviating fuel
+ degradation of fuel cladding
? flammable gas generation
– internal pressure
– loss of ductility
– stress analysis
– stress change of conductivity
+ vault-related events
– voids in the lead filling
+ waste canister failure
+ waste canister movement
+ waste containment

As all of the Site is near-surface disposal, and most "canisters" and other containers have degraded, they may experience only atmospheric pressure and remain in an unsaturated condition, with no additional hydrostatic pressure. However, hydrostatic pressure is an important FEPS at the Site, as several trenches and disposal holes have filled with water to the point of overflowing, and hydrostatic pressure may contribute to further degradation of engineered features. Thus, it is retained. (See also "hydrostatic pressure on canister" in Section 5.2.2.1.3.)

"Waste canister failure" is possible, and thus is retained. However, it is unlikely that waste containers exist for which "internal pressure" would be important, thus this is excluded.

Corrosion, and specifically corrosion of containers, is a process that can lead to release of radionuclides into the environment, thus these are retained.

FEPS pertaining to copper waste canisters (proposed for fuel disposal in some geologic repositories) and lead filling do not apply to wastes or disposal technologies at the Site. These include the issues of container stress, changes in stress, and loss of ductility as well. Thus, these are excluded. The NDA and SDA waste inventories, however, have numerous references to lead (Pb) in the waste packages, and Pb is included in the hazardous chemical inventory.

The Waste Tank Farm at the Site consists partially of tanks in concrete vaults, so "vault-related events" such as failure are retained under scenarios where the vaults are not removed.

Because the Site was a nuclear fuel reprocessing site, the FEPS for damaged fuel and degraded cladding are retained. NPR fuel with ruptured cladding is documented in NDA Deep Hole 48 (Nicholson and Hurt 1985).

"Flammable gas generation" was initially introduced in the context of the radiogeneration of H_2 in geologic repositories, but it is possible that flammable or explosive gases could exist in Site wastes. This is pending detailed inventory review.

"Waste canister failure" and "waste containment" in general are issues to be addressed at the Site, and thus are retained. "Waste canister movement" could occur via erosion and mass wasting at the Site, and thus is retained.

5.2.2.2.7 Waste Inventory

+ waste inventory
+ waste inventory heterogeneity

The waste inventory is an important feature of the Site waste disposal system. The heterogeneity of the waste is addressed as well. Therefore, these are retained.

5.2.3 Environmental Systems

5.2.3.1 Atmospheric Processes

+ atmosphere
+ dry deposition
+ wet deposition
+ atmospheric dispersion
+ atmospheric inversion
+ atmospheric turbulence
– barometric pumping
+ dust devils
+ gas diffusion into atmosphere
+ ground surface roughness
+ resuspension
+ saltation
+ topography
+ tornado
+ wind
+ wind-induced contaminant transport
– lightning
+ meteorology

Most the above FEPS marked for inclusion can contribute to atmospheric dispersion of radionuclides, and thus are retained.

Barometric pumping requires dry, large aperture fractures. This is unlikely at the Site, and so is excluded.

No direct effect of lightning on the closed disposal system is foreseen. Potential effects on plant cover that may affect evapotranspiration and erosion from fires related to lightning are addressed in other FEPS (see "brush fires" in Section 5.2.5.1.1).

5.2.3.2 Biology

5.2.3.2.1 Biochemistry

? biochemical gas generation
? biochemical processes in geosphere
? biochemical processes in repository

Biochemical processes in general are pending review for retention and inclusion in the CSM. The potential importance of biochemical processes will be evaluated based on consideration of Site conditions, waste and waste packaging, and the potential of microorganisms to affect redox and pH conditions, as well as the generation of gases in the waste layer and how that could potentially affect phase partitioning in the geosphere or chemical transformation in the waste.

The potential significance of biochemical gas generation (for example, cellulose degradation creating $^{14}CO_2$) will be evaluated during inventory review. N-dodecane, an aliphatic hydrocarbon, was used by NFS in the solvent extraction process and was disposed in the NDA when spent. The SDA contains halogenated hydrocarbons (e.g. benzene, toluene, and xylene) used in scintillation cocktails (WVNS 1994, 1995).

Biochemical processes are also important in terms of organic chemical degradation. This is addressed in Section 5.2.3.2.2 below.

5.2.3.2.2 Biotically Induced Contaminant Fate and Transport

+ animal burrowing
+ animal, plant and microbe mediated fate and transport of contaminants
+ biomass production
+ biosphere characteristics
+ bioturbation
+ burrow collapse
+ burrow excavation
+ burrow renewal
+ plant intrusion
+ plant root profile
+ plant senescence
+ plant uptake
+ vegetation

All of these biotic processes are retained, with an exception noted below. These processes involve animal (e.g., rodents, insects) radionuclide transport via burrow construction and collapse, and plant-mediated transport via plant uptake and senescence. These are distinct from plants and animals considered as food in human exposure pathways (see Section 5.2.4.1).

Microbially mediated fate and transport is possible in a number of respects. See "cellulosic degradation" (Section 5.2.3.6.2) and "biochemical gas generation" (Section 5.2.3.2.1) as examples of FEPS related to the potential impact of microbes on transport. With regard to organic chemicals, microbial biodegradation and thus production of other toxic products is an important process and thus is retained.

5.2.3.2.3 Ecological Community

+ animal populations
+ ecological response to climate change
+ ecological response to wildfire
+ ecological succession
– evolution

The makeup of the ecological community, focusing on plants and animals, is important to modeling contaminant transport of radionuclides. Ecological succession, especially in response to wildfire and long-term pressures such as climate change, is retained.

Changes in the structure of the biological community are retained in response to climate change, but not to the evolution of organisms. While biological evolution is an established ecological concept, the structural changes that this would cause in the ecological community are highly speculative.

5.2.3.2.4 Ecological Risk

+ uptake by animal, plant, root

The assessment of ecological risk is part of the West Valley PPA Model, and is retained. Note that this category may be expanded pending further review.

5.2.3.2.5 Microbiology

+ microbial systems
– radiological mutation of microbes

The potential importance of microbial systems in radioactive waste is poorly understood, but their role in the degradation of organic chemicals is important, and thus this is retained.

Speculative effects of microbial mutation are outside the scope of the West Valley PPA Model.

5.2.3.3 Climate Change

+ anthropogenic change in biosphere
+ anthropogenic climate change
+ climate change
– climate change, global
+ climate change, regional and local
+ hydrologic/hydrogeologic response to climate change
+ no ice age
+ warm climate effects

Anthropogenic changes to the biosphere, as in effects on the biotic community due to Site disturbance, are retained. Climate change, whether natural, anthropogenic, or a combination of both, will have an effect on modeling if the period of performance is sufficiently long, thus all local effects are of concern and are thus retained.

The effects of global climate change are of interest only on a regional/local scale, thus “global climate effects” is excluded.

5.2.3.4 Erosion

5.2.3.4.1 Surface Soil Erosion

+ animal burrowing inducing erosion
+ anthropogenic erosion
+ denudation and erosion
+ deposition
+ erosion
+ erosion from rainsplash
+ erosion from surface water
+ erosion from tree-throw
– erosion from wave action
+ erosion from wind
+ erosion of ground surface

Surface soils undergo erosion and related processes, such as deposition and denudation. A variety of initiating causes for erosion are retained, and may be combined into an average long-term surface erosion rate. Wave action is not one of these, as waves are not expected at the Site unless there is appreciable glacial advancement and retreat (i.e., formation of new lakes). In that case, glacial action would likely move any remaining waste to a distant location.

5.2.3.4.2 Cliff Erosion/Landslides

+ erosion of cliffs
+ landslide
+ mass wasting
– rockfalls

There are cliffs subject to mass wasting at the Site, thus these are retained. Mass wasting and landslides, such as those involving heavy precipitation and large unconsolidated hillsides, are important processes shaping the western New York landscape, and are retained. Rockfalls are not relevant to the geologic materials present at the Site, and are excluded.

5.2.3.4.3 Weathering

– chemical weathering
+ frost weathering

While not explicitly modeled, some weathering does contribute to erosion. No important chemical influences on erosion have been identified for the Site, but frost may be a factor and is retained.

5.2.3.5 Gas Phase Transport

5.2.3.5.1 Gas Generation

+ decay product gas generation
– gas generation
? gas generation from microbial degradation
– gas generation with pressurization
– hydrogen gas generation corrosion of steel
– thermally induced release of gases from pores and fluid inclusions

Gases produced as decay products are retained because they are members of important decay chains that lead to potentially important exposures. Other radioactive noble gases that commonly occur in wastes, such as ^{39}Ar and ^{85}Kr, may be part of the disposed inventory, but are not produced by radioactive decay of disposed parents. Diffusive transport of noble gases can be appreciable.

Other gases produced from microbial generation, steel corrosion, or thermal effects are not expected to produce any pressure in the disposal facility, as the containment structures are not sealed from the atmosphere. Consideration of gases from microbial degradation are pending further consideration of microbial processes in general (see Section 5.2.3.2.5).

Hydrogen generation by the corrosion of steel containers would be slow in comparison to the rate of diffusion out of the system, and, with the repository being open to atmospheric pressures, no accumulation of H_2 is anticipated. This FEPS was a concern for the sealed WIPP repository, but does not apply to the disposal configurations employed at the Site.

5.2.3.5.2 Gases in Repository and Gas Transport

+ effects of radioactive gases in repository
+ gas/water partitioning
+ gas effects in porous media
+ gas generation
+ gas phase diffusion
+ gas phase tortuosity
+ gas phase transport
+ natural air flow in porous media
+ natural gas intrusion
+ noble gases
+ radon diffusion
+ radon emanation
+ radon flux
+ volatiles

Most of these FEPS involve the transport of gases in the repository or in the surrounding environment, and thus these are all retained as various aspects of gas generation and transport.

Two in the above list, “gas effects in porous media” and “natural gas intrusion,” are particular to natural gas in the geosphere and are retained because natural gas formations are common in the region.

5.2.3.6 Geochemistry

5.2.3.6.1 Bentonite Chemistry

+ bentonite coagulation
+ bentonite degradation
+ bentonite geochemistry
+ bentonite sedimentation

The FEPS concerning bentonite chemistry were originally introduced in the context of the SKB disposal system for used nuclear fuel in Sweden. While not part of the same technology as the

SKB site, bentonite is planned as part of the backfill and/or containment system of the West Valley Site (DOE 2010a), and thus these FEPS are retained.

5.2.3.6.2 Biogeochemistry

? cellulosic degradation
? soil nutrient cycling
? metals cycling
? soil organic carbon/biomass changes

Cellulosic degradation, as a biochemical process, is pending review of the amount of cellulosic materials at the Site.

Cycling of soil nutrients and metals may be important fate and transport mechanisms and are pending review. Soil organic carbon and biomass changes may affect ^{14}C levels. The importance of this will be determined upon detailed inventory review.

5.2.3.6.3 Cement Chemistry

+ cement carbonation
+ cementitious pore water
+ recrystallization

Portland cement, as a component of concrete or controlled low-strength material (CLSM), is an important component of the waste disposal technologies that may be used or planned at the Site. Thus, these FEPS are retained.

5.2.3.6.4 Anthropogenic Changes in Geochemistry

+ acid rain
+ anthropogenic change in soil and surface water chemistry
– geochemical effects of excavation and construction
– geochemical transformation (manmade)

Acid rain has historically been an issue in the northeastern US, primarily due to lack of controls on sulfur dioxide emissions from upwind coal-fired power plants. However, recent controls on such plants have substantially reduced acid deposition. There are no monitors in Cattaraugus County, but examination of sulfur dioxide data from the past 10 years in adjoining counties (New York State 2015) reveals that these levels are now well below EPA standards. However, ambient rain samples at the SDA collected by NYSERDA have revealed pHs below 7, and in the most recent annual monitoring a pH below 4 was found (NYSERDA 2016). Therefore, acid rain is retained.

Anthropogenic effects on surface water chemistry related to future changes in climate or land use, such as increased dissolved CO_2, are anticipated to be relatively small and accommodated within parameter distributions. However, long-term leaching of constituents from the waste or other materials may change geochemical parameters such as pH and redox conditions. Additionally, acids are likely present in some areas. Therefore, anthropogenic changes are retained.

No other anthropogenic effects on geochemistry are indicated, and thus are excluded.

5.2.3.6.5 Natural Changes in Geochemistry

+ change in groundwater chemistry
+ geochemical alterations
+ geochemical change (natural)
+ geochemical transformation
+ rind formation
– thermochemical alteration
+ chemical gradients

Fundamental to the fate and transport aspects of the West Valley PPA Model are geochemical processes, which are employed throughout the Model domains in time and space. Local transformations, alterations, and other changes will occur, while the basic processes remain the same. Chemical gradients, for example, will vary in space and time, but their presence drives diffusion. Thus, these are retained.

Rind formation refers to chemical alterations of the near field due to corrosion products from the waste. These are possible at the Site, and thus this FEPS is retained. Thermal and thermochemical effects are not expected, given the shallow-buried wastes at the Site, and thus are excluded.

5.2.3.6.6 Chemical Speciation and Solubility

+ chemical speciation and solubility
+ inorganic solids/solutes
+ non-radioactive solutes

Aqueous solubility is dependent in part on chemical speciation, and solubility inputs to the West Valley PPA Model should take this into account. Inorganic solids and solutes are accounted for in solubility parameter inputs, and thus are retained.

5.2.3.6.7 Colloid Chemistry and Transport

? colloid formation in repository
? colloids and complexing agents
? colloid advection
? colloid diffusion
? colloid filtration
? colloid formation, dissolution and transport
? colloid sorption
? colloid stability
? colloid transport

Colloid formation and transport may be an important contaminant transport mechanism at the Site. However, additional research is needed into the effects of colloid-facilitated radionuclide transport. There is evidence (Hakem et al. 2000) that rapid plutonium migration has potentially resulted from colloid facilitated transport. If these FEPS are thought to have an appreciable effect on the mobility of Site radionuclides (e.g., plutonium), they may be included in the Model using effective K_d distributions.

5.2.3.6.8 Complexation Chemistry

+ complexing agents

Consideration of complexing agents may be important, including those that were used in fuel processing and are part of waste forms (see Section 5.2.2.2.5). Thus, this is retained.

5.2.3.6.9 Dissolution and Precipitation

– alpha recoil enhances dissolution
+ dissolution and leaching
– dissolution of host rock
+ dissolution, precipitation, and crystallization
+ geochemical interactions and evolution

Impacts of alpha recoil as a dissolution mechanism are likely to be minimal for waste disposed of at the Site. It is potentially applicable for spent nuclear fuel, although the Yucca Mountain Project excluded it from their FEPS list because of low consequence. The main case where alpha recoil is important is in the emanation of radon, which is covered as its own FEPS (see Section 5.2.2.2.3).

Dissolution in the context of leaching of contaminants from wastes is an important contaminant transport mechanism. In a more general context, dissolution and precipitation of contaminants in the water phase is bound by basic geochemical dynamics, and thus is retained.

The underlying bedrock geology of the Site consists of interbedded shales, siltstones, and sandstones of the Canadaway Group (DOE 2010a); thus, dissolution of host rock is not likely and is excluded.

5.2.3.6.10 Electrochemical Effects

– electrochemical reactions
– electrophoresis

Conditions leading to electrical currents in the disposed wastes, and related chemical reactions, are not likely to be present at the Site, and thus these are excluded.

The importance of electrophoresis in contaminant migration is likely to be negligible and is accounted for in parameter distributions related to solubilities and partition coefficients (K_ds); see Section 5.2.3.6.11.

5.2.3.6.11 Miscellaneous Geochemical Topics

+ buffer material chemistry
+ chemical effects
– chemical effects of construction
+ chemical effects of steel reinforcing bar in repository
+ effects of deliquescence on metals
– far field hydrochemistry—acids, oxidants, nitrates
+ groundwater geochemistry
+ ion exclusion
+ isotopic dilution

– mineralogic dehydration reactions
+ organic chemistry
+ sorption
+ surface diffusion
+ diffusion
– saltwater-freshwater
– reaction kinetics
+ water chemistry characterization

In general, "chemical effects" are accounted for in the West Valley PPA Model, and they are retained. This includes chemistry of the buffer material (backfill and cover) and other topics as noted above.

No special chemical effects are anticipated from construction per se, thus this is excluded. Steel reinforcing bar is part of the basic design, thus this is retained.

The effects of deliquescence (i.e., dissolution of a substance due to absorption of water vapor from air) are possibly important for the humid environment of the Site, thus this is retained.

No far-field (i.e., outside of engineered barriers) introduction of acids, oxidants, or nitrates is envisioned, thus this is excluded.

Mineralogic dehydration has not been observed in the glacial till at the Site, thus this is excluded.

Surface diffusion pertains to a faster rate of transport of some elements such as Cs and Sr in compacted clay layers than would be expected if they were adsorbed on the mineral surface. Compacted clay layers are part of the disposal design at the Site, thus this is retained.

Surface saltwater is not associated with the Site, thus saltwater/freshwater geochemistry is excluded. There is brine present in the deep geology of the Site, but this is addressed by other FEPS below (Section 5.2.3.11.1).

Chemical reaction kinetics are excluded. A simplifying assumption of geochemical modeling for the West Valley PPA Model is that all chemical reactions are instantaneous and reversible.

5.2.3.6.12 Redox and pH

+ pH
+ pH change
+ oxidizing conditions
? redox front
+ redox potential

The basic chemical concepts of redox (oxidation-reduction reactions) and pH are retained.

Redox fronts are unlikely to be relevant for surface water infiltration. However, this is pending review of the effects of radiolysis.

5.2.3.6.13 Waste Chemistry

– Pb/Cu electrochemical reactions
– Pb-I reactions

These FEPS are specific to lead and copper waste canisters for used nuclear fuel, which are not employed at the Site. Thus, these are excluded. Metallic Pb itself is included as a nonradioactive chemical contaminant.

5.2.3.7 Geochemistry and Hydrogeology

5.2.3.7.1 Diffusion in Water

+ water phase diffusion

Diffusion in the water phase is a basic geochemical process and is thus retained, but it is also tightly integrated with contaminant transport in water, which is a topic of hydrogeology. This and other basic hydrogeological fate and transport mechanisms are discussed in Section 5.2.3.11.3.

5.2.3.7.2 Radionuclide Transport

+ radionuclide transport

The modeling of fate and transport of radionuclides is a primary objective of the West Valley PPA Model, thus the processes contributing to radionuclide transport are retained. Fate and transport mechanisms are discussed in Section 5.2.3.11.3.

5.2.3.8 Geology

5.2.3.8.1 Breccia Pipes

– breccia pipes

Breccia pipes are not part of the Site geology, and thus are excluded.

5.2.3.8.2 Changes in Local Geology

– diagenesis
– diapirism
– induced diapirism
– metamorphism
+ hydrological/hydrogeological response to geological change

Diagenesis is possibly relevant to the Site geology, as this is a sedimentary province. However, it is unlikely to occur in the time scales of the analysis and thus is excluded.

The formation of salt diapirs, while of potential significance to WIPP or other salt-based repositories, is not part of the Site geology, and thus is excluded. Likewise, the Site is not in a predominantly metamorphic province, thus metamorphism is excluded.

Some geological changes, however, could occur at the Site (e.g., erosion). These could induce a response to hydrology and hydrogeology, and thus are retained.

5.2.3.8.3 Faulting

– discontinuities in geosphere
– far-field faulting
– fault activation
– fault generation
– faulting
+ faulting—near-field
+ faults, shear zones
+ fluids leave along new fault
– rapid fault growth

Regional subsurface geologic mapping in western New York has identified fracture lineaments and bedrock structure (DOE 2010a). The Site is located within the Bass Island Trend lineament system (Figure 3-12, DOE (2010a)), but features associated with this system itself would probably not affect the Site due to its long-term inactivity. The Clarendon-Linden Fault Zone has been identified as a source of historical seismic activity, and the Attica Splay is associated with the fault zone. Jacobi (2002), p. 106, identified potentially seismically active faults that may extend to the Site. Additionally, fracture intensification domains (Jacobi 2002) are locally associated with soil gas anomalies (e.g., methane concentrations from 40 to 1000 ppm). Faults near the Site may require additional investigation in order to determine relevance to Site stability. Faulting in the near field, shear zones, and fluid movements along faults are thus retained, but may have limited relevance as the effects would likely be overshadowed by seismic hazards (see Section 5.2.3.9.3 below). Other faulting related FEPS are excluded.

5.2.3.8.4 Fracturing

+ enhanced fracturing
+ formation of interconnected fracture systems
+ host rock fracture aperture change
– impact fracturing
+ local fracturing
+ static fracturing
+ surficial fissuring
+ fracture mechanics

Glacial till and underlying sedimentary strata throughout western New York contain systematically oriented joints and fractures. These fractures are a result of glacial rebound, stresses in the Earth's crust, stress release related to movement on the Clarendon-Linden Fault Zone, and volumetric changes in clay resulting from ion-exchange or osmotic processes (DOE 2010a). Fracture characteristics may affect movement of radionuclides in the Site hydrogeologic system (Bergeron et al. 1991). Thus, these are retained. Gas phase transport in fractures is discussed in Section 5.2.3.11.5.

Impact fracturing results from the impacts of one rocky body on another, either from rocks falling onto other rocks from a cliff (small-scale), or, for example, those resulting from meteorite impacts (larger scale). This is not likely to be important at the Site, and thus is excluded.

5.2.3.8.5 Geothermal Topics

– geothermal effects
– hydrothermal activity

Geothermal or hydrothermal activity may be present near the Site, albeit at much greater depths than would affect the Site facilities (NYSERDA 1983). Therefore, geothermal or hydrothermal activity is not likely to affect the Site in a substantial fashion, and is excluded.

5.2.3.8.6 Soils

+ near-surface temperature
– pedogenesis
+ soil and sediment

Near-surface temperatures of soils may influence air phase diffusivities, and thus are retained. Soils and sediment are retained as exposure media.

Pedogenesis (the formation of soil) is excluded, as soils are assumed to exist in a steady state throughout the time domain of the Model. There is no reason to specifically account for soil generation, thus this is excluded.

5.2.3.8.7 Subsidence

+ subsidence

Local subsidence of facility structures is retained. The fault segments and transfer zones of the Clarendon-Linden Fault Zone form fault blocks that have semi-independent subsidence and uplift histories (DOE 2010a). Therefore, geologic subsidence may also affect the Site disposal system.

5.2.3.8.8 Tectonics

– orogeny
– tectonics
– uplift and subsidence

Tectonic effects in the Site area may be associated with seismic and other geologic phenomena, such as post-glacial isostatic rebound, which are covered by other FEPS (Section 5.2.3.10). Tectonics *per se* are thus excluded.

5.2.3.8.9 Undetected Geological Features

– undetected features
– undetected fractures

The inclusion of features that are not known to exist is fundamentally speculative, and accounting for their potential effects is not defensible, thus these are excluded.

5.2.3.8.10 Volcanism

– chemical effects of magma and magmatic volatiles
– extrusive magmatic activity
– hot-spot volcanic activity
– igneous activity
– igneous intrusion
– magmatic activity
– rift system volcanic activity
– volcanic activity
– volcanic activity transports waste
– extrusive volcanism
– lava tubes

There are no volcanic related structures or active igneous phenomena in the Site area, so these FEPS are excluded.

5.2.3.8.11 Miscellaneous Geology Topics

+ stratigraphy
– surge beds

Stratigraphy refers to the structure of various geologic layers below the Site, thus this is retained, as it forms the basic geologic structure underlying the Site. Surge beds are a feature of volcanic areas, and thus are excluded (per above).

5.2.3.9 Geophysics

5.2.3.9.1 Geomagnetism

– change in the earth's magnetic field

No consequences for the Site resulting from changes in Earth’s magnetic field are anticipated, thus this is excluded.

5.2.3.9.2 Rock Mechanics

– earth tide effects
– elastic response, differential
– elastic, plastic, or brittle deformation
– external stress
– igneous activity changes rock properties
– jointed rock motion
– non-elastic response
– rock creep
– rock mechanics
– stress, excavation induced
– stress, thermally induced

Rock mechanics FEPS were generally developed for geologic repositories, and thus have limited relevance to the Site. Earth tide effects involve changes in water levels from aquifer deformation associated with cyclical gravitational attraction. Typically, these water-level fluctuations are small (< 0.15 m) and are difficult to separate from effects of local pumping and/or atmospheric

pressure changes (Inkenbrandt et al. 2005). These fluctuations are minor compared to observed water-table fluctuations of 1 to 2 m/yr associated with seasonal variations in recharge and discharge at the Site (Bergeron et al. 1987). Thus, this is excluded.

Rock mechanics effects on shallow excavations in Pleistocene and Holocene age glacial tills and sediments deposited in a U-shaped valley incised into Devonian bedrock are expected to be limited and strongly secondary to seismic activity and erosional effects on weakly consolidated sediments. Thus, elastic and non-elastic response, deformation, external stress, jointed rock motion, and rock creep FEPS are excluded.

There are no Quaternary igneous or volcanic rocks in the eastern United States (Reed et al. 2005). The probability of igneous or volcanic activity in the Site region is extremely low and there is no expectation of future changes in rock properties from igneous activity, thus this is excluded.

The characteristics of Holocene alluvium and Pleistocene glacial deposits at the Site are described in Section 3.3.2 of the FEIS (DOE 2010a). These deposits, particularly the Churchville and Hudson silt loams, are prone to erosion, particularly on slope areas (DOE (2010a), p. 3–29). Stability issues associated with the weakly consolidated sediments and potential future erosion of the glacial till plateau outweigh excavation induced stress, thus this is excluded. Wastes disposed at the Site are not expected to produce local elevated temperatures, thus thermally induced stress is excluded.

5.2.3.9.3 Seismicity

+ earthquake
+ earthquake, anthropogenic
+ seismic activity
+ seismic-induced repository damage
+ seismicity
– seismicity due to igneous activity

As previously discussed, the Clarendon-Linden Fault Zone and the Attica Splay exist in proximity to the Site, and historical earthquakes have occurred in the region, possibly associated with this fault zone (Jacobi 2002). There are no identified Quaternary faults in the eastern United States, so seismic hazards in the area are assessed from background intraplate seismic events. The Independent Expert Review Team for the Site suggested that the scientific basis for seismic hazard assessment in the FEIS be expanded with inclusion of seismic zones and both probabilistic and deterministic hazard analysis (Garrick et al. 2009a). Historical earthquakes, however, were not due to igneous activity, so that FEPS is excluded. Given the shallow-land burial configurations at the Site, and the cover design using unconsolidated materials, seismic activity of historical intensity may not have appreciable effects on containment structures themselves, but liquefaction has been identified as a potential issue (DOE 2010a). Additionally, seismic activity may increase the frequency and scale of mass-wasting events such as landslides. Anthropogenic earthquakes are possible, as western New York is the northern extent of the Marcellus shale formation, which has been subject to extensive hydraulic fracturing for the purpose of natural gas extraction (although this practice is currently banned in New York, there is no reason to expect that such a ban would be permanent). Therefore, most of the seismicity FEPS are retained.

5.2.3.9.4 Local Subsidence

– subsidence fractures end above repository
– subsidence fractures reach repository

Multiple bedrock structures have been identified in the Site region including the Clarendon-Linden Fault Zone, the Elzevir-Frontenac Boundary Zone, the Attica Splay, and the Bass Island Trend (see Figure 3-12, DOE (2010a)). Future reactivation of these structures may possibly occur with low rates of continuing isostatic uplift from Pleistocene retreat of continent ice sheets following the last glacial maximum, and/or background intraplate seismic activity. Two lines of evidence suggest that these features are unlikely to affect subsidence at the Site. First, the Clarendon-Linden fault system does not intersect the Site. The Attica Splay trends toward the Site but it is not known whether it directly intersects with the Site. Second, small-scale movement associated with isostatic rebound on any bedrock structures beneath the Site is unlikely to propagate upward through the weakly consolidated Pleistocene and Holocene sediments above. Deformation should be absorbed through combined compaction and/or porosity changes in the sediments. Effects of local rock subsidence are expected to be secondary to subsidence in the waste zone itself. Therefore, these FEPS are excluded. Subsidence within the waste and disposal system is described in Section 5.2.2.1.7.

5.2.3.10 Glaciology

+ glacially induced faulting
+ glacial deposits
? glacial activity
? glacial effects
? glacial erosion
? glaciation
+ isostatic subsidence and rebound
? gases under permafrost
? periglacial effects
? permafrost

The Site is located in an area that was formerly covered by the Laurentide Ice Sheet during the Pleistocene epoch, and the Site is located on glacial till deposits. Therefore, the area was formerly subject to all of the glaciology FEPS listed. Given a return to future glacial conditions, it is possible that the Site could be subject to glacial FEPS again. However, it is likely that the entire Site could be appreciably eroded before the next glacial period, especially if anthropogenic climate change delays this period. This timing will be investigated in the context of the CSM and will determine whether glaciation is explicitly modeled or not.

The region is subject to post-glacial isostatic rebound, as discussed in the FEIS in the context of erosion. A gradual western tilting could increase the stream gradients in Cattaraugus and Buttermilk Creeks, but this effect will be minor compared to the rapid erosion rates that are already experienced. This rebound effect, therefore, is accounted for within the context of erosion considered in Sections 5.2.3.4.1 and 5.2.3.4.2.

5.2.3.11 Hydrogeology

5.2.3.11.1 Brine Occurrence

+ brine migration
+ brine pockets
+ gas or brine pockets

Cattaraugus County is one of the top oil- and natural gas-producing counties in New York. For example, a total of 630 active gas wells existed in the county in 2014 (NYDEC 2014). Brine (salt water) is associated with natural gas formations. Thus, these FEPS are retained.

5.2.3.11.2 Changes in Hydrogeology

– desertification
+ resaturation
+ anthropogenic change to hydrogeology
– dewatering of host rock
+ human-induced actions on groundwater recharge
+ hydrogeologic effects of excavation and construction
+ induced hydrological change
+ intentional artificial groundwater recharge or withdrawal

Desertification is not likely in the environment of western New York in any envisioned time scale or climate changes, thus this is excluded.

Resaturation, which implies the introduction of large amounts of water into the waste disposal facility, is possible given the high precipitation of western New York, and thus is retained. Dewatering of the host rock, which would occur in a location where groundwater would be removed for the purposes of construction, is not envisioned for the shallow waste disposal system design of the Site, and thus is excluded.

Human-induced changes to the hydrologic and hydrogeologic system (for example, with regard to irrigation or septic leach fields after site closure), are retained. Intentional withdrawal could also occur from a water supply well or pump-and-treat system (e.g., existing groundwater remediation). The Site currently pumps groundwater from underlying bedrock to provide potable and fire suppression water.

Anthropogenic effects related to climate or land use that may affect infiltration are addressed in other FEPS.

5.2.3.11.3 Hydrogeological Fate and Transport Mechanisms

– convection
+ advection
+ diffusion
+ matrix diffusion
+ dilution
+ dilution in groundwater

Advection and dispersion will be modeled in the West Valley PPA Model, and thus advection is retained. Convection of fluids will not be explicitly modeled, as there is no driving mechanism

such as appreciable thermal or density gradients. Therefore, convection is excluded. Diffusion in the air and water phases within porous media, as well as dilution of radionuclides in fluids (air and water), are retained.

5.2.3.11.4 Dissolution of Geological Materials

– formation of dissolution cavities in salt

This FEPS was suggested for geologic repositories in or near massive salt formations (e.g., the WIPP site), and does not apply to the Site. Although salt and salt extraction occur in western New York, formations such as those at WIPP do not appear to exist in the vicinity of the Site. Thus, this is excluded.

5.2.3.11.5 Fracture Hydrogeology

– cooling joints
– fracture coatings
+ fracture fill
+ fracture flow

The modeling of fractures was discussed in Section 5.2.3.8.4, and fracture flow with respect to gas phase transport is also retained.

Cooling joints are associated with igneous rocks, which are not present at the Site, and thus this is excluded.

Fracture coatings are not of specific interest to fracture flow, and thus are excluded. However, fracture fill is important, and thus is retained.

5.2.3.11.6 Groundwater Hydraulics

+ advection-dispersion
+ aquifers
+ capillary rise
+ change in groundwater system
– chemically induced density effects in groundwater flow
+ condensation in the repository
+ condensation zone around repository
+ dilution within a water supply well
+ extreme channel flow of oxidants and nuclides
+ film flow enters repository
+ flow diversion around repository
+ flow shadow below repository
+ fluid interactions
+ fluids carry waste to rivers or tributaries
+ fluids carry waste to wells or springs
+ focused recharge
+ focusing of unsaturated flow (fingers, weeps)
– geosphere dehydration due to waste heat
– geosphere rehydration following dehydration due to waste heat
+ groundwater
+ groundwater conditions
+ groundwater discharge

+ groundwater flow
+ groundwater recharge
+ groundwater well capture efficiency
+ hydraulic/hydrogeological processes and conditions (in geosphere)
+ hydraulic/hydrogeological processes and conditions (in wastes)
– hydraulic conductivity change—excavation/backfilling effect
+ injection of liquid wastes
+ injection wells
+ lateral diversion of groundwater flow
+ lateral flow enters repository
+ matrix imbibition
+ multiphase flow
– natural geothermal effects on saturated zone flow
– natural geothermal effects on unsaturated zone flow
+ perched groundwater
+ pore water residence time
+ preferential pathways
+ radial dispersion
– repository dehydration due to waste heat
– repository-induced geothermal effects on unsaturated zone flow
– repository-induced thermal effects on saturated zone flow
+ seismically induced changes in perched water
+ subsurface evaporation
– thermally induced fluid migration
+ vadose zone

The field of groundwater hydraulics is fundamental to the modeling of groundwater flow, which is a prerequisite to modeling contaminant fate and transport in groundwater. Most of these FEPS are retained as part of groundwater hydraulics calculations.

In 2014 there were 13 active wastewater (from oil/gas development) injection wells in Cattaraugus County (NYDEC 2014). One bedrock injection well and four bedrock observation wells were installed on the WNYNSC in the late 1960s for hydrofracture testing, in order to evaluate the potential for liquid waste disposal at the Site (de Laguna 1972). Future injection wells are possible, therefore such wells are retained.

No chemically induced density effects (e.g. dissolution of salt) are indicated at the Site, thus this is excluded.

Engineered features such as slurry walls intended to divert groundwater flow are present at the Site, and will be considered as potential remedial options under Phase 2 decision making. These are intended to alter the flow of groundwater, creating diversions and flow shadows. Thus, these are retained.

Given the nature of the wastes disposed at the Site, no waste heat is generated, nor would there be “geosphere dehydration,” so these are excluded. This is discussed more fully in Section 5.2.5.1.8.

No changes in porous medium hydraulic conductivity would result from the use of backfill, or from excavation. The backfill has its own material properties, as does the surrounding host rock, but these properties will not change because of their use. Therefore, these are excluded.

Multiphase flow in the unsaturated zone, including relative permeabilities and capillary suction, will be modeled for the Site, thus this is retained.

No natural geothermal effects in unsaturated or saturated flow are anticipated, nor is thermally induced fluid migration of any kind, therefore these are excluded.

The FEPS concerning the generation of waste heat are in reference to nuclear fuels, but not the wastes disposed at the Site. Wastes could produce heat in exothermic reactions (see Section 5.2.5.1.8) or pyrophoric reactions (see Section 5.2.2.2.3).

5.2.3.11.7 Groundwater Modeling Parameters

– fluid pressure changes in time
+ gravity
+ hydraulic conductivity
+ permeability
+ seismically induced changes in porosity and permeability
+ surface tension
– thermally induced changes to fluid properties
+ vertical groundwater gradients
– head is below outfall

Groundwater flow responds to gravity, hydraulic conductivity, and permeability of porous media, surface tension of water, and groundwater gradients. These FEPS are all retained.

Fluid pressure changing in time has been suggested as a FEPS in the context of thermal causes (IAEA 1983), but, as stated previously, no thermal sources are identified in the wastes or the environment at the Site, nor are any thermally induced changes to other fluid properties anticipated.

Given the seismically active location of western New York (see Section 5.2.3.9.3), it is possible that seismically induced changes to porosity or permeability could occur, and thus are retained.

“Head is below outfall” is assumed to refer to a groundwater head being lower than the elevation of a discharge point, and its effect on radionuclide release and transport within a facility. This does not directly impact shallow-land disposal facility performance at the Site, and so is excluded.

5.2.3.11.8 Groundwater Particulate Transport

+ transport of particles larger than colloids

This FEPS is addressed in the context of sediment transport (see Section 5.2.3.12.5).

5.2.3.11.9 Water Intrusion into Repository

– repository resaturation due to waste cooling
+ water from a confined aquifer enters repository
+ water from an unconfined aquifer enters repository
+ water intrusion ("bathtubbing")

With the exception of resaturation due to waste cooling, these FEPS are potentially important at the Site, as it is subject to water intrusion from precipitation and groundwater, and all are retained.

5.2.3.11.10 Influence of Weathering on Hydrogeology

+ weathering of flow paths

Subsurface fractures are expected to be subject to additional weathering or dissolution (e.g., via erosion), and thus this is retained.

5.2.3.12 Hydrology

5.2.3.12.1 Changes in Hydrology

+ change in hydrology, anthropogenic
+ change in hydrology, natural
+ change in surface water
+ hydrologic stresses
– hydrology change from igneous activity
+ hydrology change from seismic activity
– large-scale alterations of hydrology

Most changes in the hydrologic system are retained, but for reasons stated above changes due to igneous activity are excluded from further consideration. Large-scale changes in hydrology other than those related to climate change or erosion, which are evaluated in other FEPS (see Sections 5.2.3.3 and 5.2.3.4), or glaciation (see Section 5.2.3.10), are not anticipated, and thus are excluded.

5.2.3.12.2 Infiltration

+ episodic infiltration
+ evaporation
+ flow through buffer/backfill
+ hydrological regime and water balance (near-surface)
+ infiltration and evapotranspiration
+ precipitation, temperature, soil, water balance

All FEPS related to the infiltration of water into surface soils are retained. The Site is subject to infiltration from both precipitation and groundwater.

5.2.3.12.3 Inundation

– flooding
+ large episodic runoff events
+ ponding

According to the FEIS, the Site is currently outside the 100-year floodplains of nearby creeks and brooks, so substantial flooding is unlikely in the short term. No longer-period flood mapping is available (DOE 2010a). However, given the difference in elevation between the Site and the thalweg of Buttermilk Creek, it is highly unlikely that substantial flooding from this source will occur, at least until the Site is eroded by mass wasting, in which case flooding would not be a

comparatively important FEPS. Therefore, flooding is excluded. The effects of water prior to closure are addressed via "repository flooding during operation" (see Section 5.2.2.1.5).

Large episodic runoff events (e.g. from thunderstorm rains, snowmelt, etc.) are possible at the Site, and thus are retained. Local ponding may occur as a consequence of subsidence of the disposal units, and is therefore retained.

5.2.3.12.4 Precipitation

– hurricane
+ pluvial periods
+ precipitation
+ precipitation—extreme
– precipitation—hail
+ precipitation—monsoon rain
+ thunderstorms

Hurricanes and their remnants have affected New York, but the effects on Site facilities are largely expected to be related to precipitation. Therefore, hurricanes *per se* are excluded. The enhanced precipitation resulting from hurricanes is retained, along with monsoon rains, thunderstorms, and other extreme events. Aside from its contributions to total precipitation, hail is excluded as no unique influence of hail on system performance has been identified.

5.2.3.12.5 Sediment Transport

+ freshwater sediment transport and deposition
+ sediment transport
+ sedimentation

All FEPS related to sediment transport are retained, as erosion and stream action are important at the Site.

5.2.3.12.6 Surface Water

+ lake level change
+ lakes, rivers, streams and springs
– river processes
+ surface water transport and mixing
+ dams, canals, pipelines, water collection/storage facilities
– natural dam formation/failure
+ reservoir construction/failure

The nearest lake that could be of concern is Lake Erie. "Lake level change" could possibly be of concern if contaminated sediments become exposed in the future, thus it is retained. The Site's elevation is sufficiently high that it is highly unlikely that the Site elevation would be decreased (via erosion), or the lake level increased, to the extent that flooding from this source would be a concern.

There are numerous streams near the Site that could affect the facility, especially considering long-term erosion, so these FEPS are retained. Two reservoirs are located on the Site, and several small reservoirs are located upstream of the Site within the Buttermilk Creek watershed, and their failure could lead to mass wasting events, covered in Section 5.2.3.4.2.

5.2.3.13 Marine Issues

– coastal erosion development of estuaries
– coastal features
– marine features
– marine processes
– storm surge
– tsunami
– sea level change

Given the location of the Site in western New York, all marine processes are excluded from further consideration because their effects are specific to coastlines. The one marine process that has effects far-reaching enough to influence the Site is hurricanes, discussed in Section 5.2.3.12.4.

5.2.3.14 Material Properties

5.2.3.14.1 Properties of Porous Media

+ material properties of backfill
+ material properties of porous media
+ material property change
+ rock heterogeneity

All material properties are important in the West Valley PPA Model, and thus are retained.

5.2.3.14.2 Swelling

+ swelling of clay backfill
+ swelling of corrosion products

The swelling of clays was introduced for the Swedish technology of using bentonite backfill to surround copper disposal canisters. Although this technology is not employed at the Site, clays may be used as a backfill material at the Site due to local availability; thus, this is retained.

The swelling of corrosion products would be relevant to steel-reinforced concrete, which is employed in some disposal areas of the Site. Steel can corrode, leading to structural failure of reinforced concrete, so this is retained.

5.2.4 Exposure and Activities

5.2.4.1 Human Exposure

5.2.4.1.1 Agriculture/Aquaculture

+ agriculture/aquaculture
– agriculture in canyons
– agriculture on mesatop
+ irrigation
+ irrigation with groundwater
+ irrigation with surface water

Aquaculture is excluded as it has no historical basis at the Site itself. Agriculture is retained, as there is extensive agriculture throughout the area. Both "canyon" and "mesatop" agriculture are FEPS associated with southwestern US sites, and thus are excluded for the West Valley Site. Irrigation applies to the effect of farm or garden irrigation on the infiltration rate and related radionuclide transport, and thus is retained. Irrigation with either groundwater or surface water is possible, so these are retained.

5.2.4.1.2 Demographics

+ community characteristics
+ social and institutional developments
+ urban development
+ demographics

Community, social, and institutional changes consistent with historical, present day, and foreseeable future states are retained. Based upon current and surrounding land uses, essentially any type of development could occur in the future, including a town or city on the Site. Demographics are of primary concern with regard to population-level dose estimates, so this FEPS is retained.

5.2.4.1.3 Dose Calculations

+ dose response
+ dosimetry
– sensitization to radiation effects

"Dose response" refers to the general model form relating radiation dose and effects, as well as to radionuclide-specific dose-response curves. This is retained only for modeling endpoints other than radiation dose (e.g. cancer risk).

Specific sensitizing effects of radiation, including organism responses and assumptions related to co-exposure to radiosensitizing drugs, would have little effect on the results of the West Valley PPA Model and are excluded.

5.2.4.1.4 Human Behaviors

+ future human actions
+ future human behavior
– human response to climate change

Future human actions and behavior are extrapolated from historical and current information, and thus are retained. Developing specific scenarios of how local human behaviors and responses may change as a function of future climate change would be conjecture and is outside the scope of the Model.

5.2.4.1.5 Human Exposure

+ contamination of non-food products
+ human characteristics (physiology, metabolism)

"Contamination of non-food products" is possibly relevant to wood used for heating, cooking, or other fires. Ceremonial or medicinal plants may be a component of some Amerindian scenarios (see Section 5.2.4.1.9). Thus, these are retained.

"Human characteristics (physiology, metabolism)" refers to interindividual variability that will be captured in the West Valley PPA Model input parameter distributions, and thus is retained.

5.2.4.1.6 Ingestion Human Exposure Pathway

+ drinking water, foodstuffs and drugs
+ food and water processing and preparation
+ ingestion of contaminated animal products
+ ingestion of drinking water
+ ingestion of food crops grown in contaminated soils and irrigated with well water

Ingestion of contaminated foods may be a feature of several human exposure scenarios, and thus is retained. This includes wild animals (e.g., deer, fish) and plants. "Food and water processing and preparation" addresses lag times between harvest and consumption, loss during food preparation, and the effects of food processing and water treatment; thus this is retained. Contamination pathways for foods may include contaminated soil, and/or irrigation or livestock watering with contaminated well water, and thus are retained.

5.2.4.1.7 Ingestion Animal Exposure Pathway

+ grazing

Grazing of livestock is retained due to animals' potential ingestion of contaminated forage, as well as direct ingestion of contaminated surface soil.

5.2.4.1.8 Inhalation Human Exposure Pathway

+ radon and radon decay product exposure

Radon and progeny are major sources of inhalation risk for humans, and thus are retained.

5.2.4.1.9 Land Use Scenarios

+ land use
+ land use change
+ Amerindian scenarios
+ dwelling construction
+ dwelling occupation
– kiva construction
– kiva occupation
– occupation of canyons
– occupation of mesas
+ post-closure inhabitation
+ recreation
+ septic drain field
+ underground construction
+ unintrusive site investigation
+ commercial development
+ industrial development

The Site is surrounded by a variety of land uses including towns, rural residential development, commercial/industrial development, farming, and so on. Therefore, all of these types of development are possible at the Site in the future after institutional knowledge of the Site is lost.

Future Amerindian scenarios are possible at the Site, and thus are retained, especially due to the nearby present-day Seneca Nation of Indians (SNI) Territories.

Residential dwellings could be built and occupied on the Site following loss of IC, so these are retained. Such dwellings could have basements, thus "underground construction" could occur and is retained. This could also occur with regard to commercial or industrial development (see below). Residential or other development could involve septic drain fields, thus this is retained.

"Kiva construction," "kiva occupation," "occupation of canyons," and "occupation of mesas" are all specific to southwestern US sites, and thus are excluded.

It is likely that nonintrusive site investigation would occur in any sort of development scenario, thus this is retained.

A large variety of commercial and/or industrial development is possible at the Site, based upon existing development in the area. Therefore, these FEPS have been added and are retained.

5.2.4.1.10 Water Supply

+ water supply—surface water
+ water well
+ water well—community
+ water well—household
+ groundwater use

Impoundment of surface water above the Site that would be in contact with contaminated media is possible after the Site erodes, thus this is retained. Water wells of any type are likely in any number of development scenarios, thus these are retained.

5.2.4.2 Human and/or Ecological Exposures and Risk

5.2.4.2.1 Exposure Media Concentrations

+ exposure media concentrations
+ intrusion into accumulation zone in the biosphere

Exposure media (e.g., soil, water, biota) concentrations are estimated in the West Valley PPA Model, thus this is retained. "Intrusion into accumulation zone in the biosphere" applies to radionuclides that have accumulated in biosphere media such as soils and sediments, thus this is retained.

5.2.4.2.2 External Irradiation/Immersion

+ direct radiation from airborne radionuclides
+ exposed sediments in a reservoir
+ external irradiation
+ external irradiation from soil or sediment
+ immersion in contaminated water

External irradiation encompasses both soil/sediment contaminant sources and airborne sources such as suspended particulates, thus these are retained. “Exposed sediments in a reservoir” is relevant due to the presence of the Scoby Dam, in Cattaraugus Creek, downstream of Buttermilk Creek. This is therefore retained. Immersion in contaminated water could occur in surface waters around the Site, and thus is retained.

5.2.4.2.3 Food Source Contamination

+ animal uptake of radionuclides
+ plant uptake of radionuclides
+ rainsplash (soil onto plants)

Animal and plant uptake of radionuclides in this context refers to incorporation into biotic tissues, as opposed to animals and plants as transport mechanisms of radionuclides in the disposal system and the environment. Animal and plant uptake is evaluated in conjunction with agricultural exposure, hunting, and fishing, and thus is retained. Rainsplash resulting in deposition of soil onto the leaves of food plants can contribute to plant uptake of radionuclides as well as to direct soil ingestion by humans and other animal receptors, and thus is retained.

5.2.4.2.4 Human and Ecological Exposure

+ exposure modes
+ impacts of concern

“Exposure modes” is understood to be synonymous with exposure pathways (ingestion, inhalation, external), and thus is retained. “Impacts of concern” is assumed to relate to identification of human effects endpoints such as radiological dose, cancer risk, and chemical toxicity, and thus is retained.

5.2.4.2.5 Ingestion Human and Ecological Exposure Pathways

+ diet and fluid intake
+ ingestion of contaminated soil
+ ingestion of radionuclides
+ surface water ingestion
+ uptake of contaminants in food chain

Diet, water, and soil ingestion are all potentially important exposure pathways at the Site, thus they are retained. Uptake of contaminants in the food chain is important in terms of agricultural use of the Site, as well as wild game and fish ingestion, and thus is retained.

5.2.4.2.6 Inhalation Human Pathway

+ inhalation of radionuclides

Inhalation of gas phase radionuclides, or solid phase radionuclides in dust, are both potentially important, and thus are retained.

5.2.4.2.7 Dermal Human Pathway

+ dermal exposure

Dermal absorption of radionuclides is not typically evaluated, as most radionuclides are metals or metal compounds, and have limited dermal absorption potential. However, this has not been evaluated for a large number of metals, and thus is uncertain. In general, nonradioactive contaminants (especially organic compounds) may be absorbed through the skin, thus this is retained.

5.2.4.2.8 Land Use and Ecological Systems

+ wild land and water use

This addresses foodstuffs and resources from natural or semi-natural tracts of land as well as the general representation of an intact ecological system and habitat; i.e. it is possible that the Site could revert to "wildness." It is of particular relevance to recreational and Amerindian land use scenarios, and thus is retained.

5.2.4.2.9 Toxicity

+ chemical toxicity of wastes
+ chemical toxicant stability
+ radiological toxicity

"Chemical toxicity of wastes" applies to both nonradioactive toxicants, as well as nonradiological toxicity of some radionuclides such as uranium (e.g., kidney toxicity), and thus is retained. "Chemical toxicant stability" is also retained. Radiological toxicity is evaluated implicitly in radiological effective dose and explicitly in cancer risk endpoints, and thus is retained.

5.2.4.3 Inadvertent Human Intrusion Issues

5.2.4.3.1 Inadvertent Human Intrusion

+ inadvertent human intrusion
– igneous event precedes inadvertent human intrusion
+ seismic event precedes inadvertent human intrusion
+ erosional event precedes inadvertent human intrusion

Inadvertent human intrusion is likely at the Site via a variety of mechanisms, and so is retained. Igneous activity is not expected to have an effect on the Site, as it is in a sedimentary province, and thus this is excluded. As discussed previously, seismicity is a concern at the Site, and could facilitate human intrusion, thus it is retained. Erosion will eventually expose any disposed waste at the Site, and thus facilitate intrusion, so this is retained.

5.2.4.3.2 Resource Extraction

+ groundwater extraction
+ mining
+ drilling and mining
+ drilling into repository
+ fossil fuel extraction
+ geothermal resources
+ hydraulic fracturing

+ mine shafts
+ other future uses of host rock
+ quarrying
+ geological resources
+ natural resource exploration/extraction
– tunneling
– undetected past intrusion
+ undiscovered boreholes
+ boreholes

FEPS related to groundwater extraction are discussed in Section 5.2.4.1.10.

There are two major resources that involve mining and drilling in the vicinity of the Site: oil/gas and gravel extraction. Cattaraugus County is one of the top oil- and gas-producing counties in New York. Additionally, more than 70 state-regulated commercial sand and gravel mines and gravel pits operate in Cattaraugus County, as well as a shale mine (DOE 2010a). Thus, any activities involving mining, quarrying, or drilling are retained. Hydraulic fracturing for natural gas is currently banned in New York, but it has been practiced in the past and may be in the future, thus it is retained. Given the long history of resource extraction, there could be undiscovered boreholes (e.g., for oil/gas, or for water) at the Site, thus this is retained. Although geothermal resources in western New York have not been exploited to a large extent historically, it is possible that these resources could be developed to a greater extent in the future. Therefore, this is retained.

"Tunneling" is not consistent with the waste disposal system design nor with historical, present day, or foreseeable future land use, thus this is excluded. It is possible that "undetected past intrusion" has occurred, but this would have little effect on performance of the Site, and thus is excluded.

5.2.4.4 Intentional Human Intrusion Issues

5.2.4.4.1 Intentional Intrusion

– exhumation
– archeological intrusion
– intentional intrusion
– malicious intrusion
– waste retrieval
– underground storage of energy resources
– underground nuclear testing
– reuse of boreholes
– weapons testing

Deliberate and intentional intrusion scenarios are difficult FEPS to consider in terms of probability. There is no precedent to draw upon (e.g., there has been no known deliberate removal of waste from closed permanent waste disposal facilities). Regardless, intentional intrusion would not be expected to result in appreciably different doses than many unintentional intrusion scenarios involving direct waste exposure (e.g., mining and drilling). Additionally, all of the unintentional intrusion FEPS that are applicable at a waste disposal facility assume that institutional and societal knowledge of wastes has been lost. If such knowledge has been lost, then logically it is highly unlikely that any sort of intentional intrusion would occur (i.e., a

potential intruder would have no knowledge of buried wastes). Conversely, if institutional/societal knowledge is not lost, then none of the unintentional intrusion FEPS would be applicable (e.g., it is highly unlikely that a known radioactive waste disposal facility would be mined for gravel). As all regulatory frameworks and previous PAs assume loss of institutional/societal knowledge and focus on unintentional intrusion, the choice is made here to also focus on this. Therefore, all intentional intrusion FEPS are globally excluded.

5.2.5 Miscellaneous FEPS

5.2.5.1.1 Accidents and Other Unplanned Events

– accidents and unplanned events
+ brush fire
+ wild fire
+ gas generation—explosion or fire
– H_2/O_2 explosions
– explosions, fire and crashes
– use of explosive devices

The FEPS "accidents and unplanned events" is assumed to apply to the period during excavation, construction, waste emplacement, and closure as other FEPS address accidental events occurring post-closure. This, this is excluded.

The FEPS "brush fire" and "wild fire" may pertain to impacts on plant cover that in turn may affect evapotranspiration and erosion. These are retained, but addressed in development of model parameter distributions rather than as explicit components of the West Valley PPA Model. The FEPS "gas generation—explosion or fire" will be retained because explosive gases (nickel carbonyl) were found to have been disposed at MDA B, a disposal site at LANL during a period similar to that of operations at West Valley.

Consideration of the FEPS "H_2/O_2 explosions" is not supported by knowledge of waste form or disposal technology at the Site. Impacts from sabotage related to explosive devices essentially amount to intentional intrusion, and thus are excluded.

Garrick et al. (2009b) conducted an analysis of various disruptive events at the Site, including airplane crashes and gas explosions. None of the events were of sufficient frequency to be retained.

5.2.5.1.2 Extraterrestrial Objects

– celestial bodies
– meteorites

The FEPS "celestial bodies" and "meteorites" are both assumed to refer to direct meteorite impact at the Site. This is considered to be highly improbable (Garrick et al. 2009b), and thus is excluded.

5.2.5.1.3 Human-induced Contaminant Transport

+ human-action-mediated transport of contaminants

Any human actions that facilitate contaminant transport are retained. An example is enhanced infiltration due to the effect of farm irrigation or septic leach fields, or via drilling a well.

5.2.5.1.4 Intentional Destruction

– sabotage
– war

Acts of sabotage or war with the intent of destroying the facility are highly unlikely, and amount to intentional intrusion (which has been globally excluded, per Section 5.2.4.4). The justification for such acts is difficult to imagine. It is possible that actions associated with war (such as bomb explosions) would compromise the facility, but the probability of this is impossible to estimate. Thus, these are excluded.

5.2.5.1.5 Speculative Events

– extraterrestrial events
– future technological development
– ozone layer failure

Substantive effects on the Site wastes related to the FEPS "extraterrestrial events," such as solar flares, supernovas, or alien contact, are considered to be highly unlikely and are thus excluded.

Future technological development may be addressed with regard to specific FEPS, such as drilling, but in general will have little impact on the Site and thus is excluded.

5.2.5.1.6 Nuclear Processes

? criticality, far-field
? criticality, near-field
– radiation effects
– radiation effects in repository
– radiation effects on bentonite
+ radioactive decay and ingrowth
+ radioactive decay and ingrowth in the biosphere
? radiolysis
? recoil of alpha-decay

No transport pathways have been identified that would lead to significant accumulation of fissile materials in the far-field, but this will be evaluated in more detail during the review of the Site inventory. Similarly, although packing and orientation of wastes containing fissile material is intended to preclude the possibility of criticality, there are drums of cemented NPR fuel with ruptured cladding disposed at the NDA. Therefore, criticality in the near-field will be evaluated further.

Radiation effects on the wastes, containers, shaft seals, backfill, and other engineered features of the Site will likely be minimal for the types of wastes disposed at the Site. Therefore, these are excluded.

Radioactive decay and ingrowth of progeny in the disposed wastes and throughout the modeled environment will be modeled in the West Valley PPA Model, and thus are included.

The impact of radiolysis on reduction-oxidation conditions in the disposal system is potentially relevant for wastes, pending review of the Site inventory. If relevant, this will be addressed in the context of model parameter distributions.

The FEPS "recoil of alpha-decay" concerns the possible destruction of fuel pellet (waste) structure induced by high energy alpha-particles. Although alpha recoil is a contributing factor in the estimation of the radon escape/production ratio, this process is uncertain in terms of importance for the wastes disposed at the Site, and will be investigated further.

5.2.5.1.7 Reconcentration in Environmental Media

+ accumulation in peat
+ accumulation in sediment
+ accumulation in soils
+ reconcentration in environmental media

The FEPS "accumulation in peat" is relevant to the Site environment, as peat mines exist in Cattaraugus County, so this is retained. Reconcentration or accumulation of radionuclides in other environmental media subsequent to release and transport, including peat, soils, and sediments, are retained. Reconcentration of radionuclides in the environment could conceivably be caused by sufficient reconcentration of fissionable materials, and thus is retained.

5.2.5.1.8 Thermal Effects

? exothermic reactions in the repository
– natural thermal effects
? heat distribution in repository
? heat generation in repository
? presence of a heat source
? radiogenic heat
? thermal (nuclear and chemical)
? thermal buoyancy
? thermal cracking
? thermal effects on chemistry and microbial activity
– thermal effects on radionuclide transport
– thermophoresis
– thermal effects on the biosphere
– thermal effects on the buffer material
– thermal effects on water flow
? thermal processes and conditions (in wastes and repository)
? thermal sensitization of waste package
? thermally induced stress in repository components
? thermally induced stress in waste package
? thermochemical change
– thermo-hydro-mechanical effects
? thermal effects from concrete hydration

"Exothermic reactions in the repository" pertains to chemical reactions that generate heat. Such a reaction is known to have occurred in a TRU waste stream from LANL (DOE 2015), but it is unclear at this time whether this would occur in Site wastes. Other FEPS grouped under "thermal effects" address heat generated by radioactive decay. Natural thermal effects such as heat gradients sufficient to impact radionuclide transport have not been identified at the Site.

The presence of nuclear fuel and related consequences will be evaluated in more detail during review of the Site inventory. For example, the possibility of gas-phase convection ("thermal buoyancy"), cracking of waste containers, or effects on waste packages due to radiogenic heat might be evaluated if wastes capable of generating sufficient heat are identified during inventory review.

Any thermal effects related to radioactive decay would occur within the disposed wastes and would not exert a direct influence on transport processes, including diffusive effects (thermophoresis), in the environment outside the disposal system. Thermal effects related to radioactive decay would likely have no discernible hydro-mechanical impacts on the near-surface Site disposal system, and thus are excluded.

5.2.5.2 Modeling Issues

These FEPS are highly generalized and pertain to the context and boundaries of the modeling environment.

+ modeling
+ radionuclide release outside the reference biosphere
+ spatial domain
+ timescale domain

Modeling of radionuclide release, transport, and human and ecological effects, with associated spatial and temporal boundaries, encompass the implementation of the CSM in the West Valley PPA Model, and thus are retained. Radionuclide transport beyond the Model boundaries (reference biosphere) is captured in the Model as accumulation of radioactivity in model "sinks," and thus is retained.

6.0 Use of FEPS in Developing the Conceptual Site Model

Following the establishment of a collection of FEPS that are relevant to the Site, a CSM that includes these FEPS is developed. The CSM defines how the disposal units and contaminated facilities and residuals are conceived to function, and how future human and ecological risks might result from the release of radioactive and chemical wastes. The CSM provides the foundation for the development of a quantitative West Valley PPA Model that implements this understanding. The CSM provides descriptions of the following:

- The physical environment where the West Valley Site is located.
- The regulatory context that helps to define the scope of the modeling.
- The disposed wastes.
- The engineered disposal units (SDA and NDA).
- Other contaminated facilities or residuals resulting from their remediation.

- The potential release pathways for radionuclides from the wastes into the environment.
- The transport pathways for radionuclides within and among environmental media.
- The potentially complete exposure pathways for humans and ecological receptors under relevant land use scenarios.
- The methods and endpoints used to assess potential human and ecological effects.

Many of the retained FEPS listed in Table 2 apply to more than a single topic in the CSM, so there is not a one-to-one mapping. For example, the FEPS "subsidence" is relevant to attributes of the engineered disposal system with respect to cause, and is also relevant to infiltration rate with respect to effects.

While the CSM integrates the retained FEPS, it is not limited in scope to only those topics defined in the FEPS. The collection of FEPS analyzed for applicability to the Site reflects the expertise of individuals working on PAs for a number of designs of disposal systems. Although many FEPS are generally applicable to any disposal system, each individual disposal system may have certain unique attributes that have not previously been encountered or recorded. The West Valley PPA Model is also unusual as a PA in that it considers many contaminated sites that were not the result of intentional disposals. Much of the information evaluated in the CSM is unique to the Site and the Model, and is captured in the FEPS in only a highly generalized manner.

7.0 References

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Appendix: FEPS Listings

This Appendix lists the features, events, processes, and scenarios (FEPS) identified for evaluation in CSM development. Table 1 contains all initial FEPS values, with references to their sources. The column of interest is that titled "Normalized FEPS," as these FEPS are those that are screened for inclusion in the CSM for the Site. This is followed by Table 2, which documents the results of screening the FEPS for the West Valley PPA Model.

Notes for Table 1:

Text in the "Original FEPS" column preserves the original sources' formatting, including punctuation and capitalization, where applicable.

Numbers in the Reference column are: 1: French et al. (2008), 2: FEPS added by Neptune, 3: SNL (2008), 4: NEA (2000), 5: NEA (2001), 6: Andersson et al. (1989), 7: Koplik et al. (1982), 8: Hunter (1989), 9: IAEA (1983), 10: Guzowski (1991), 11: Burkholder (1979), 12: Hertzler and Atwood (1989), 13: Merrett and Gillespie (1983), 14: NEA (1992), and 15: Hunter (1983).

References for Andersson et al. (1989), Burkholder (1979), Guzowski (1991), Hertzler and Atwood (1989), Hunter (1983), Hunter (1989), IAEA (1983), Koplik et al. (1982), and Merrett and Gillespie (1983) were cited in Guzowski and Newman (1993). NEA (1992), also cited in Guzowski and Newman (1993), has been largely superseded by NEA (2001).

Table 1. List of FEPS prior to screening, organized by topic.

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
regulatory context				
institutional control	active institutional control	active institutional control	active institutional control	1
			active institutional control	2
			Administrative Control of the Repository Site	3
			Administrative control, repository site	4
		post-closure surface activities	Post-closure surface activities	5
	loss of institutional control	loss of institutional control	loss of institutional control	1
			loss of institutional control	2
	monitoring	post-closure monitoring	Monitoring of repository	4
			Monitoring of the Repository	3
			postclosure monitoring	6
			post-closure monitoring	5
	passive institutional control	passive institutional control	passive institutional control	1
			passive institutional control	2

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
	records and markers	loss of records	loss of records	5
			loss of records	6
		records and markers	Records and Markers for the Repository	3
			Records and markers, repository	4
regulatory issues	regulatory issues	regulatory issues	Regulatory requirements and exclusions	4
			Regulatory Requirements and Exclusions	3
engineered systems				
engineering	construction defect	closure failure	abandonment of unsealed repository	5
			Incomplete Closure	3
			non-sealed repository	6
			unsealed boreholes and/or shafts	6
		faulty backfill placement	Error in Backfill Emplacement	3
		inadequate backfill compaction, voidage	inadequate backfill or compaction voidage	5
		poor quality construction	poor quality construction	5
			poorly constructed repository	6
	drip shields	drip shield failure modes	Advection of Liquids and Solids Through Cracks in the Drip Shield	3
			Creep of Metallic Materials in the Drip Shield	3
			Early Failure of Drip Shields	3
			General Corrosion of Drip Shields	3
			Localized Corrosion of Drip Shields	3
			Mechanical Impact on Drip Shield	3
			Microbially Influenced Corrosion of Drip Shields	3
			Oxygen Embrittlement of Drip Shields	3
			Stress Corrosion Cracking of Drip Shields	3
		hydrostatic pressure on drip shield	Hydrostatic Pressure on Drip Shield	3
		thermal sensitization of drip shields	Thermal Sensitization of Drip Shields	3
	engineered features	degradation of engineered features	Chemical Degradation of Emplacement Pallet	3
			Chemical Degradation of Invert	3
			Chemical Effects at repository Component Interfaces	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Chemical Effects of Rock Reinforcement and Cementitious Materials in repository	3
			Mechanical Degradation of Emplacement Pallet	3
			Mechanical Degradation of Invert	3
			Mechanical Effects at repository Component Interfaces	3
			Mechanical Effects of Rock Reinforcement Materials in repository	3
		hydrostatic pressure on canister	hydrostatic pressure on canister	6
			Hydrostatic Pressure on Waste Package	3
		seal performance	Degradation of Seals	3
			Flow Through Seals (Access Ramps and Ventilation Shafts)	3
			Radionuclide Transport Through Seals	3
			seal - rock interactions	7
			seal performance	8
			Seals. cavern/tunnel/shaft	4
	material defect	defect in backfill	backfill material deficiencies	6
		waste canister defects	common cause canister defects - Quality control	6
	mechanical failure	failure of waste packages	Early Failure of Waste Packages	3
		floor buckling	Floor Buckling	3
		mechanical failure of backfill	mechanical failure of buffer/backfill	6
		mechanical failure of repository	Drift Collapse	3
			mechanical failure of repository	6
		seal failure	degradation of hole- and shaft seals	6
			exploration bore-hole seal failure	9
			investigation borehole seal failure and degradation	5
			shaft and borehole seal degradation	10
			shaft or access tunnel seal failure and degradation	5
			shaft seal failure	11
			shaft seal failure	9
			shaft seal failure	7
			shaft/borehole seal failure	12

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
	operational activities	ground disturbance	site disturbance	1
		pavement	pavement	1
		phased operations	effects of phased operation	5
		remediation	Remedial actions	4
		repository flooding during operation	repository flooding during operation	5
		repository ventilation	Preclosure Ventilation	3
		schedule and planning	Schedule and planning	4
			Schedule and Planning	3
		unsuccessful attempt of site improvement	unsuccessful attempt of site improvement	6
	operational error	accidents during operation	accidents during operation	5
			accidents during operation	6
		waste disposal error	Faulty operation	9
			improper waste emplacement	11
			improper waste emplacement	12
			improper waste emplacement	7
			radioactive waste disposal error	5
	repository design	design modification	design modification	5
		faulty design	Faulty design	9
			Improper design of operation	7
		poorly designed repository	Inadequate Quality Control and Deviations from Design	3
			poorly designed repository	6
		repository design and construction	Excavation/construction	4
			Repository design	4
			Repository Design	3
		retrievability	Retrievability	4
			Retrievability	3
	subsidence	repository convergence	cavities and repository drifts converge	5
		subsidence in the waste zone	Effects of Subsidence	3
			subsidence / collapse	5
			subsidence / settlement	1
			subsidence of canister	7
			subsidence of waste	1
	waste configuration	disposal pits	disposal pits	1
		disposal shafts	disposal shafts	1
waste	co-disposal of nonradioactive waste	co-disposal of nonradioactive waste	non-nuclear waste disposal	11
			non-nuclear waste disposal	7
	co-disposal of radioactive waste	co-disposal of radioactive waste	co-storage of other waste	6

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Interactions Between Co-Disposed Waste	3
			Interactions Between Co-Located Waste	3
			near storage of other waste	6
		co-disposal of reactive wastes	co-disposal of reactive wastes (deliberate)	5
	co-disposal of undesirable materials	inadvertent inclusion of undesirable materials	decontamination materials left	6
			inadvertent inclusion of undesirable materials	5
			stray materials left	6
			Undesirable Materials Left	3
	disposal configuration	faulty waste placement	Error in Waste Emplacement	3
			faulty waste emplacement	9
		waste placement	Emplacement of wastes and backfilling	4
			Physical Form of Waste Package and Drip Shield	3
			Repository-Scale Spatial Heterogeneity of Emplaced Waste	3
	nuclear processes	criticality	criticality	11
			criticality	12
			criticality	7
			criticality	6
			nuclear criticality	9
			Nuclear criticality	4
			nuclear criticality	5
			nuclear criticality	8
			nuclear fission	1
		criticality, in waste	In-Package Criticality (Degraded Configurations)	3
			In-Package Criticality (Intact Configuration)	3
			In-Package Criticality Resulting from a Seismic Event (Degraded Configurations)	3
			In-Package Criticality Resulting from a Seismic Event (Intact Configuration)	3
			In-Package Criticality Resulting from an Igneous Event (Degraded Configurations)	3
			In-Package Criticality Resulting from an Igneous Event (Intact Configuration)	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			In-Package Criticality Resulting from Rockfall (Degraded Configurations)	3
			In-Package Criticality Resulting from Rockfall (Intact Configuration)	3
		nuclear activation	nuclear activation	1
	source release	glass waste form cracking	HLW Glass Cracking	3
		glass waste form degradation	HLW Glass Degradation (Alteration, Dissolution, and Radionuclide Release)	3
		glass waste form recrystallization	HLW Glass Recrystallization	3
		heterogeneity of waste forms (chemical, physical)	CSNF Degradation (Alteration, Dissolution, and Radionuclide Release)	3
			DSNF Degradation (Alteration, Dissolution, and Radionuclide Release)	3
			heterogeneity of waste forms (chemical, physical)	5
		I, Cs-migration to fuel surface	I, Cs-migration to fuel surface	6
			Radionuclide Release from Gap and Grain Boundaries	3
		induced chemical change (solubility sorption, species equilibrium, mineralization)	induced chemical changes (solubility sorption, species equilibrium, mineralization)	5
		interactions of waste and repository materials with host materials	Chemical Effects of Waste-Rock Contact	3
			interactions of host materials and ground water with repository material (ex. concrete carbonation, sulphate attack)	5
			interactions of waste and repository materials with host materials (electrochemical corrosive agents)	5
		pyrophoric waste event	Pyrophoricity from DSNF	3
		radon emanation from waste	radon emanation from waste	2
		waste / rock interaction	waste / rock interaction	8
			waste package - geology interactions	11
			waste package - geology interactions	7
			waste package-rock interactions	9
	waste characterization	radioactive source in waste	Presence of a radioactive source	13
		unanticipated waste composition	unanticipated waste composition	12

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		waste characterization	Waste allocation	4
			Waste form materials and characteristics	4
	waste chemistry	chemical effects of void space in waste package	Chemical Effects of Void Space in Waste Package	3
		chemical liquid waste disposal	chemical liquid waste disposal	11
			chemical liquid waste disposal	12
			chemical liquid waste disposal	9
			chemical liquid waste disposal	7
		geochemical processes in waste	Chemical/geochemical processes and conditions (in wastes and [repository])	4
		interactions with corrosion products and waste	interactions with corrosion products and waste	6
		introduced complexing agents and cellulosics	introduced complexing agents and cellulosics	5
			Organic/Cellulosic Materials in Waste	3
		solubility within fuel matrix	solubility within fuel matrix	6
	waste containment	change in hydrostatic pressure on container	changed hydrostatic pressure on canister	6
		corrosion	corrosion	11
			corrosion	9
			corrosion	7
			corrosion	1
			corrosive agents, sulphides, oxygen etc	6
			internal corrosion due to waste	6
			pitting	6
		corrosion of containers	General Corrosion of Waste Packages	3
			Internal Corrosion of Waste Packages Prior to Breach	3
			Localized Corrosion of Waste Packages	3
			metallic corrosion	14
			Microbially Influenced Corrosion of Waste Packages	3
			Re-Dissolution of Precipitates Directs More Corrosive Fluids to Waste Packages	3
			Stress Corrosion Cracking of Waste Packages	3
			Volume Increase of Corrosion Products Impacts Cladding	3
			Volume Increase of Corrosion Products Impacts Other repository Components	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Volume Increase of Corrosion Products Impacts Waste Package	3
		corrosion of copper waste canisters	backfill effects on copper corrosion	6
			chemical reactions (copper corrosion)	6
			Copper Corrosion in repository	3
			role of chlorides in copper corrosion	6
		creep in copper waste containers	creeping of copper	6
		damaged or deviating fuel	damaged or deviating fuel	6
		degradation of fuel cladding	Cladding Unzipping	3
			Creep Rupture of Cladding	3
			Degradation of Cladding from Waterlogged Rods	3
			Degradation of Cladding Prior to Disposal	3
			Diffusion-Controlled Cavity Growth in Cladding	3
			DSNF Cladding	3
			Enhanced Corrosion of Cladding from Dissolved Silica	3
			General Corrosion of Cladding	3
			Hydride Cracking of Cladding	3
			Internal Pressurization of Cladding	3
			Localized (Crevice) Corrosion of Cladding	3
			Localized (Fluoride Enhanced) Corrosion of Cladding	3
			Localized (Pitting) Corrosion of Cladding	3
			Localized (Radiolysis Enhanced) Corrosion of Cladding	3
			Mechanical Impact on Cladding	3
			Microbially Influenced Corrosion (MIC) of Cladding	3
			Naval SNF Cladding	3
			Stress Corrosion Cracking (SCC) of Cladding	3
		flammable gas generation	Flammable Gas Generation from DSNF	3
		internal pressure	internal pressure	6
		loss of ductility	loss of ductility	6
		stress analysis	stress analysis	13
		stress change of conductivity	stress changes of conductivity	6

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		vault-related events	vault-related events	13
		voids in the lead filling	voids in the lead filling	6
		waste canister failure	Advection of Liquids and Solids Through Cracks in the Waste Package	3
			cracking along welds	6
			Creep of Metallic Materials in the Waste Package	3
			Hydride Cracking of Drip Shields	3
			Hydride Cracking of Waste Packages	3
			random canister defects - Quality control	6
			release of radionuclides from failed canister	6
			role of the eventual channeling within the canister	6
			stress corrosion cracking	6
		waste canister movement	canister migration	7
			canister movement	11
			canister movement	9
			canister movement	7
			canister or container movement	5
			Consolidation of repository Components	3
			movement of canister in buffer/backfill	6
		waste containment	Container materials and characteristics	4
			Episodic Or Pulse Release from Repository	3
			Long-Term Release of Radionuclides from The Repository	3
			Mechanical Impact on Waste Package	3
			Mechanical processes and conditions (in wastes and [repository])	4
	waste inventory	waste inventory	Grouping of DSNF Waste Types Into Categories	3
			Inventory, radionuclide and other material	4
			Waste Inventory	3
		waste inventory heterogeneity	Heterogeneity of Waste Inventory	3
environmental systems				
atmosphere	atmosphere	atmosphere	Atmosphere	4
	atmospheric deposition	dry deposition	particulate dry deposition	1

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		wet deposition	below-cloud scavenging (washout)	1
			in-cloud scavenging (rainout)	1
			particulate wet deposition	1
	atmospheric dispersion	atmospheric dispersion	atmospheric dispersion	1
			atmospheric transport	1
			Atmospheric transport of contaminants	4
			Atmospheric Transport of Contaminants	3
		atmospheric inversion	atmospheric inversion	1
		atmospheric turbulence	atmospheric turbulence	1
		barometric pumping	barometric pumping	1
		dust devils	dust devils	1
			Dust devils	2
		gas diffusion into atmosphere	gaseous diffusion into atmosphere	1
		ground surface roughness	ground surface roughness	1
		resuspension	particulate resuspension	1
			resuspension of dust	2
		saltation	saltation	1
		topography	topography	1
			Topography and morphology	4
			Topography and Morphology	3
		tornado	tornado	12
			tornado	1
		wind	wind	1
		wind-induced contaminant transport	wind-induced contaminant transport	1
	meteorology	lightning	lightning	1
		meteorology	Meteorology	4
biology	biochemical effects	biochemical gas generation	biochemical gas generation	11
		biochemical processes in geosphere	Biological/biochemical processes and conditions (in geosphere)	4
		biochemical processes in repository	Biological/biochemical processes and conditions (in waste and [repository])	4
	biotically-induced contaminant fate and transport	animal burrowing	Animal burrowing	2
			Animal Burrowing/Intrusion	3
			animal burrows	1
			animal intrusion	1
			burrowing animals	1

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		animal, plant and microbe mediated fate and transport of contaminants	Animal, plant and microbe mediated transport of contaminants	4
		biomass production	biomass production	1
		biosphere characteristics	Biosphere Characteristics	3
		bioturbation	soil and sediment bioturbation	5
		burrow collapse	burrow collapse	1
		burrow excavation	burrow excavation	1
		burrow renewal	burrow renewal	1
		plant intrusion	plant intrusion	1
		plant root profile	plant root profile	1
			uptake by deep rooting species	5
		plant senescence	plant litter generation	1
			plant senescence	1
		plant uptake	plant root uptake	1
			plant uptake	5
		vegetation	Vegetation	4
	ecological community	animal populations	Animal populations	4
		ecological response to climate change	Ecological response to climate changes	4
			ecological response to climatic change	5
		ecological response to wildfire	ecological change (ex. forest fire cycles)	5
		ecological succession	ecological succession	1
	ecological risk	uptake by animal, plant, root	uptake by animal, plant, root	5
	evolution	evolution	plant and animal evolution	5
			Species evolution	4
			Species Evolution	3
	microbiology	microbial systems	Ecological/biological microbial systems	4
			microbes	6
			Microbial Activity in repository	3
			Microbial Activity in the SZ	3
			Microbial Activity in the UZ	3
			microbial interactions	5
			Microbial/biological/plant-mediated processes,	4
		radiological mutation of microbes	Radiological Mutation of Microbes	3
climate change	anthropogenic changes in biosphere	anthropogenic change in biosphere	Biosphere alteration	7
	anthropogenic climate change	anthropogenic climate change	anthropogenic climate changes (greenhouse effect)	5
			climate control	12
			Climate control	9

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			climate modification	11
			climate modification	7
			Human influences on climate	4
			Human Influences on Climate	3
			human-induced climate change	6
	climate change	climate change	climate change	1
			Climate Change	3
			climatic change	12
			climatic change	9
			climatic change	8
			Climatic fluctuations	7
			Greenhouse Gas Effects	3
		climate change, global	Climate change, Global	4
		climate change, regional and local	Climate change, regional and local	4
		hydrologic / hydrogeologic response to climate change	Climate Modification Increases Recharge	3
			Hydrological/hydrogeological response to climate changes	4
			Water Table Decline	3
			Water Table Rise Affects SZ	3
			Water Table Rise Affects UZ	3
		no ice age	no ice age	5
			no ice age	6
		warm climate effects	Warm climate effects (tropical and desert)	4
erosion	erosion	animal burrowing inducing erosion	animal burrows (inducing erosion)	1
		anthropogenic erosion	erosion enhanced by engineered surface water controls	1
		denudation and erosion	denudation	13
			denudation	9
			denudation (eolian and fluvial)	5
			Denudation and fluvial erosion	13
			Denudation and Stream Erosion	11
			Denudation and stream erosion	7
			Erosion/Denudation	3
		deposition	Deposition	3
			Erosion and deposition	4
			Erosion and sedimentation	4
			erosion/ sedimentation	10
		erosion	erosion of buffer/backfill	6
			erosion on surface/sediments	6
			land erosion	12
		erosion from rainsplash	rainsplash (inducing erosion)	1
		erosion from surface water	fluvial erosion	13

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			river, stream, channel erosion (downcutting)	5
			stream erosion	9
			surface water erosion	1
		erosion from tree-throw	tree-throw (inducing erosion)	1
		erosion from wave action	erosion from wave action	2
			seiches	10
		erosion from wind	soil loss due to wind erosion	1
		erosion of ground surface	surface erosion	1
	mass wasting	erosion of cliffs	cliff erosion	1
		landslide	land slide	5
			landslide	12
			landslides	1
		mass wasting	mass wasting	1
			mass wasting	2
			mass wasting	10
		rockfalls	Rockfall	3
			rockfalls	1
	weathering	chemical weathering	chemical denudation and weathering	5
		frost weathering	frost weathering	5
gas phase transport	gas generation	decay product gas generation	decay product gas generation	11
			decay product gas generation	12
			decay product gas generation	7
			decay-product gas generation	9
			Gas Generation (He) from Waste Form Decay	3
			gas generation: He production	6
		gas generation	gas generation	9
			gas generation	7
			Gas generation	6
			gas generation waste effect	8
			Gas sources and effects (in wastes and [repository])	4
			generation of radioactive gases	5
		gas generation from microbial degradation	Gas Generation (CO2, CH4, H2S) from Microbial Degradation	3
			microbiological (effects on corrosion/degradation, solubility/complexation, gas generation, ex. CH4,CO2)	5
		gas generation with pressurization	Gas Generation (Repository Pressurization)	5
			Gas Generation (Repository Pressurization)	3
		hydrogen gas generation corrosion of steel	Gas Generation (H2) from Waste Package Corrosion	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		thermally induced release of gases from pores and fluid inclusions	Thermally induced release of gases from pores and fluid inclusions	5
	gas phase transport	effects of radioactive gases in repository	Effects of Radioactive Gases in repository	3
		gas / water partitioning	gas/water partitioning	1
		gas effects in porous media	Gas Effects in the SZ	3
			Gas Effects in the UZ	3
		gas generation	Gas sources and effects (in geosphere)	4
		gas phase diffusion	gas phase diffusion	1
		gas phase tortuosity	gas phase tortuosity	1
		gas phase transport	gas mediated transport	5
			gas transport	6
			gas transport in bentonite	6
			Gas Transport in Geosphere	3
			Gas Transport in repository	3
			Gas-mediated transport of contaminants	4
		natural air flow in porous media	Natural Air Flow in the UZ	3
		natural gas intrusion	methane intrusion	6
			natural gas intrusion	5
		noble gases	Noble gases	4
		radon diffusion	radon diffusion	1
		radon emanation	radon emanation	2
		radon flux	radon flux	1
		volatiles	Volatiles and potential for volatility	4
geochemistry	bentonite chemistry	bentonite coagulation	coagulation of bentonite	6
		bentonite degradation	degradation of the bentonite by chemical reactions	6
		bentonite geochemistry	effects of bentonite on ground-water chemistry	6
		bentonite sedimentation	sedimentation of bentonite	6
	biogeochemistry	cellulosic degradation	cellulosic degradation	5
		soil nutrient cycling	soil nutrient cycling	2
		metals cycling	metals cycling	2
		soil organic carbon/biomass changes	soil organic carbon/biomass changes	2
	cement chemistry	cement carbonation	cement carbonation	2
		cementitious pore water	reactions with cement pore water	6
		recrystallization	recrystallization	6
	change in geochemistry, anthropogenic	acid rain	Acid Rain	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		anthropogenic change in soil and surface water chemistry	Altered Soil Or Surface Water Chemistry	3
			altered soil or surface water chemistry	14
			altered surface water chemistry by humans	6
		geochemical effects of excavation and construction	Chemical Changes in the Near-Field from Backfill	3
			Chemical Effects of Excavation and Construction in the Near-Field	3
		geochemical transformation (manmade)	geochemical changes from manmade causes	12
	change in geochemistry, natural	change in groundwater chemistry	change of groundwater chemistry in nearby rock	6
		geochemical alterations	geochemical alterations	11
			geochemical alterations	7
		geochemical change (natural)	geochemical changes from natural causes	12
		geochemical transformation	chemical transformations	5
			geochemical change	9
		rind formation	Chemical Interaction With Corrosion Products	3
			Rind (Chemically Altered Zone) Forms in the Near-Field	3
		thermochemical alteration	Thermo-Chemical Alteration in the SZ (Solubility, Speciation, Phase Changes, Precipitation/Dissolution)	3
			Thermo-Chemical Alteration in the UZ (Solubility, Speciation, Phase Changes, Precipitation/Dissolution)	3
			Thermo-Chemical Alteration of the Calico Hills Unit	3
			Thermo-Chemical Alteration of the Topopah Spring Basal Vitrophyre	3
	chemical gradients	chemical gradients	chemical gradients (electrochemical effects and osmosis)	14
	chemical speciation and solubility	chemical speciation and solubility	aqueous solubility	1
			chemical speciation	1
			Radionuclide Solubility in the Excavation Disturbed Zone	3
			Radionuclide Solubility Limits in the Biosphere	3
			Radionuclide Solubility Limits in the SZ	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Radionuclide Solubility Limits in the UZ	3
			Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and repository	3
			solubility and precipitation	6
			solubility limit	5
			Speciation and solubility, contaminant	4
		inorganic solids / solutes	Inorganic solids/solutes	4
		non-radioactive solutes	non-radioactive solute plume in geosphere (effect on redox, ph and sorption)	5
	colloids	colloid formation in repository	colloid generation - source	6
			Formation of Microbial Colloids in repository	3
			Formation of Pseudo-Colloids (Corrosion Product) in repository	3
			Formation of Pseudo-Colloids (Natural) in repository	3
			Formation of True (Intrinsic) Colloids in repository	3
		colloids and complexing agents	colloids, complexing agents	6
	complexation	complexing agents	Chemical/complexing agents, effects on contaminant speciation/transport	4
			Complexation in repository	3
			Complexation in the SZ	3
			Complexation in the UZ	3
			complexing agents	5
			complexing agents	6
	deliquescence	effects of deliquescence on metals	Localized Corrosion on Drip Shield Surfaces Due to Deliquescence	3
			Localized Corrosion on Waste Package Outer Surface Due to Deliquescence	3
	dissolution / precipitation	alpha recoil enhances dissolution	Alpha Recoil Enhances Dissolution	3
		dissolution and leaching	dissolution	12
			dissolution	8
			dissolution chemistry	6
			Dissolutioning	11
			Dissolutioning	7
			Erosion or Dissolution of Backfill	3
			Large-Scale Dissolution	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			leaching	1
			leaching	8
			Recycling of Accumulated Radionuclides from Soils to Groundwater	3
		dissolution of host rock	dissolution other than leaching	8
		dissolution, precipitation, and crystallization	dissolution, precipitation, and crystallization	5
			Dissolution, precipitation, and crystallization, contaminant	4
		geochemical interactions and evolution	Geochemical Interactions and Evolution in the SZ	3
			Geochemical Interactions and Evolution in the UZ	3
	electrochemistry	electrochemical reactions	Electrochemical Effects in repository	3
			natural telluric electrochemical reactions	6
	electrophoresis	electrophoresis	coupled effects (electrophoresis)	6
	geochemical effects	buffer material chemistry	near field buffer chemistry	6
			perturbed buffer material chemistry	6
		chemical effects	chemical effects	12
			Chemical effects	7
		chemical effects of construction	Chemical Effects of Excavation and Construction in repository	3
		chemical effects of steel reinforcing bar in repository	chemical effects of rock reinforcement	6
		far field hydrochemistry - acids, oxidants, nitrates	far field hydrochemistry - acids, oxidants, nitrates	6
		groundwater geochemistry	Chemical Characteristics of Groundwater in the SZ	3
			Chemical Characteristics of Groundwater in the UZ	3
		ion exclusion	ion exclusion	1
		isotopic dilution	isotopic dilution	6
			Isotopic Dilution	3
		mineralogic dehydration reactions	Mineralogic Dehydration Reactions	3
	organic chemistry	organic chemistry	Organics and potential for organic forms	4
	partitioning	sorption	chemical sorption	1
			saturation of sorption sites	6
			Solid-mediated transport of contaminants	4
			sorption	6
			sorption (linear/non-linear, reversible/irreversible)	5

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Sorption in the SZ	3
			Sorption in the UZ	3
			Sorption of Dissolved Radionuclides in repository	3
			Sorption/desorption processes, contaminant	4
	pH	pH	pH	1
		pH change	pH-deviations	6
	redox	oxidizing conditions	oxidizing conditions	6
		redox front	redox front	6
		redox potential	oxidation/reduction potential	1
			redox potential	6
			Reduction-Oxidation Potential in Drifts	3
			Reduction-Oxidation Potential in Waste Package	3
	saltwater chemistry	saltwater-freshwater	effects at saline-freshwater interface	5
			saline or fresh ground-water intrusion	6
			saline or freshwater intrusion	5
	surface chemistry	surface diffusion	diffusion - surface diffusion	6
	waste chemistry	Pb / Cu electrochemical reactions	repository induced Pb/Cu electrochemical reactions	6
		Pb-I reactions	Pb-I reactions	6
	water chemistry in repository	reaction kinetics	Reaction Kinetics in Drifts	3
			Reaction Kinetics in Waste Package	3
		water chemistry characterization	Chemical Characteristics of Water in Drifts	3
			Chemical Characteristics of Water in Waste Package	3
			Chemistry of Water Flowing into the Drift	3
			Chemistry of Water Flowing into the Waste Package	3
geochemistry; hydrogeology	colloid transport	colloid advection	Advection of Colloids in repository	3
		colloid diffusion	Diffusion of Colloids in repository	3
		colloid filtration	Filtration of Colloids in repository	3
		colloid formation, dissolution and transport	colloid formation, dissolution and transport	5
		colloid sorption	Sorption of Colloids in repository	3
		colloid stability	Stability of Colloids in repository	3
		colloid transport	colloid generation and transport	6
			Colloidal Transport in the SZ	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Colloidal Transport in the UZ	3
			Colloids. contaminant interactions and transport with	4
			Formation of Colloids (Waste-Form) By Co-Precipitation in repository	3
			Gravitational Settling of Colloids in repository	3
			Sorption of Colloids at Air-Water Interface	3
	diffusion	water phase diffusion	water phase diffusion	1
	radionuclide transport	radionuclide transport	Coupled Effects on Radionuclide Transport in repository	3
			Radionuclide Transport in Backfill	3
			Radionuclide Transport in the Excavation Disturbed Zone	3
geology	breccia pipes	breccia pipes	breccia pipes	11
			breccia pipes	9
			breccia pipes	7
			breccia-pipe formation	8
	changes in rock	diagenesis	diagenesis	11
			diagenesis	12
			diagenesis	9
			diagenesis	7
			Diagenesis	4
			diagenesis	5
			diagenesis	6
			Diagenesis	3
		diapirism	diapirism	11
			diapirism	12
			diapirism	9
			diapirism	7
			diapirism	5
			diapirism	10
			Diapirism	3
			Salt diapirism and dissolution	4
			Salt Diapirism and Dissolution	3
		induced diapirism	induced diapirism	8
		metamorphism	metamorphic activity	5
			Metamorphism	4
			Metamorphism	3
	discontinuities in geosphere	discontinuities in geosphere	Discontinuities, large scale (in geosphere)	4
	faulting	far-field faulting	far-field faulting	11
			far-field faulting	7
		fault activation	fault activation	5

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Fault Displacement Damages repository Components	3
		fault generation	fault generation	5
			new fault formation	13
		faulting	fault zone	1
			faulting	12
			faulting	9
			faulting	6
			faulting	8
			faulting	10
			Faults	3
			slow fault growth	13
		faulting - near-field	near-field faulting	11
			near-field faulting	7
		faults, shear zones	faults, shear zones	11
			faults, shear zones	9
			faults, shear zones	7
		fluids leave along new fault	fluids leave along new fault	15
		rapid fault growth	rapid fault growth	13
	fracturing	enhanced fracturing	enhanced rock fracturing	6
		formation of interconnected fracture systems	formation of interconnected fracture systems	10
		host rock fracture aperture change	host rock fracture aperture changes	5
		impact fracturing	impact fracturing	11
			impact fracturing	7
		local fracturing	Fractures	3
			fracturing due to elevated temperature and gas pressure.	5
			local fracturing	11
			local fracturing	9
			local fracturing	7
		static fracturing	Static Fracturing	11
			Static fracturing	7
		surficial fissuring	surficial fissuring	11
			surficial fissuring	7
	geothermal	geothermal effects	Thermal processes and conditions (in geosphere)	4
		hydrothermal activity	Hydrothermal activity	4
			Hydrothermal Activity	3
	hydrogeological changes	hydrological / hydrogeological response to geological change	Hydrological / hydrogeological response to geological changes	4
	soils	near-surface temperature	near-surface temperature	1
		pedogenesis	pedogenesis	0
		soil and sediment	Soil and sediment	4
			Soil Type	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
	stratigraphy	stratigraphy	Geological units, other	4
			Stratigraphy	3
		surge beds	surge beds	1
	subsidence	subsidence	local subsidence/caving	12
			stress field changes, settling, subsidence or caving	5
			subsidence	8
			subsidence and caving	10
	tectonics	orogeny	orogenic	9
			Orogenic Diastrophism	11
			Orogenic diastrophism	7
		tectonics	effect of plate movements	6
			epeirogenic	9
			Epeirogenic Displacement	11
			Epeirogenic displacement	7
			plate movement/tectonic change	5
			tectonic activity - large scale	6
			Tectonic Activity - Large Scale	3
			Tectonic movements and orogeny	4
		uplift and subsidence	regional subsidence or uplift	12
			regional subsidence or uplift (also applies to subsurface)	10
			uplift and subsidence	6
			uplift and subsidence (orogenic, isostatic)	5
			Uplift/subsidence	9
	undetected geological features	undetected features	Undetected Features	11
			undetected features (faults, fracture networks, shear zones, brecciation, gas pockets)	5
			Undetected features (In geosphere)	4
			Undetected Features in the SZ	3
			Undetected Features in the UZ	3
			undetected features or processes	12
		undetected fractures	undetected discontinuities	6
			undetected fracture zones	6
	volcanism	chemical effects of magma and magmatic volatiles	Chemical Effects of Magma and Magmatic Volatiles	3
		extrusive magmatic activity	extrusive magmatic activity	11
			extrusive magmatic activity	7
		hot-spot volcanic activity	hot-spot volcanic activity	13
		igneous activity	igneous activity	12

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		igneous intrusion	Igneous emplacement	11
			Igneous emplacement	7
			Igneous intrusion	8
			Igneous Intrusion Interacts With repository Components	3
			Igneous Intrusion Into Repository	3
			intruding dikes	6
			intrusive	9
			intrusive dikes	9
			intrusive magmatic activity	11
			intrusive magmatic activity	7
		magmatic activity	Magmatic activity	9
			Magmatic activity	7
			magmatic activity	10
			magmatic activity (intrusive, extrusive)	5
			Volcanic and magmatic activity	4
		rift system volcanic activity	rift system volcanic activity	13
		volcanic activity	Ashfall	3
			Volcanic activity	13
			volcanic activity	10
			volcanic cinders	1
			volcanic eruption	1
			volcanism	6
		volcanic activity transports waste	Ash Redistribution in Groundwater	3
			Ash Redistribution Via Soil and Sediment Transport	3
			Eruptive Conduit to Surface Intersects Repository	3
			Magma Or Pyroclastic Base Surge Transports Waste	3
	volcanism, extrusive	extrusive volcanism	extrusive	9
		lava tubes	lava tubes	11
			lava tubes	9
			lava tubes	7
geophysics	geomagnetism	change in the earth's magnetic field	Changes in the Earth's Magnetic Field	3
			changes in the earth's magnetic field	0
			changes of the magnetic field	6
	rock mechanics	earth tide effects	earth tide effects	1
			Earth Tides	3
		elastic response, differential	differential elastic response	11
			differential elastic response	9
			differential elastic response	7

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		elastic, plastic, or brittle deformation	Deformation, elastic, plastic or brittle	4
			electro-chemical cracking	6
		external stress	external stress	6
		fracture mechanics	fracture mechanics analysis	13
			partial closure of fracture in excavation damage zones	5
			readjustment of rock along joints	7
		igneous activity changes rock properties	Igneous Activity Changes Rock Properties	3
		jointed rock motion	jointed rock motion	13
		non-elastic response	nonelastic response	7
			non-elastic response	11
			non-elastic response	9
			non-elastic response	5
		rock creep	creeping of rock mass	6
			Salt Creep	3
		rock mechanics	Mechanical processes and conditions (in geosphere)	4
			Rock Properties of Host Rock and Other Units	3
		stress, excavation induced	changes in in-situ stress field	5
			Excavation disturbed zone, host rock	4
			excavation induced stress/fracturing in host rock	10
			excavation/backfilling effects on nearby rock	6
			Mechanical Effects of Excavation and Construction in repository	3
			Mechanical Effects of Excavation and Construction in the Near-Field	3
		stress, thermally induced	change in local state of stress	7
			thermally induced stress/fracturing in host rock	10
			Thermally-Induced Stress Changes in the Near-Field	3
			Thermo-Mechanical Stresses Alter Characteristics of Faults Near Repository	3
			Thermo-Mechanical Stresses Alter Characteristics of Fractures Near Repository	3
			Thermo-Mechanical Stresses Alter Characteristics of Rocks Above and Below The Repository	3
	seismicity	earthquake	earthquake	1

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			earthquake from natural causes	12
			earthquakes	6
		earthquake, anthropogenic	earthquake from manmade causes	12
		seismic activity	Seismic activity	13
			seismic activity	10
			seismicity	1
			Seismicity	4
			seismicity	5
		seismic-induced repository damage	Seismic Ground Motion Damages repository Components	3
			Seismic-Induced Drift Collapse Alters In-Drift Chemistry	3
			Seismic-Induced Drift Collapse Alters In-Drift Thermohydrology	3
			Seismic-Induced Drift Collapse Damages repository Components	3
			Seismic-Induced Rockfall Damages repository Components	3
		seismicity	seismicity	9
		seismicity due to igneous activity	Seismicity Associated With Igneous Activity	3
	subsidence	subsidence fractures end above repository	subsidence fractures end above repository	15
		subsidence fractures reach repository	subsidence fractures reach repository	15
glaciology	faulting	glacially-induced faulting	glacially induced faulting	13
	glacial deposits	glacial deposits	glacial deposits	2
	glacial effects	glacial activity	glacial activity	12
		glacial effects	Glacial and Ice Sheet Effect	3
			Glacial and ice sheet effects, local	4
		glacial erosion	glacial erosion	13
			glacial erosion	9
		glaciation	Glaciation	13
			Glaciation	11
			Glaciation	7
			glaciation	6
			glaciation	8
			glaciation	10
			glaciation (erosion/deposition, glacial loading, hydrogeological change)	5
	isostatic effects	isostatic subsidence and rebound	isostasy	11
			isostasy	7

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Isostatic	9
			subsidence and rebound	13
	periglacial effects	gases under permafrost	accumulation of gases under permafrost	6
		periglacial effects	Periglacial effects	4
			Periglacial Effects	3
			periglacial effects (permafrost, high seasonality)	5
		permafrost	permafrost	6
			permafrost affects repository	15
hydrogeology	brine occurrence	brine migration	migration of brine aquifer	8
			migration of intracrystalline brine inclusions	8
		brine pockets	brine pockets	9
			effects of brine pocket	8
		gas or brine pockets	gas or brine pockets	11
			gas or brine pockets	7
	change in hydrogeology	desertification	desert and unsaturation	6
		resaturation	resaturation	6
	change to hydrogeology, anthropogenic	anthropogenic change to hydrogeology	alteration of hydrological conditions	13
			anthropogenic alteration of subsurface hydrogeology	1
			anthropogenic infiltration and recharge	2
			enhanced ground-water flow	6
		dewatering of host rock	dewatering	11
		human-induced actions on groundwater recharge	human-induced actions on ground-water recharge	6
		hydrogeologic effects of excavation and construction	Changes In Fluid Saturations in the Excavation Disturbed Zone	3
		induced hydrological change	induced hydrological changes (fluid pressure, density convection, viscosity)	5
		intentional artificial groundwater recharge or withdrawal	intentional artificial ground-water recharge or withdrawal	11
			intentional artificial ground-water recharge or withdrawal	9
			intentional artificial ground-water recharge or withdrawal	7
	convection	convection	convection	7
	advection	advection	advection	2
	diffusion	diffusion	diffusion	5
			Diffusion in the SZ	3
			Diffusion in the UZ	3
			Diffusion of Dissolved Radionuclides in repository	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			diffusion out of the repository	8
			diffusive mixing occurs	15
		matrix diffusion	matrix diffusion	5
			matrix diffusion	6
			Matrix Diffusion in the SZ	3
			Matrix Diffusion in the UZ	3
	dilution	dilution	dilution	6
			mass, isotopic and species dilution	5
		dilution in groundwater	Dilution of Radionuclides in Groundwater	3
	dissolution	formation of dissolution cavities in salt	formation of dissolution cavities	10
	fracture hydrogeology	cooling joints	cooling joints	1
		fracture coatings	fracture coatings	1
		fracture fill	fracture fill	1
		fracture flow	fracture flow	1
			fracture flow in porous media	1
			Fracture Flow in the UZ	3
	groundwater hydraulics	advection-dispersion	advection and dispersion	5
			Advection and Dispersion in the SZ	3
			Advection and Dispersion in the UZ	3
			Advection of Dissolved Radionuclides in repository	3
			dispersion	6
			Flow Through Invert	3
			fluid migration	11
			local fluid migration	7
			Saturated Flow in the repository	3
			Unsaturated Flow in the repository	3
			Water Influx at the Repository	3
			water phase advection	1
		aquifers	Aquifers and water-bearing features, near surface	4
			regional aquifer	1
		capillary rise	Capillary Effects (Wicking) in repository	3
			Capillary Rise in the UZ	3
		change in groundwater system	changes of ground-water flow	6
			Effects of Drip Shield on Flow	3
			flux through repository is altered	15
			normal flow increases	15

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Perturbation of ground-water system	7
		chemically-induced density effects in groundwater flow	Chemically-Induced Density Effects on Groundwater Flow	3
		condensation in the repository	Condensation Forms at Repository Edges (Repository-Scale Cold Traps)	3
			Condensation Forms on Roofs of Drifts (Drift-Scale Cold Traps)	3
			Condensation on Underside of Drip Shield	3
		condensation zone around repository	Condensation Zone Forms Around Drifts	3
		dilution within a water supply well	dilution within a water supply well	1
		extreme channel flow of oxidants and nuclides	extreme channel flow of oxidants and nuclides	6
		film flow enters repository	Film Flow into the Repository	3
		flow diversion around repository	Flow Diversion Around Repository Drifts	3
		flow shadow below repository	Drift Shadow Forms Below Repository	3
		fluid interactions	fluid interactions	12
			fluid interactions	9
		fluids carry waste to rivers or tributaries	fluids carry waste to rivers or tributaries	15
		fluids carry waste to wells or springs	fluids carry waste to wells or springs	15
		focused recharge	focused recharge	1
		focusing of unsaturated flow (fingers, weeps)	Focusing of Unsaturated Flow (Fingers, Weeps)	3
		geosphere dehydration due to waste heat	Geosphere Dry-Out Due to Waste Heat	3
		geosphere rehydration following dehydration due to waste heat	Resaturation of Geosphere Dry-Out Zone	3
		groundwater	groundwater	1
		groundwater conditions	ground-water conditions (saturated/unsaturated)	5
		groundwater discharge	groundwater discharge	1
			ground-water discharge (to surface water, springs, soils, wells, and marine)	5
			Groundwater Discharge to Surface Within The Reference Biosphere	3
		groundwater flow	fluid migration	9
			ground-water flow	9
			ground-water flow	8
			ground-water flow (Darcy, non-Darcy, intergranular fracture,	5

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			ground-water flow paths are shortened	15
			Saturated Groundwater Flow in the Geosphere	3
			Unsaturated Groundwater Flow in the Geosphere	3
			Water-Conducting Features in the SZ	3
		groundwater recharge	groundwater recharge	1
			groundwater recharge/discharge	6
			Infiltration and Recharge	3
			recharge to ground water	5
		groundwater well capture efficiency	groundwater well capture efficiency	1
		hydraulic / hydrogeological processes and conditions (in geosphere)	Hydraulic/hydrogeological processes and conditions (in geosphere)	4
		hydraulic / hydrogeological processes and conditions (in wastes)	Hydraulic/hydrogeological processes and conditions (in wastes and [repository])	4
		hydraulic conductivity change - excavation / backfilling effect	hydraulic conductivity change - excavation/backfilling effect	6
		injection of liquid wastes	injection of liquid wastes	5
		injection wells	injection wells	10
		lateral diversion of groundwater flow	lateral diversion of groundwater flow	1
			lateral ground-water flow in the unsaturated zone	12
		lateral flow enters repository	Lateral Flow from Solitario Canyon Fault Enters Drifts	3
		matrix imbibition	Matrix Imbibition in the UZ	3
		multiphase flow	multiphase flow and gas driven flow	5
		natural geothermal effects on saturated zone flow	Natural Geothermal Effects on Flow in the SZ	3
		natural geothermal effects on unsaturated zone flow	Natural Geothermal Effects on Flow in the UZ	3
		perched groundwater	Locally Saturated Flow at Bedrock/Alluvium Contact	3
			perched groundwater	1
			Perched Water Develops	3
		pore water residence time	pore water residence time	1
		preferential pathways	Enhanced Influx at the Repository	3
			Flow Through Rock Reinforcement Materials in repository	3
			preferential pathways in the buffer/backfill	6

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		radial dispersion	radial dispersion	12
		repository dehydration due to waste heat	Repository Dry-Out Due to Waste Heat	3
		repository-induced geothermal effects on unsaturated zone flow	Repository-Induced Thermal Effects on Flow in the UZ	3
		repository-induced thermal effects on saturated zone flow	Repository-Induced Thermal Effects on Flow in the SZ	3
		seismically-induced changes in perched water	Seismic Activity Alters Perched Water Zones	3
		subsurface evaporation	evaporation within a mesa	1
		thermally-induced fluid migration	fluids do not recirculate in response to thermal gradients	15
			fluids recirculate in response to thermal gradients	15
			geothermally induced flow	6
			Thermal Convection Cell Develops in SZ	3
		vadose zone	vadose zone	1
	groundwater parameters	fluid pressure changes in time	fluid pressure changes	11
			fluid pressure changes	7
		gravity	gravity	1
		hydraulic conductivity	hydraulic conductivity	1
		permeability	permeability	1
		seismically-induced changes in porosity and permeability	Seismic Activity Changes Porosity and Permeability of Faults	3
			Seismic Activity Changes Porosity and Permeability of Fractures	3
			Seismic Activity Changes Porosity and Permeability of Rock	3
		surface tension	surface tension (porous media capillarity)	1
		thermally-induced changes to fluid properties	fluid pressure, density, viscosity changes	9
		vertical groundwater gradients	vertical groundwater gradients	1
		head is below outfall	head is below outfall	15
	particulate transport in water	transport of particles larger than colloids	Transport of Particles Larger Than Colloids in repository	3
			Transport of Particles Larger Than Colloids in the SZ	3
			Transport of Particles Larger Than Colloids in the UZ	3
	water intrusion	repository resaturation due to waste cooling	Repository Resaturation Due to Waste Cooling	3

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		water from a confined aquifer enters repository	water from a confined aquifer enters repository	15
		water from an unconfined aquifer enters repository	water from the unconfined aquifer enters repository	15
		water intrusion ("bathtubbing")	Induced Hydrologic Changes in Invert	3
			water intrusion ("bathtubbing")	2
	weathering of flow paths	weathering of flow paths	dissolution of fracture fillings/precipitations	6
			fracture mineralization and weathering	5
			weathering of flow paths	6
hydrology	change in hydrology	change in hydrology, anthropogenic	human-induced changes in surface hydrology	6
			hydrology change from manmade causes	12
		change in hydrology, natural	hydrology change	9
			hydrology change from natural causes	12
		change in surface water	Modification of hydrologic regime	7
		hydrologic stresses	Hydrologic Stresses	10
		hydrology change from igneous activity	Hydrologic Response to Igneous Activity	3
		hydrology change from seismic activity	Hydrologic Response to Seismic Activity	3
		large-scale alterations of hydrology	Large-scale alterations of hydrology	9
	infiltration	episodic infiltration	Effects of Rapid Influx into the Repository	3
			Flow in the UZ from Episodic Infiltration	3
		evaporation	evaporation of water	1
		flow through buffer / backfill	Flow in the Backfill	3
			flow through buffer/backfill	6
		hydrological regime and water balance (near-surface)	Hydrological regime and water balance (near-surface)	4
			Surface Runoff and Evapotranspiration	3
		infiltration and evapotranspiration	infiltration and evapotranspiration	12
			infiltration of water	1
			transpiration	1
		precipitation, temperature, soil, water balance	precipitation, temperature, soil, water balance	5
	inundation	flooding	Flooding	11
			flooding	9
			Flooding	7
			flooding	10

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			site flooding	5
			Site Flooding (During Construction and Operation)	3
		large episodic runoff events	large episodic runoff events	1
		ponding	ponding	1
	precipitation	hurricane	coastal surge, storms, and hurricanes	5
			hurricane	12
			hurricanes	10
		pluvial periods	pluvial periods	10
		precipitation	precipitation	1
			Precipitation	3
		precipitation - extreme	extremes of precipitation, snow melt and associated flooding	5
		precipitation - hail	hail	1
		precipitation - monsoon rain	monsoon rain	1
		thunderstorms	thunderstorms	1
	sediment transport	freshwater sediment transport and deposition	freshwater sediment transport and deposition	5
		sediment transport	sediment transport	1
			Soil and Sediment Transport in the Biosphere	3
		sedimentation	Sedimentation	11
			sedimentation	9
			Sedimentation	7
			Sedimentation	2
			sedimentation	8
			sedimentation/ aggradation	12
	surface water	lake level change	river flow and lake level changes	5
		lakes, rivers, streams and springs	Lakes, rivers, streams and springs	4
		river processes	flow channels close and reopen later	15
			location of river channel changes	15
			location of river channel changes and flow through repository is altered	15
			river meander	5
			river meandering	6
			rivers rechanneled	5
		surface water transport and mixing	Surface Water Transport and Mixing	3
	surface water management	dams, canals, pipelines, water collection / storage facilities	Water Management Activities	3
		natural dam formation / failure	dam and reservoir formation from natural causes	12

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		reservoir construction / failure	dam and reservoir, manmade	12
			damming of streams or rivers	10
			dams and reservoirs, built/drained	5
			reservoirs	11
			reservoirs	9
			reservoirs	7
marine issues	coastal erosion	coastal erosion development of estuaries	coastal erosion and estuarine development	5
	coastal features	coastal features	Coastal features	4
	marine issues	marine features	Marine features	4
			Marine Features	3
		marine processes	marine sediment transport and deposition	5
		storm surge	storm surge	2
		tsunami	tsunamis	10
	sea level change	sea level change	change in sea level	6
			sea level change	12
			sea level change	9
			Sea Level change	4
			sea-level rise/fall	5
			sea-level variations	10
material properties	material properties	material properties of backfill	Buffer/backfill materials and characteristics	4
		material properties of porous media	porous media density	1
			porous media porosity	1
			porous medium material properties	1
		material property change	Chemical Properties and Evolution of Backfill	3
			material property changes	11
			material property changes	9
			material property changes	7
			material property changes	5
			rapid reduction of backfill porosity because backfill additives and/or moisture are present	5
			Thermal-Mechanical Effects of Backfill	3
			Thermal-Mechanical Properties and Evolution of Backfill	3
		rock heterogeneity	rock heterogeneity (permeability, mineralogy), affecting water and	5
	swelling	swelling of clay backfill	swelling of bentonite into tunnels and cracks	6

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			uneven swelling of bentonite	6
		swelling of corrosion products	swelling of corrosion products	6
exposure and activities				
human exposure	agriculture / aquaculture	agriculture / aquaculture	agricultural and fisheries practice changes	5
			Agricultural Land Use and Irrigation	3
			agriculture	1
			Animal Farms and Fisheries	3
			Rural and agricultural land and water use (incl. fisheries)	4
		agriculture in canyons	canyon agriculture	2
		agriculture on mesatop	mesatop agriculture	2
		irrigation	irrigation	11
			irrigation	9
			irrigation	7
			irrigation	5
			irrigation	10
		irrigation with groundwater	irrigation with groundwater	1
		irrigation with surface water	irrigation with surface water	1
	demographics	community characteristics	Community characteristics	4
		social and institutional developments	Social and Institutional developments	4
			Social and Institutional Developments	3
		urban development	city on the site	6
			demographic change, urban development	5
			establishment of new population center	11
			establishment of population center	7
			Urban and Industrial land and water use	4
			Urban and Industrial Land and Water Use	3
	dose response	dose response	Dose response assumptions	4
			Radiation Doses	3
		dosimetry	Dosimetry	4
		sensitization to radiation effects	Sensitization to Radiation	3
	exposure media concentrations	intrusion into accumulation zone in the biosphere	intrusion into accumulation zone in the biosphere	6
	groundwater use	groundwater use	groundwater use	1
			water producing well	6
			withdrawal wells	10
	human behavior	future human actions	Future human action assumptions	4

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			human surface activities	12
		future human behavior	Future human behavior (target group) assumptions	4
			Habits (non-diet related behavior)	4
			Human Lifestyle	3
		human response to climate change	Human response to climate changes	4
	human exposure	contamination of non-food products	Contaminated Non-Food Products and Exposure	3
			Non-food products, contaminant concentrations in	4
		human characteristics (physiology, metabolism)	Human characteristics (physiology, metabolism)	4
			Human Characteristics (Physiology, Metabolism)	3
	ingestion	drinking water, foodstuffs and drugs	Contaminated Drinking Water, Foodstuffs and Drugs	3
			Drinking water, foodstuffs and drugs, contaminant concentrations in	4
		food and water processing and preparation	Food and water processing and preparation	4
		ingestion of contaminated animal products	ingestion of contaminated animal products	1
		ingestion of drinking water	ingestion of drinking water	1
		ingestion of food crops grown in contaminated soils and irrigated with well water	ingestion of food crops grown in contaminated soils and irrigated with well water	1
	ingestion by animals	grazing	grazing	1
	inhalation	radon and radon decay product exposure	Radon and radon daughter exposure	4
			Radon and Radon Decay Product Exposure	3
	population dose / risk	demographics	Adults, children, Infants and other variations	4
	receptor scenarios	land use	land use	1
		land use change	land use change	5
		Amerindian scenarios	Amerindian scenarios	2
		dwelling construction	residential construction	2
		dwelling occupation	Dwellings	4
			Dwellings	3
		kiva construction	kiva construction	2
		kiva occupation	kiva occupation	2
		occupation of canyons	occupation of canyons	1
		occupation of mesas	occupation of mesas	1
		post-closure inhabitation	nearby residents	2
			occupation by community	2

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			occupation by homesteaders	2
			occupation by puebloans	2
			post-closure inhabitation	2
		recreation	Leisure and other uses of environment	4
		septic drain field	septic drain field	2
		underground construction	underground construction	5
			underground dwellings	6
		unintrusive site investigation	Unintrusive Site Investigation	3
		commercial development	commercial development	2
		industrial development	industrial development	2
	water supply	water supply - surface water	mesatop surface water impoundment and ingestion	2
		water well	Wells	3
		water well - community	community (municipal) water well	2
		water well - household	household water well	2
human exposure; ecorisk	exposure media concentrations	exposure media concentrations	Environmental media, contaminant concentrations in	4
	external irradiation / immersion	direct radiation from airborne radionuclides	direct radiation from airborne radionuclides	1
		exposed sediments in a reservoir	exposed sediments in a reservoir	2
		external irradiation	External Exposure	3
		external irradiation from soil or sediment	direct radiation from contaminated soils	1
		immersion in contaminated water	immersion in contaminated water	2
	food contamination	animal uptake of radionuclides	animal uptake	5
			Animal Uptake	3
			Fish Uptake	3
		plant uptake of radionuclides	plant root uptake of radionuclides	1
			Plant Uptake	3
		rainsplash (soil onto plants)	rainsplash (soil onto plants)	2
	human exposure	exposure modes	Exposure modes	4
		impacts of concern	Impacts of concern	4
	ingestion	diet and fluid intake	Diet and fluid Intake	4
		ingestion of contaminated soil	ingestion of contaminated soil	1
		ingestion of radionuclides	Ingestion	3
		surface water ingestion	surface water as a drinking water resource	1
		uptake of contaminants in food chain	Food chains, uptake of contaminants in	4
	dermal	dermal absorption	dermal absorption	2

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
	inhalation	inhalation of radionuclides	Inhalation	3
			inhalation of airborne radionuclides	1
			inhalation of contaminated dust (particulates)	1
			inhalation of radioactive gases	1
			inhalation pathways	2
	land use	wild land and water use	Wild and natural land and water use	4
			Wild and Natural Land and Water Use	3
	toxicity	chemical toxicity of wastes	chemical toxicity of wastes	6
			Nonradiological toxicity/effects	4
		chemical toxicant stability	Chemical/organic toxin stability	4
		radiological toxicity	Radiological toxicity/effects	4
inadvertent human intrusion	inadvertent human intrusion	igneous event precedes inadvertent human intrusion	Igneous Event Precedes Human Intrusion	3
		inadvertent human intrusion	Inadvertent future intrusion	9
			Inadvertent future intrusion	7
			Inadvertent Future Intrusions	10
			Inadvertent Human Intrusion	3
			inadvertent intrusion	1
			unanticipated intrusion	12
		seismic event precedes inadvertent human intrusion	Seismic Event Precedes Human Intrusion	3
		erosional event precedes inadvertent human intrusion	erosional event precedes inadvertent human intrusion	2
	resource extraction	mining	mining	10
		drilling and mining	drilling and mining	13
		drilling into repository	drilling	10
			Drilling activities (human intrusion)	4
			Drilling Activities (Human Intrusion)	3
			drilling into repository	8
			Effects of Drilling Intrusion	3
			exploitation drilling	5
			exploratory drilling	9
			exploratory drilling	5
			well-drilling inadvertent intruder	12
		fossil fuel extraction	fossil fuel resources	1
		geological resources	Geological resources	4
		geothermal resources	geothermal energy production	5
			geothermal energy production	6
			geothermal resources	1
		groundwater extraction	ground-water abstraction	5

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			groundwater resources	1
		hydraulic fracturing	hydraulic fracturing	11
			hydraulic fracturing	7
			hydraulic fracturing	2
		mine shafts	mine shafts	11
			mine shafts	9
			mine shafts	7
		mining	effects of mining for resources	8
			minerals (pumice, obsidian)	1
			ores (gold, silver, uranium)	1
			resource mining	5
			resource mining (mineral hydrocarbon, geothermal, salt)	11
			resource mining (mineral, water, hydrocarbon, geothermal, salt, etc)	9
			resource mining (salt, mineral, hydrocarbon, geothermal)	7
		natural resource exploration / extraction	Mining and other underground activities (human intrusion)	4
			Mining and Other Underground Activities (Human Intrusion)	3
			mining inadvertent intruder	12
			natural resource exploration/extraction	1
		other future uses of host rock	other future uses of crystalline rock	6
		quarrying	mining of aggregate	1
			quarrying, near surface extraction	5
		tunneling	tunneling	5
		undetected past intrusion	Undetected Past Intrusion	11
			undetected past intrusion	12
			Undetected past intrusion	9
			Undetected past intrusion	7
			undetected past intrusions (boreholes, mining)	5
		undiscovered boreholes	undiscovered boreholes	11
			undiscovered boreholes	9
			undiscovered boreholes	7
		boreholes	future boreholes and undetected past boreholes	6
			Influx Through Holes Drilled in Drift Wall or Crown	3
			Open Site Investigation Boreholes	3
intentional human intrusion	intentional intrusion	archeological intrusion	archeological exhumation	11

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			archeological exhumation	9
			archeological exhumation	7
			archeological intrusion	6
			archeological investigation	5
		exhumation	excavation	13
			exhumation	8
			Repository Excavation	3
		intentional intrusion	Deliberate Human Intrusion	3
			Intentional Intrusion	11
			intentional intrusion	12
			Intentional intrusion	9
			Intentional intrusion	7
			Site Investigation	4
		malicious intrusion	malicious intrusion (sabotage, act of war)	5
		waste retrieval	intentional waste retrieval	2
			recovery of repository materials	5
			waste recovery	11
			waste recovery	9
			waste recovery	7
			waste retrieval, mining	6
land use	underground storage	underground storage of energy resources	storage of hydrocarbons or compressed air	11
			storage of hydrocarbons, compressed air, or hot water	7
			stored energy	7
	waste disposal	reuse of boreholes	reuse of boreholes	6
	weapons testing	underground nuclear testing	underground nuclear testing	5
			underground test of nuclear devices	6
		weapons testing	weapons testing	11
			weapons testing	12
			weapons testing	7
miscellaneous FEPS				
miscellaneous	accidents and unplanned events	accidents and unplanned events	Accidents and unplanned events	4
			Accidents and Unplanned Events During Construction and Operation	3
		brush fire	brush fire	12
		gas generation - explosion or fire	fire and explosion of waste after burial	12
			Gas Explosions in repository	3
		H2 / O2 explosions	H2/O2 explosions	6
		wild fire	wild fire / forest fire	2
	explosion / fire	explosions, fire and crashes	explosions	6
			explosions	10

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Explosions and crashes	4
			Explosions and Crashes (Human Activities)	3
			Explosions and Crashes (related to plane crashes, weapons testing, bombs, etc.)	2
			fire and explosion	12
		use of explosive devices	use of explosive devices	13
	extraterrestrial objects	celestial bodies	Celestial bodies	10
		meteorite	determination of meteorite impact frequencies	13
			meteorite	6
			Meteorite impact	13
			meteorite impact	12
			meteorite impact	9
			Meteorite impact	4
			meteorite impact	5
			Meteorite impact	8
			meteorite impact	10
			Meteorite Impact	3
			Meteorites	11
			Meteorites	7
			probability of meteorite damage	13
	human-induced transport	human-action-mediated transport of contaminants	Human-action-mediated transport of contaminants	4
	intentional destruction	sabotage	chemical sabotage	6
			sabotage	11
			sabotage	9
			sabotage	7
			sabotage	5
			sabotage	8
			sudden energy release	6
		war	nuclear war	6
			war	11
			war	9
			war	7
			warfare	8
	miscellaneous	boreholes	future boreholes and undetected past boreholes	6
			Influx Through Holes Drilled in Drift Wall or Crown	3
			Open Site Investigation Boreholes	3
		extraterrestrial events	Extraterrestrial Events	3
		future technological development	Technological developments	4

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
			Technological Developments	3
		head is below outfall	head is below outfall	15
		ozone layer failure	Ozone Layer Failure	3
	nuclear processes	criticality, far-field	Far-Field Criticality	3
			Far-Field Criticality Resulting from a Seismic Event	3
			Far-Field Criticality Resulting from an Igneous Event	3
			Far-Field Criticality Resulting from Rockfall	3
		criticality, near-field	Near-Field Criticality	3
			Near-Field Criticality Resulting from a Seismic Event	3
			Near-Field Criticality Resulting from an Igneous Event	3
			Near-Field Criticality Resulting from Rockfall	3
		radiation effects	Radiation effects	7
			Radiation effects (In wastes and [repository])	4
		radiation effects in repository	Radiation Damage in repository	3
			radiation effects on canister	6
		radiation effects on bentonite	radiation effects on bentonite	6
		radioactive decay and ingrowth	radioactive decay and ingrowth	1
			Radioactive Decay and Ingrowth	3
			Radioactive decay and in-growth	4
			radioactive decay and ingrowth (chain decay)	5
		radioactive decay and ingrowth in the biosphere	Radionuclide Alteration During Biosphere Transport	3
		radiolysis	radiolysis	11
			radiolysis	9
			radiolysis	7
			radiolysis	6
			Radiolysis	3
			radiolysis of NaCl	5
			radiolysis of water	5
			radiolysis waste effect	8
		recoil of alpha-decay	recoil of alpha-decay	6
	reconcentration in environmental media	accumulation in peat	accumulation in peat	6
		accumulation in sediment	accumulation in sediments	6

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		accumulation in soils	accumulation in soils and organic debris	5
			Radionuclide Accumulation in Soils	3
		reconcentration in environmental media	reconcentration	6
	thermal effects	exothermic reactions in the repository	Exothermic Reactions in the repository	3
		heat distribution in repository	Non-Uniform Heat Distribution in repository	3
		heat generation in repository	Heat Generation in repository	3
		natural thermal effects	natural thermal effects	5
		presence of a heat source	presence of a heat source	13
		radiogenic heat	radioactive decay; heat	6
		thermal (nuclear and chemical)	Thermal (nuclear and chemical)	14
		thermal buoyancy	thermal buoyancy	6
			Two-Phase Buoyant Flow/Heat Pipes	3
		thermal cracking	thermal cracking	6
		thermal effects from concrete hydration	thermal effects (concrete hydration)	14
		thermal effects on chemistry and microbial activity	Thermal Effects on Chemistry and Microbial Activity in the repository	3
		thermal effects on radionuclide transport	Thermal Effects on Transport in repository	3
		thermal effects on the biosphere	Effects of Repository Heat on The Biosphere	3
		thermal effects on the buffer material	thermal effects on the buffer material	6
		thermal effects on water flow	Thermal Effects on Flow in the repository	3
			Thermally Driven Flow (Convection) in Drifts	3
			Thermally-Driven Flow (Convection) in Waste Packages	3
		thermal processes and conditions (in wastes and repository)	Thermal processes and conditions (in wastes and [repository])	4
		thermal sensitization of waste package	Thermal Sensitization of Waste Packages	3
		thermally-induced stress in repository components	Thermal Expansion/Stress of in-Drift repository Components	3
		thermally-induced stress in waste package	Thermal Expansion/Stress of in-Package repository Components	3
		thermochemical change	thermochemical changes	6
		thermo-hydro-mechanical effects	thermo-hydro-mechanical effects	6

Topic	Subtopic	Normalized FEPS	Original FEPS (as in reference)	Reference
		thermophoresis	soret effect [thermophoresis]	6
modeling	modeling	modeling	Model and Data Issues	3
		radionuclide release outside the reference biosphere	Groundwater Discharge to Surface Outside The Reference Biosphere	3
			Radionuclide Release Outside The Reference Biosphere	3
		spatial domain	Spatial domain of concern	4
			Spatial Domain of Concern	3

Notes for Table 2:

Table 2 lists the normalized FEPS, screened for inclusion in the CSM for the Site. These normalized FEPS are cross-referenced to specific sections in this FEPS document. FEPS retained for discussion in the CSM are here identified in the "Retain?" column with "+", and those excluded with "–". FEPS for which classification is pending review are identified with "?".

Table 2. List of normalized FEPS identifying the results of screening for inclusion in the West Valley Site CSM, organized by topic.

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
regulatory context				
institutional control	active institutional control	active institutional control	+	5.2.1.1.1
		post-closure surface activities	+	5.2.1.1.1
	loss of institutional control	loss of institutional control	+	5.2.1.1.1
	monitoring	post-closure monitoring	+	5.2.1.1.2
	passive institutional control	passive institutional control	+	5.2.1.1.1
	records and markers	loss of records	+	5.2.1.1.1
		records and markers	+	5.2.1.1.1
regulatory issues	regulatory issues	regulatory issues	+	5.2.1.2
engineered systems				
engineering	construction defect	closure failure	–	5.2.2.1.1
		faulty backfill placement	+	5.2.2.1.1
		inadequate backfill compaction, voidage	+	5.2.2.1.1
		poor quality construction	+	5.2.2.1.1
	drip shields	drip shield failure modes	–	5.2.2.1.2
		hydrostatic pressure on drip shield	–	5.2.2.1.2
		thermal sensitization of drip shields	–	5.2.2.1.2
	engineered features	degradation of engineered features	+	5.2.2.1.3
		hydrostatic pressure on canister	+	5.2.2.1.3
		seal performance	+	5.2.2.1.3
	material defect	defect in backfill	+	5.2.2.1.1
		waste canister defects	+	5.2.2.1.1

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
	mechanical failure	failure of waste packages	+	5.2.2.1.4
		floor buckling	–	5.2.2.1.4
		mechanical failure of backfill	+	5.2.2.1.4
		mechanical failure of repository	+	5.2.2.1.4
		seal failure	+	5.2.2.1.4
	operational activities	ground disturbance	+	5.2.2.1.5
		pavement	+	5.2.2.1.5
		phased operations	+	5.2.2.1.5
		remediation	–	5.2.2.1.5
		repository flooding during operation	+	5.2.2.1.5
		repository ventilation	–	5.2.2.1.5
		schedule and planning	+	5.2.2.1.5
		unsuccessful attempt of site improvement	+	5.2.2.1.5
	operational error	accidents during operation	–	5.2.2.1.5
		waste disposal error	+	5.2.2.1.5
	repository design	design modification	–	5.2.2.1.6
		faulty design	–	5.2.2.1.6
		poorly designed repository	–	5.2.2.1.6
		repository design and construction	+	5.2.2.1.6
		retrievability	+	5.2.2.1.6
	subsidence	repository convergence	–	5.2.2.1.7
		subsidence in the waste zone	+	5.2.2.1.7
	waste configuration	disposal pits	+	5.2.2.1.6
		disposal shafts	+	5.2.2.1.6
waste	co-disposal of nonradioactive waste	co-disposal of nonradioactive waste	+	5.2.2.2.1
	co-disposal of radioactive waste	co-disposal of radioactive waste	+	5.2.2.2.1
		co-disposal of reactive wastes	+	5.2.2.2.1
	co-disposal of undesirable materials	inadvertent inclusion of undesirable materials	+	5.2.2.2.1
	disposal configuration	faulty waste placement	+	5.2.2.1.6
		waste placement	+	5.2.2.1.6
	nuclear processes	criticality	?	5.2.2.2.2
		criticality, in waste	?	5.2.2.2.2

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		nuclear activation	?	5.2.2.2.2
	source release	glass waste form cracking	–	5.2.2.2.3
		glass waste form degradation	–	5.2.2.2.3
		glass waste form recrystallization	–	5.2.2.2.3
		heterogeneity of waste forms (chemical, physical)	+	5.2.2.2.3
		I, Cs-migration to fuel surface	?	5.2.2.2.3
		induced chemical change (solubility sorption, species equilibrium, mineralization)	+	5.2.2.2.3
		interactions of waste and repository materials with host materials	+	5.2.2.2.3
		pyrophoric waste event	?	5.2.2.2.3
		radon emanation from waste	+	5.2.2.2.3
		waste / rock interaction	+	5.2.2.2.3
	waste characterization	radioactive source in waste	+	5.2.2.2.4
		unanticipated waste composition	+	5.2.2.2.4
		waste characterization	+	5.2.2.2.4
	waste chemistry	chemical effects of void space in waste package	+	5.2.2.2.5
		chemical liquid waste disposal	+	5.2.2.2.5
		geochemical processes in waste	+	5.2.2.2.5
		interactions with corrosion products and waste	+	5.2.2.2.5
		introduced complexing agents and cellulosics	+	5.2.2.2.5
		solubility within fuel matrix	+	5.2.2.2.5
	waste containment	change in hydrostatic pressure on container	+	5.2.2.2.6
		corrosion	+	5.2.2.2.6
		corrosion of containers	+	5.2.2.2.6
		corrosion of copper waste canisters	–	5.2.2.2.6
		creep in copper waste containers	–	5.2.2.2.6
		damaged or deviating fuel	+	5.2.2.2.6
		degradation of fuel cladding	+	5.2.2.2.6
		flammable gas generation	?	5.2.2.2.6
		internal pressure	–	5.2.2.2.6
		loss of ductility	–	5.2.2.2.6

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		stress analysis	–	5.2.2.2.6
		stress change of conductivity	–	5.2.2.2.6
		vault-related events	+	5.2.2.2.6
		voids in the lead filling	–	5.2.2.2.6
		waste canister failure	+	5.2.2.2.6
		waste canister movement	+	5.2.2.2.6
		waste containment	+	5.2.2.2.6
	waste inventory	waste inventory	+	5.2.2.2.7
		waste inventory heterogeneity	+	5.2.2.2.7
environmental systems				
atmosphere	atmosphere	atmosphere	+	5.2.3.1
	atmospheric deposition	dry deposition	+	5.2.3.1
		wet deposition	+	5.2.3.1
	atmospheric dispersion	atmospheric dispersion	+	5.2.3.1
		atmospheric inversion	+	5.2.3.1
		atmospheric turbulence	+	5.2.3.1
		barometric pumping	–	5.2.3.1
		dust devils	+	5.2.3.1
		gas diffusion into atmosphere	+	5.2.3.1
		ground surface roughness	+	5.2.3.1
		resuspension	+	5.2.3.1
		saltation	+	5.2.3.1
		topography	+	5.2.3.1
		tornado	+	5.2.3.1
		wind	+	5.2.3.1
		wind-induced contaminant transport	+	5.2.3.1
	meteorology	lightning	–	5.2.3.1
		meteorology	+	5.2.3.1
biology	biochemical effects	biochemical gas generation	?	5.2.3.2.1
		biochemical processes in geosphere	?	5.2.3.2.1
		biochemical processes in repository	?	5.2.3.2.1

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
	biotically-induced contaminant fate and transport	animal burrowing	+	5.2.3.2.2
		animal, plant and microbe mediated fate and transport of contaminants	+	5.2.3.2.2
		biomass production	+	5.2.3.2.2
		biosphere characteristics	+	5.2.3.2.2
		bioturbation	+	5.2.3.2.2
		burrow collapse	+	5.2.3.2.2
		burrow excavation	+	5.2.3.2.2
		burrow renewal	+	5.2.3.2.2
		plant intrusion	+	5.2.3.2.2
		plant root profile	+	5.2.3.2.2
		plant senescence	+	5.2.3.2.2
		plant uptake	+	5.2.3.2.2
		vegetation	+	5.2.3.2.2
	ecological community	animal populations	+	5.2.3.2.3
		ecological response to climate change	+	5.2.3.2.3
		ecological response to wildfire	+	5.2.3.2.3
		ecological succession	+	5.2.3.2.3
	ecological risk	uptake by animal, plant, root	+	5.2.3.2.4
	evolution	evolution	–	5.2.3.2.3
	microbiology	microbial systems	+	5.2.3.2.5
		radiological mutation of microbes	–	5.2.3.2.5
climate change	anthropogenic changes in biosphere	anthropogenic change in biosphere	+	5.2.3.3
	anthropogenic climate change	anthropogenic climate change	+	5.2.3.3
	climate change	climate change	+	5.2.3.3
		climate change, global	–	5.2.3.3
		climate change, regional and local	+	5.2.3.3
		hydrologic / hydrogeologic response to climate change	+	5.2.3.3
		no ice age	+	5.2.3.3
		warm climate effects	+	5.2.3.3
erosion	erosion	animal burrowing inducing erosion	+	5.2.3.4.1

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		anthropogenic erosion	+	5.2.3.4.1
		denudation and erosion	+	5.2.3.4.1
		deposition	+	5.2.3.4.1
		erosion	+	5.2.3.4.1
		erosion from rainsplash	+	5.2.3.4.1
		erosion from surface water	+	5.2.3.4.1
		erosion from tree-throw	+	5.2.3.4.1
		erosion from wave action	–	5.2.3.4.1
		erosion from wind	+	5.2.3.4.1
		erosion of ground surface	+	5.2.3.4.1
	mass wasting	erosion of cliffs	+	5.2.3.4.2
		landslide	+	5.2.3.4.2
		mass wasting	+	5.2.3.4.2
		rockfalls	–	5.2.3.4.2
	weathering	chemical weathering	–	5.2.3.4.3
		frost weathering	+	5.2.3.4.3
gas phase transport	gas generation	decay product gas generation	+	5.2.3.5.1
		gas generation	–	5.2.3.5.1
		gas generation from microbial degradation	?	5.2.3.5.1
		gas generation with pressurization	–	5.2.3.5.1
		hydrogen gas generation corrosion of steel	–	5.2.3.5.1
		thermally induced release of gases from pores and fluid inclusions	–	5.2.3.5.1
	gas phase transport	effects of radioactive gases in repository	+	5.2.3.5.2
		gas / water partitioning	+	5.2.3.5.2
		gas effects in porous media	+	5.2.3.5.2
		gas generation	+	5.2.3.5.2
		gas phase diffusion	+	5.2.3.5.2
		gas phase tortuosity	+	5.2.3.5.2
		gas phase transport	+	5.2.3.5.2
		natural air flow in porous media	+	5.2.3.5.2

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		natural gas intrusion	+	5.2.3.5.2
		noble gases	+	5.2.3.5.2
		radon diffusion	+	5.2.3.5.2
		radon emanation	+	5.2.3.5.2
		radon flux	+	5.2.3.5.2
		volatiles	+	5.2.3.5.2
geochemistry	bentonite chemistry	bentonite coagulation	+	5.2.3.6.1
		bentonite degradation	+	5.2.3.6.1
		bentonite geochemistry	+	5.2.3.6.1
		bentonite sedimentation	+	5.2.3.6.1
	biogeochemistry	cellulosic degradation	?	5.2.3.6.2
		soil nutrient cycling	?	5.2.3.6.2
		metals cycling	?	5.2.3.6.2
		soil organic carbon/biomass changes	?	5.2.3.6.2
	cement chemistry	cement carbonation	+	5.2.3.6.3
		cementitious pore water	+	5.2.3.6.3
		recrystallization	+	5.2.3.6.3
	change in geochemistry, anthropogenic	acid rain	+	5.2.3.6.4
		anthropogenic change in soil and surface water chemistry	+	5.2.3.6.4
		geochemical effects of excavation and construction	–	5.2.3.6.4
		geochemical transformation (manmade)	–	5.2.3.6.4
	change in geochemistry, natural	change in groundwater chemistry	+	5.2.3.6.5
		geochemical alterations	+	5.2.3.6.5
		geochemical change (natural)	+	5.2.3.6.5
		geochemical transformation	+	5.2.3.6.5
		rind formation	+	5.2.3.6.5
		thermochemical alteration	–	5.2.3.6.5
	chemical gradients	chemical gradients	+	5.2.3.6.5
	chemical speciation and solubility	chemical speciation and solubility	+	5.2.3.6.6
		inorganic solids / solutes	+	5.2.3.6.6
		non-radioactive solutes	+	5.2.3.6.6
	colloids	colloid formation in repository	?	5.2.3.6.7

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
	complexation	complexing agents	+	5.2.3.6.8
	deliquescence	effects of deliquescence on metals	+	5.2.3.6.11
	dissolution / precipitation	alpha recoil enhances dissolution	–	5.2.3.6.9
		dissolution and leaching	+	5.2.3.6.9
		dissolution of host rock	–	5.2.3.6.9
		dissolution, precipitation, and crystallization	+	5.2.3.6.9
		geochemical interactions and evolution	+	5.2.3.6.9
	electrochemistry	electrochemical reactions	–	5.2.3.6.10
	electrophoresis	electrophoresis	–	5.2.3.6.10
	geochemical effects	buffer material chemistry	+	5.2.3.6.11
		chemical effects	+	5.2.3.6.11
		chemical effects of construction	–	5.2.3.6.11
		chemical effects of steel reinforcing bar in repository	+	5.2.3.6.11
		far field hydrochemistry - acids, oxidants, nitrates	–	5.2.3.6.11
		groundwater geochemistry	+	5.2.3.6.11
		ion exclusion	+	5.2.3.6.11
		isotopic dilution	+	5.2.3.6.11
		mineralogic dehydration reactions	–	5.2.3.6.11
	organic chemistry	organic chemistry	+	5.2.3.6.11
	partitioning	sorption	+	5.2.3.6.11
	pH	pH	+	5.2.3.6.12
		pH change	+	5.2.3.6.12
	redox	oxidizing conditions	+	5.2.3.6.12
		redox front	?	5.2.3.6.12
		redox potential	+	5.2.3.6.12
	saltwater chemistry	saltwater-freshwater	–	5.2.3.6.11
	surface chemistry	surface diffusion	+	5.2.3.6.11
	waste chemistry	Pb / Cu electrochemical reactions	–	5.2.3.6.13
		Pb-I reactions	–	5.2.3.6.13
	water chemistry in repository	reaction kinetics	–	5.2.3.6.11
		water chemistry characterization	+	5.2.3.6.11

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
geochemistry; hydrogeology	colloid transport	colloid advection	?	5.2.3.6.7
		colloid diffusion	?	5.2.3.6.7
		colloid filtration	?	5.2.3.6.7
		colloid formation, dissolution and transport	?	5.2.3.6.7
		colloid sorption	?	5.2.3.6.7
		colloid stability	?	5.2.3.6.7
		colloid transport	?	5.2.3.6.7
	diffusion	water phase diffusion	+	5.2.3.7.1
	radionuclide transport	radionuclide transport	+	5.2.3.7.2
geology	breccia pipes	breccia pipes	–	5.2.3.8.1
	changes in rock	diagenesis	–	5.2.3.8.2
		diapirism	–	5.2.3.8.2
		induced diapirism	–	5.2.3.8.2
		metamorphism	–	5.2.3.8.2
	discontinuities in geosphere	discontinuities in geosphere	–	5.2.3.8.3
	faulting	far-field faulting	–	5.2.3.8.3
		fault activation	–	5.2.3.8.3
		fault generation	–	5.2.3.8.3
		faulting	–	5.2.3.8.3
		faulting - near-field	+	5.2.3.8.3
		faults, shear zones	+	5.2.3.8.3
		fluids leave along new fault	+	5.2.3.8.3
		rapid fault growth	–	5.2.3.8.3
	fracturing	enhanced fracturing	+	5.2.3.8.4
		formation of interconnected fracture systems	+	5.2.3.8.4
		host rock fracture aperture change	+	5.2.3.8.4
		impact fracturing	–	5.2.3.8.4
		local fracturing	+	5.2.3.8.4
		static fracturing	+	5.2.3.8.4
		surficial fissuring	+	5.2.3.8.4
	geothermal	geothermal effects	–	5.2.3.8.5

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		hydrothermal activity	–	5.2.3.8.5
	hydrogeological changes	hydrological / hydrogeological response to geological change	+	5.2.3.8.2
	soils	near-surface temperature	+	5.2.3.8.6
		pedogenesis	–	5.2.3.8.6
		soil and sediment	+	5.2.3.8.6
	stratigraphy	stratigraphy	+	5.2.3.8.11
		surge beds	–	5.2.3.8.11
	subsidence	subsidence	+	5.2.3.8.7
	tectonics	orogeny	–	5.2.3.8.8
		tectonics	–	5.2.3.8.8
		uplift and subsidence	–	5.2.3.8.8
	undetected geological features	undetected features	–	5.2.3.8.9
		undetected fractures	–	5.2.3.8.9
	volcanism	chemical effects of magma and magmatic volatiles	–	5.2.3.8.10
		extrusive magmatic activity	–	5.2.3.8.10
		hot-spot volcanic activity	–	5.2.3.8.10
		igneous activity	–	5.2.3.8.10
		igneous intrusion	–	5.2.3.8.10
		magmatic activity	–	5.2.3.8.10
		rift system volcanic activity	–	5.2.3.8.10
		volcanic activity	–	5.2.3.8.10
		volcanic activity transports waste	–	5.2.3.8.10
	volcanism, extrusive	extrusive volcanism	–	5.2.3.8.10
		lava tubes	–	5.2.3.8.10
geophysics	geomagnetism	change in the earth's magnetic field	–	5.2.3.9.1
	rock mechanics	earth tide effects	–	5.2.3.9.2
		elastic response, differential	–	5.2.3.9.2
		elastic, plastic, or brittle deformation	–	5.2.3.9.2
		external stress	–	5.2.3.9.2
		fracture mechanics	–	5.2.3.8.4
		igneous activity changes rock properties	–	5.2.3.9.2
		jointed rock motion	–	5.2.3.9.2

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		non-elastic response	–	5.2.3.9.2
		rock creep	–	5.2.3.9.2
		rock mechanics	–	5.2.3.9.2
		stress, excavation induced	–	5.2.3.9.2
		stress, thermally induced	–	5.2.3.9.2
	seismicity	earthquake	+	5.2.3.9.3
		earthquake, anthropogenic	+	5.2.3.9.3
		seismic activity	+	5.2.3.9.3
		seismic-induced repository damage	+	5.2.3.9.3
		seismicity	+	5.2.3.9.3
		seismicity due to igneous activity	–	5.2.3.9.3
	subsidence	subsidence fractures end above repository	–	5.2.3.9.4
		subsidence fractures reach repository	–	5.2.3.9.4
glaciology	faulting	glacially-induced faulting	+	5.2.3.10
	glacial deposits	glacial deposits	+	5.2.3.10
	glacial effects	glacial activity	?	5.2.3.10
		glacial effects	?	5.2.3.10
		glacial erosion	?	5.2.3.10
		glaciation	?	5.2.3.10
	isostatic effects	isostatic subsidence and rebound	+	5.2.3.10
	periglacial effects	gases under permafrost	?	5.2.3.10
		periglacial effects	?	5.2.3.10
		permafrost	?	5.2.3.10
hydrogeology	brine occurrence	brine migration	+	5.2.3.11.1
		brine pockets	+	5.2.3.11.1
		gas or brine pockets	+	5.2.3.11.1
	change in hydrogeology	desertification	–	5.2.3.11.2
		resaturation	+	5.2.3.11.2
	change to hydrogeology, anthropogenic	anthropogenic change to hydrogeology	+	5.2.3.11.2
		dewatering of host rock	–	5.2.3.11.2
		human-induced actions on groundwater recharge	+	5.2.3.11.2
		hydrogeologic effects of excavation and construction	+	5.2.3.11.2

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		induced hydrological change	+	5.2.3.11.2
		intentional artificial groundwater recharge or withdrawal	+	5.2.3.11.2
	convection	convection	–	5.2.3.11.3
	advection	advection	+	5.2.3.11.3
	diffusion	diffusion	+	5.2.3.11.3
		matrix diffusion	+	5.2.3.11.3
	dilution	dilution	+	5.2.3.11.3
		dilution in groundwater	+	5.2.3.11.3
	dissolution	formation of dissolution cavities in salt	–	5.2.3.11.4
	fracture hydrogeology	cooling joints	+	5.2.3.11.5
		fracture coatings	–	5.2.3.11.5
		fracture fill	+	5.2.3.11.5
		fracture flow	+	5.2.3.11.5
	groundwater hydraulics	advection-dispersion	+	5.2.3.11.6
		aquifers	+	5.2.3.11.6
		capillary rise	+	5.2.3.11.6
		change in groundwater system	+	5.2.3.11.6
		chemically-induced density effects in groundwater flow	–	5.2.3.11.6
		condensation in the repository	+	5.2.3.11.6
		condensation zone around repository	+	5.2.3.11.6
		dilution within a water supply well	+	5.2.3.11.6
		extreme channel flow of oxidants and nuclides	+	5.2.3.11.6
		film flow enters repository	+	5.2.3.11.6
		flow diversion around repository	+	5.2.3.11.6
		flow shadow below repository	+	5.2.3.11.6
		fluid interactions	+	5.2.3.11.6
		fluids carry waste to rivers or tributaries	+	5.2.3.11.6
		fluids carry waste to wells or springs	+	5.2.3.11.6
		focused recharge	+	5.2.3.11.6
		focusing of unsaturated flow (fingers, weeps)	+	5.2.3.11.6
		geosphere dehydration due to waste heat	–	5.2.3.11.6

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		geosphere rehydration following dehydration due to waste heat	–	5.2.3.11.6
		groundwater	+	5.2.3.11.6
		groundwater conditions	+	5.2.3.11.6
		groundwater discharge	+	5.2.3.11.6
		groundwater flow	+	5.2.3.11.6
		groundwater recharge	+	5.2.3.11.6
		groundwater well capture efficiency	+	5.2.3.11.6
		hydraulic / hydrogeological processes and conditions (in geosphere)	+	5.2.3.11.6
		hydraulic / hydrogeological processes and conditions (in wastes)	+	5.2.3.11.6
		hydraulic conductivity change - excavation / backfilling effect	–	5.2.3.11.6
		injection of liquid wastes	+	5.2.3.11.6
		injection wells	+	5.2.3.11.6
		lateral diversion of groundwater flow	+	5.2.3.11.6
		lateral flow enters repository	+	5.2.3.11.6
		matrix imbibition	+	5.2.3.11.6
		multiphase flow	+	5.2.3.11.6
		natural geothermal effects on saturated zone flow	–	5.2.3.11.6
		natural geothermal effects on unsaturated zone flow	–	5.2.3.11.6
		perched groundwater	+	5.2.3.11.6
		pore water residence time	+	5.2.3.11.6
		preferential pathways	+	5.2.3.11.6
		radial dispersion	+	5.2.3.11.6
		repository dehydration due to waste heat	–	5.2.3.11.6
		repository-induced geothermal effects on unsaturated zone flow	–	5.2.3.11.6
		repository-induced thermal effects on saturated zone flow	–	5.2.3.11.6
		seismically-induced changes in perched water	+	5.2.3.11.6
		subsurface evaporation	+	5.2.3.11.6
		thermally-induced fluid migration	–	5.2.3.11.6
		vadose zone	+	5.2.3.11.6

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
	groundwater parameters	fluid pressure changes in time	–	5.2.3.11.7
		gravity	+	5.2.3.11.7
		hydraulic conductivity	+	5.2.3.11.7
		permeability	+	5.2.3.11.7
		seismically-induced changes in porosity and permeability	+	5.2.3.11.7
		surface tension	+	5.2.3.11.7
		thermally-induced changes to fluid properties	–	5.2.3.11.7
		vertical groundwater gradients	+	5.2.3.11.7
		head is below outfall	–	5.2.3.11.7
	particulate transport in water	transport of particles larger than colloids	+	5.2.3.11.8
	water intrusion	repository resaturation due to waste cooling	–	5.2.3.11.9
		water from a confined aquifer enters repository	+	5.2.3.11.9
		water from an unconfined aquifer enters repository	+	5.2.3.11.9
		water intrusion ("bathtubbing")	+	5.2.3.11.9
	weathering of flow paths	weathering of flow paths	+	5.2.3.11.10
hydrology	change in hydrology	change in hydrology, anthropogenic	+	5.2.3.12.1
		change in hydrology, natural	+	5.2.3.12.1
		change in surface water	+	5.2.3.12.1
		hydrologic stresses	+	5.2.3.12.1
		hydrology change from igneous activity	–	5.2.3.12.1
		hydrology change from seismic activity	+	5.2.3.12.1
		large-scale alterations of hydrology	–	5.2.3.12.1
	infiltration	episodic infiltration	+	5.2.3.12.2
		evaporation	+	5.2.3.12.2
		flow through buffer / backfill	+	5.2.3.12.2
		hydrological regime and water balance (near-surface)	+	5.2.3.12.2
		infiltration and evapotranspiration	+	5.2.3.12.2
		precipitation, temperature, soil, water balance	+	5.2.3.12.2
	inundation	flooding	–	5.2.3.12.3
		large episodic runoff events	+	5.2.3.12.3
		ponding	+	5.2.3.12.3
	precipitation	hurricane	–	5.2.3.12.4

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		pluvial periods	+	5.2.3.12.4
		precipitation	+	5.2.3.12.4
		precipitation - extreme	+	5.2.3.12.4
		precipitation - hail	–	5.2.3.12.4
		precipitation - monsoon rain	+	5.2.3.12.4
		thunderstorms	+	5.2.3.12.4
	sediment transport	freshwater sediment transport and deposition	+	5.2.3.12.5
		sediment transport	+	5.2.3.12.5
		sedimentation	+	5.2.3.12.5
	surface water	lake level change	+	5.2.3.12.6
		lakes, rivers, streams and springs	+	5.2.3.12.6
		river processes	–	5.2.3.12.6
		surface water transport and mixing	+	5.2.3.12.6
	surface water management	dams, canals, pipelines, water collection / storage facilities	+	5.2.3.12.6
		natural dam formation / failure	–	5.2.3.12.6
		reservoir construction / failure	+	5.2.3.12.6
marine issues	coastal erosion	coastal erosion development of estuaries	–	5.2.3.13
	coastal features	coastal features	–	5.2.3.13
	marine issues	marine features	–	5.2.3.13
		marine processes	–	5.2.3.13
		storm surge	–	5.2.3.13
		tsunami	–	5.2.3.13
	sea level change	sea level change	–	5.2.3.13
material properties	material properties	material properties of backfill	+	5.2.3.14.1
		material properties of porous media	+	5.2.3.14.1
		material property change	+	5.2.3.14.1
		rock heterogeneity	+	5.2.3.14.1
	swelling	swelling of clay backfill	+	5.2.3.14.2
		swelling of corrosion products	+	5.2.3.14.2
exposure and activities				
human exposure	agriculture / aquaculture	agriculture / aquaculture	+	5.2.4.1.1

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		agriculture in canyons	–	5.2.4.1.1
		agriculture on mesatop	–	5.2.4.1.1
		irrigation	+	5.2.4.1.1
		irrigation with groundwater	+	5.2.4.1.1
		irrigation with surface water	+	5.2.4.1.1
	demographics	community characteristics	+	5.2.4.1.2
		social and institutional developments	+	5.2.4.1.2
		urban development	+	5.2.4.1.2
	dose response	dose response	+	5.2.4.1.3
		dosimetry	+	5.2.4.1.3
		sensitization to radiation effects	–	5.2.4.1.3
	exposure media concentrations	intrusion into accumulation zone in the biosphere	+	5.2.4.2.1
	groundwater use	groundwater use	+	5.2.4.1.10
	human behavior	future human actions	+	5.2.4.1.4
		future human behavior	+	5.2.4.1.4
		human response to climate change	–	5.2.4.1.4
	human exposure	contamination of non-food products	+	5.2.4.1.5
		human characteristics (physiology, metabolism)	+	5.2.4.1.5
	ingestion	drinking water, foodstuffs and drugs	+	5.2.4.1.6
		food and water processing and preparation	+	5.2.4.1.6
		ingestion of contaminated animal products	+	5.2.4.1.6
		ingestion of drinking water	+	5.2.4.1.6
		ingestion of food crops grown in contaminated soils and irrigated with well water	+	5.2.4.1.6
	ingestion by animals	grazing	+	5.2.4.1.7
	inhalation	radon and radon decay product exposure	+	5.2.4.1.8
	population dose / risk	demographics	+	5.2.4.1.2
	land use scenarios	land use	+	5.2.4.1.9
		land use changes	+	5.2.4.1.9
		Amerindian scenarios	+	5.2.4.1.9
		dwelling construction	+	5.2.4.1.9
		dwelling occupation	+	5.2.4.1.9

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		kiva construction	–	5.2.4.1.9
		kiva occupation	–	5.2.4.1.9
		occupation of canyons	–	5.2.4.1.9
		occupation of mesas	–	5.2.4.1.9
		post-closure inhabitation	+	5.2.4.1.9
		recreation	+	5.2.4.1.9
		septic drain field	+	5.2.4.1.9
		underground construction	+	5.2.4.1.9
		unintrusive site investigation	+	5.2.4.1.9
		commercial development	+	5.2.4.1.9
		industrial development	+	5.2.4.1.9
	water supply	water supply - surface water	+	5.2.4.1.10
		water well	+	5.2.4.1.10
		water well - community	+	5.2.4.1.10
		water well - household	+	5.2.4.1.10
human exposure; ecorisk	exposure media concentrations	exposure media concentrations	+	5.2.4.2.1
	external irradiation / immersion	direct radiation from airborne radionuclides	+	5.2.4.2.2
		exposed sediments in a reservoir	+	5.2.4.2.2
		external irradiation	+	5.2.4.2.2
		external irradiation from soil or sediment	+	5.2.4.2.2
		immersion in contaminated water	+	5.2.4.2.2
	food contamination	animal uptake of radionuclides	+	5.2.4.2.3
		plant uptake of radionuclides	+	5.2.4.2.3
		rainsplash (soil onto plants)	+	5.2.4.2.3
	human exposure	exposure modes	+	5.2.4.2.4
		impacts of concern	+	5.2.4.2.4
	ingestion	diet and fluid intake	+	5.2.4.2.5
		ingestion of contaminated soil	+	5.2.4.2.5
		ingestion of radionuclides	+	5.2.4.2.5
		surface water ingestion	+	5.2.4.2.5

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		uptake of contaminants in food chain	+	5.2.4.2.5
	dermal exposure	dermal exposure	+	5.2.4.2.5
	inhalation	inhalation of radionuclides	+	5.2.4.2.6
	land use	wild land and water use	+	5.2.4.2.7
	toxicity	chemical toxicity of wastes	+	5.2.4.2.9
		chemical toxicant stability	+	5.2.4.2.9
		radiological toxicity	+	5.2.4.2.9
inadvertent human intrusion	inadvertent human intrusion	igneous event precedes inadvertent human intrusion	–	5.2.4.3.1
		inadvertent human intrusion	+	5.2.4.3.1
		seismic event precedes inadvertent human intrusion	+	5.2.4.3.1
		erosional event precedes inadvertent human intrusion	+	5.2.4.3.1
	resource extraction	mining	+	5.2.4.3.2
		drilling and mining	+	5.2.4.3.2
		drilling into repository	+	5.2.4.3.2
		fossil fuel extraction	+	5.2.4.3.2
		geological resources	+	5.2.4.3.2
		geothermal resources	+	5.2.4.3.2
		groundwater extraction	+	5.2.4.3.2
		hydraulic fracturing	+	5.2.4.3.2
		mine shafts	+	5.2.4.3.2
		mining	+	5.2.4.3.2
		natural resource exploration / extraction	+	5.2.4.3.2
		other future uses of host rock	+	5.2.4.3.2
		quarrying	+	5.2.4.3.2
		tunneling	–	5.2.4.3.2
		undetected past intrusion	–	5.2.4.3.2
		boreholes	+	5.2.4.3.2
intentional human intrusion	intentional intrusion	archeological intrusion	–	5.2.4.4.1
		exhumation	–	5.2.4.4.1
		intentional intrusion	–	5.2.4.4.1

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
		malicious intrusion	–	5.2.4.4.1
		waste retrieval	–	5.2.4.4.1
	underground storage	underground storage of energy resources	–	5.2.4.4.1
	waste disposal	reuse of boreholes	–	5.2.4.4.1
	weapons testing	underground nuclear testing	–	5.2.4.4.1
		weapons testing	–	5.2.4.4.1
miscellaneous FEPS				
miscellaneous	accidents and unplanned events	accidents and unplanned events	–	5.2.5.1.1
		brush fire	+	5.2.5.1.1
		gas generation - explosion or fire	+	5.2.5.1.1
		H_2 / O_2 explosions	–	5.2.5.1.1
		wild fire	+	5.2.5.1.1
	explosion / fire	explosions, fire and crashes	–	5.2.5.1.1
		use of explosive devices	–	5.2.5.1.1
	extraterrestrial objects	celestial bodies	–	5.2.5.1.2
		meteorite	–	5.2.5.1.2
	human-induced transport	human-action-mediated transport of contaminants	+	5.2.5.1.3
	intentional destruction	sabotage	–	5.2.5.1.4
		war	–	5.2.5.1.4
	miscellaneous			
		extraterrestrial events	–	5.2.5.1.2
		future technological development	–	5.2.5.1.5
		ozone layer failure	–	5.2.5.1.5
	nuclear processes	criticality, far-field	?	5.2.5.1.6
		criticality, near-field	?	5.2.5.1.6
		radiation effects	–	5.2.5.1.6
		radiation effects in repository	–	5.2.5.1.6
		radiation effects on bentonite	–	5.2.5.1.6
		radioactive decay and ingrowth	+	5.2.5.1.6
		radioactive decay and ingrowth in the biosphere	+	5.2.5.1.6
		radiolysis	?	5.2.5.1.6
		recoil of alpha-decay	?	5.2.5.1.6

Topic	Subtopic	Normalized FEPS	Retain?	FEPS section
	reconcentration in environmental media	accumulation in peat	+	5.2.5.1.7
		accumulation in sediment	+	5.2.5.1.7
		accumulation in soils	+	5.2.5.1.7
		reconcentration in environmental media	+	5.2.5.1.7
	thermal effects	exothermic reactions in the repository	?	5.2.5.1.8
		heat distribution in repository	?	5.2.5.1.8
		heat generation in repository	?	5.2.5.1.8
		natural thermal effects	–	5.2.5.1.8
		presence of a heat source	?	5.2.5.1.8
		radiogenic heat	?	5.2.5.1.8
		thermal (nuclear and chemical)	?	5.2.5.1.8
		thermal buoyancy	?	5.2.5.1.8
		thermal cracking	?	5.2.5.1.8
		thermal effects from concrete hydration	?	5.2.5.1.8
		thermal effects on chemistry and microbial activity	?	5.2.5.1.8
		thermal effects on radionuclide transport	–	5.2.5.1.8
		thermal effects on the biosphere	–	5.2.5.1.8
		thermal effects on the buffer material	–	5.2.5.1.8
		thermal effects on water flow	–	5.2.5.1.8
		thermal processes and conditions (in wastes and repository)	?	5.2.5.1.8
		thermal sensitization of waste package	?	5.2.5.1.8
		thermally-induced stress in repository components	?	5.2.5.1.8
		thermally-induced stress in waste package	?	5.2.5.1.8
		thermochemical change	?	5.2.5.1.8
		thermo-hydro-mechanical effects	?	5.2.5.1.8
		thermophoresis	–	5.2.5.1.8
modeling	modeling	modeling	+	5.2.5.2
		radionuclide release outside the reference biosphere	+	5.2.5.2
		spatial domain	+	5.2.5.2
		timescale domain	+	5.2.5.2