Technical Evaluation Report

For US Ecology Low-Level Waste Disposal Facility, Richland Washington

Final Report

U.S. Nuclear Regulatory Commission
Office of Federal and State Materials
and Environmental Management Programs
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ABBREVIATIONS/ACRONYMS

ADAMS	Agencywide Document Access and Management System
ALARA	As Low As Is Reasonably Achievable
Am	americium
Ba	barium
Bq	becquerel
C	carbon
°C	degree Celsius
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
Ci	curie
Cm	curium
cm	centimeter
cm^3	cubic centimeters
Co	cobalt
Cs	cesium
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOH	Department of Health
DQA	data quality assessment
DQO	data quality objective
DUST	MS Disposal Unit Source Term Multiple Species
DSA	documented safety analysis
EDF	engineering design file
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
Eu	europium
°F	degrees Fahrenheit
FORTRAN	formula translation/translator (high-level programming language)
FR	Federal Register
ft	foot
ft^3	cubic feet
g	grams
gal	gallon
GWSCREEN	A Semi-Analytical Model for Assessment of the Groundwater Pathway from Surface or Buried Contamination
H-3	tritium
ha	hectare
HCM	hydrogeological conceptual model
HDPE	high-density polyethylene
HLW	high-level radioactive waste

ABBREVIATIONS/ACRONYMS (continued)

hr	hour
HRRs	highly radioactive radionuclides
HWMA	Hazardous Waste Management Act
I	iodine
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Engineering and Environmental Laboratory
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
in	inches
K_d	distribution coefficient
K_h	hydraulic conductivity
km	kilometers
L	liters
LNT	linear no-threshold
LLW	low-level radioactive waste
m	meters
m^3	cubic meters
MBq	mega becquerel
MCi	million curies
MCL	maximum contaminant level
MCP	management control procedure
mi	miles
mL/g	milliliters/gram
MOU	Memorandum of Understanding
mph	miles per hour
mrem	millirem
mSv	millisievert
NAS	National Academy of Sciences
Nb	niobium
nCi	nano Curie
Ni	nickel
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
ORIGEN2	Isotope Generation and Depletion Code
oz	ounce
PA	performance assessment
pCi/L	picocuries/liter
pH	measure of acidity (minus the log of the hydrogen ion concentration)
PMF	probable maximum flood
PMP	probable maximum precipitation
PNNL	Pacific Northwest National Laboratory
PORFLOW	Code Used to Model Multiphase Fluid Flow, Heat and Mass Transport in Variably Saturated Porous and Fractured Media
Pu	plutonium
QA	quality assurance

RAI	request for additional information
RCRA	Resource Conservation and Recovery Act
rem	unit of dose equivalent
RI/BRA	remedial investigation/baseline risk assessment
RPP	Radiological Protection Plan
s	second
SAP	sampling and analysis plan
Sb	antimony
SNF	spent nuclear fuel
Sr	strontium
SRM	Staff Requirements Memorandum
SRP	standard review plan
Sv	Sievert
TAR	Technical Assistance Request
Tc	technetium
TEDE	total effective dose equivalent
TER	Technical Evaluation Report
TFA	Tank Focus Area
TFF	Tank Farm Facility
TRU	transuranic
U	uranium
USGS	U.S. Geological Survey
WIR	waste incidental to reprocessing
Y	yittrium
yr	year

EXECUTIVE SUMMARY

The State of Washington Department of Health (Washington DOH) requested technical assistance from the United States Nuclear Regulatory Commission (NRC) to address issues raised by the Confederated Bands of Tribes of Yakama Nation and Confederated Tribes of the Umatilla Indian Reservation concerning early waste disposals at the US Ecology facility located on the U.S. Department of Energy Hanford Site in Richland, Washington. The technical assistance request posed two questions:

1. Did waste licensed by the NRC for disposal at the US Ecology disposal facility during the period 1965 to 1980 meet the four performance objectives of 10 CFR 61 (and WAC 246-250), even though it may have contained transuranics in excess of 100 nCi/gm?

2. What is the potential radiological risk to worker's health and safety if waste is exhumed? Exhumation of waste would encompass seven trenches which contain approximately 1,267,000 cubic feet of waste. These trenches are pre-Part 61.

NRC staff clarified the scope of the request to include special nuclear material disposed of in six (not seven as stated in the request) trenches prior to a license condition and the effective date of the 10 CFR Part 61 rulemaking that limited the concentration of transuranic waste that could be disposed of at the facility. Part 61 of 10 CFR is the NRC's first comprehensive effort to provide licensing requirements and performance standards for land disposal of radioactive waste. Performance objectives in 10 CFR Part 61, Subpart C were established to provide reasonable assurance that the site would be designed, operated, and closed in a way that is protective of human health and safety.

NRC has reviewed an extensive amount of US Ecology and Washington DOH generated information regarding the inventory, characteristics and performance of the disposal facility to reach conclusions regarding the ability of early waste disposals to meet performance objectives in 10 CFR, Part 61, Subpart C and associated Washington Administrative Code, WAC-246-250.

Based on this review, NRC staff concludes the following:

1. NRC has reasonable assurance that the US Ecology disposal facility can be operated and closed to meet the performance objectives in 10 CFR Part 61, Subpart C (and associated WAC-246-250) provided certain key assumptions in site performance assessments (PA) are met. Key assumptions include the following:

    - The inventory of key radionuclides such as isotopes of uranium (U) is similar to or less than assumed in the PA analyses.
    - Lack of explicit consideration of certain early (pre-Part 61) waste disposal practices (e.g., less stringent controls on waste segregation, waste form stability, and other controls based on waste classification system) does not lead to a significant underestimation of risk due to a greater potential for increased infiltration, leaching, and waste concentrations.

- Mobility of key radionuclides such as U isotopes is not significantly under-estimated (e.g., distribution coefficients, solubility limits, and mobile release fractions are appropriate).
- The as-emplaced engineered cover will perform as well as assumed in site performance assessment analyses with respect to infiltration and radon mitigation.

Other NRC staff conclusions include the following:

2. Washington DOH efforts to refine the inventory for the disposal facility are expected to lead to reduced uncertainty and better estimates of facility risk.

3. In general, the methodology used in Washington DOH's groundwater modeling and risk assessment are technically sound.

4. Remaining uncertainty in disposal facility risk is considered acceptably low to allow closure decisions to be made.

5. Based on Washington DOH's risk assessment calculations, installation of a Phase 1 cover is expected to minimize future dose to potential receptors for more mobile constituents predicted to impact groundwater earlier in the compliance period.

The key assumptions listed above and major areas of uncertainty in assessing performance of the disposal facility are discussed in greater detail in Chapter 2. Recommendations for future studies and monitoring are provided in Chapter 4.

As part of the technical assistance request, NRC staff also evaluated potential costs (e.g., worker risks) associated with exhumation, characterization and re-packaging of waste in six pre-Part 61 trenches. Data from similar DOE waste excavation projects were collected and scaled to US Ecology trench volumes to provide a range of potential worker risks and project costs. Although previous projects have shown that risks to workers involved in the excavation, retrieval, characterization, and processing of TRU waste from disposal sites can be maintained below regulatory limits, the cost associated with this type of project at the US Ecology disposal facility is expected to be prohibitive. Additionally, the benefits of trench waste exhumation are limited considering the results of Washington DOH's PA that show that most of the risk associated with the disposal facility is related to mobile fractions of contaminants that may have already leached out of the disposal trenches into the underlying vadose zone. Additional details related to NRC staff's analysis and conclusions with respect to technical assistance request question number 2 are provided in Chapter 3.

1 INTRODUCTION:

1.1 Facility and Site Description:

The US Ecology Low Level Radioactive Waste (LLRW) Disposal Facility is located in Benton County, Washington, latitude 46° 32' 17" N longitude 119° 33' 29" W, near the center of the U.S. Department of Energy Hanford Site in Richland, Washington. The site is approximately 6.2 miles (9.9 km) from the nearest current Native American Reservation boundary. The 100 acre (0.4 km^2) facility is bounded on all sides by federal land controlled by the DOE.

The 100 acre (0.4 km^2) US Ecology LLRW Disposal Facility is a site that was subleased from Washington State. The Hanford Site is located within the Pasco Basin area of southeastern Washington, near the confluence of the Columbia and Yakima Rivers. The nearest population center is Richland, which is located about three miles from the southernmost boundary of the Hanford Site. The Pasco Basin is surrounded by the Rocky Mountains to the east and the Cascade Mountains to the west and south.

The facility is located south of Gable Mountain and Gable Butte, east of Yakima Ridge, and north of Rattlesnake Hills and Red Mountain in the Separations Area. The Separations Area covers 82 square miles (212.4 square kilometers) near the center of the Hanford Site. The Separations Area encompasses the 200-East and 200-West Areas where DOE had processing facilities along with disposal facilities. The Columbia River, the natural surface water body nearest US Ecology is about 7 miles (11.27 km) east at its closest point or approximately 16 miles (25.7 km) in the direction of groundwater flow.

The US Ecology LLRW Disposal facility has been in operation since 1965 and has been continuously operated by US Ecology, Inc. (US Ecology or processors). The site is licensed to receive low-level radioactive waste. Disposal access is currently limited to 11 states by the Rocky Mountain and Northwest Interstate Compact. During the period of 1965 to 1983, the site would receive waste from generators throughout the country. The majority of the low level radioactive waste currently disposed at the site (approximately 80%) is from generators in Washington and Oregon.

LLRW is primarily disposed of by shallow-land burial. The disposal trenches are opened, as needed, and used in an alternating sequence to allow room for the stockpiling of excavated soil and to facilitate trench access. The waste containers are placed in the trench, with a minimum distance of 8 ft (2.44 m) left between the top of the waste and the original ground surface. The trench is backfilled with the previously excavated soil.

The site currently consists of 18 land disposal trenches that vary dimensionally from 300 to 1,000 ft long (91.4 to 304.8 m), 25 to 150 ft wide (7.62 to 45.72 m), and 20 to 45 ft deep (6.1 to 13.7 m). The site also hosts four 30-ft deep caissons located between trenches 3 and 4 and three underground steel tanks ranging in size from 1,000 to 20,000 gallon (3785.4 to 75708 liters).

US Ecology originally had five underground steel tanks, ranging in size from 1,000 to 20,000 gallon (3785.4 to 75708 liters), which were installed in the late 1960s for evaporating and solidifying liquid resin wastes: use of these tanks was discontinued in the early 1970s. The tanks and associated wastes were left in place with little attention until early 1985. US Ecology removed the liquid waste from the tanks and subsequently removed and disposed of two of the five tanks. The remaining three tanks were filled with concrete. US Ecology then placed plastic over the tank area to prevent the contaminated soil from becoming airborne.

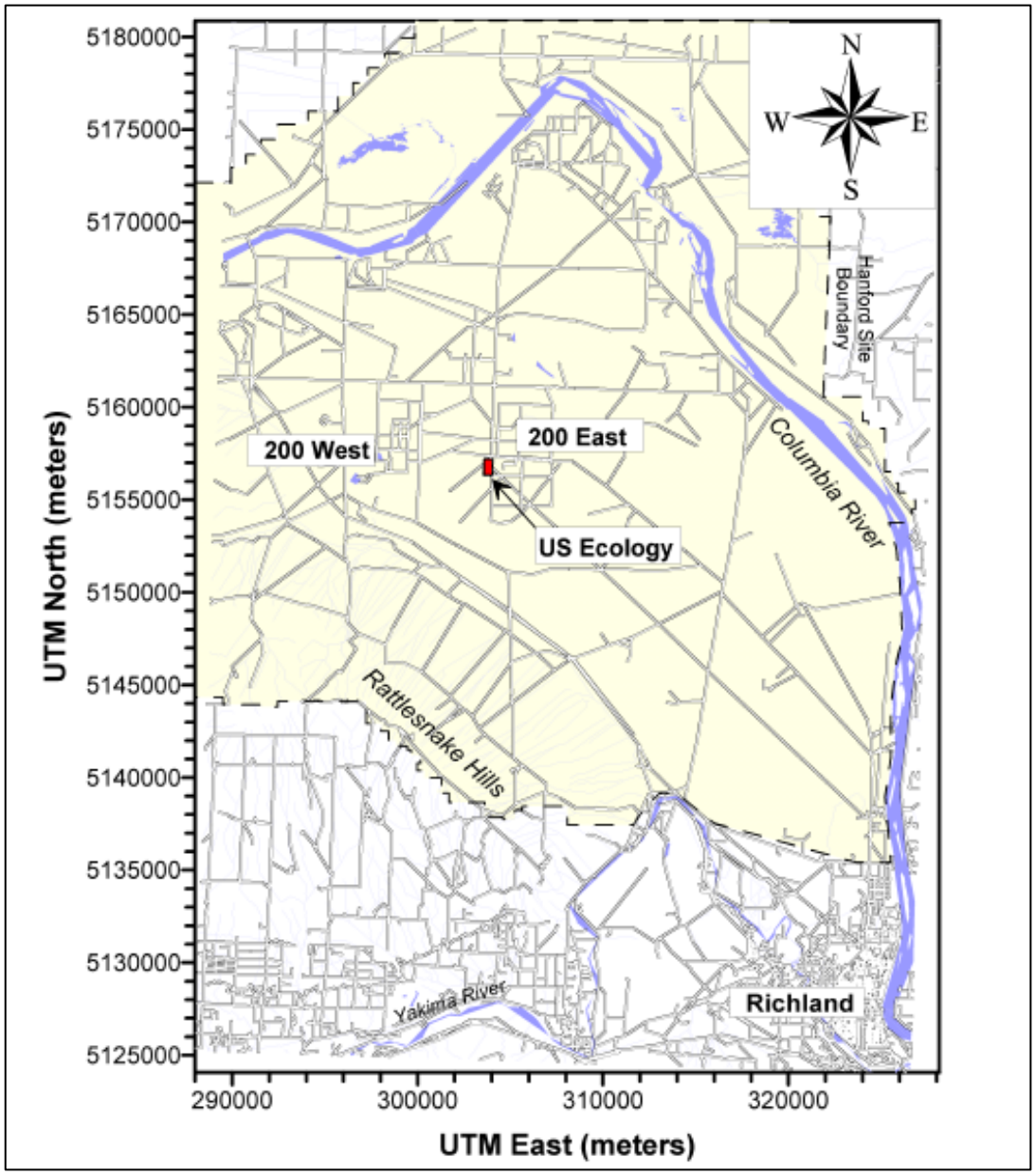

Figure 1-1 Location of US Ecology at the Hanford Site (Taken from the Washington DOH's FEIS [2004])

1.2 Regulatory History:

1.2.1 US Ecology Licensing History:

In September 10, 1964, Washington State and the Atomic Energy Commission (AEC) entered into a 100-year lease agreement for 1,000 acres (4.05 square kilometers) acres of land on the Hanford Site. Subsequently the state subleased 100 acres (0.4 squared kilometers) to a commercial entity that later became the US Ecology LLRW Disposal Facility. In 1974, the Energy Reorganization Act abolished the AEC and created the NRC and Energy Research and Development Administration (which later became part of the DOE). U.S. DOE assumed the responsibility for the lease agreement. In 1965, the State of Washington leased 100 acres (0.4 km^2) of this land to California Nuclear, Inc. the first licensed operator of the LLRW disposal site. In 1968 the Nuclear Engineering Co. acquired California Nuclear, Inc. and took over operations. In 1981 Nuclear Engineering Co. changed its name to US Ecology, Inc.

In December 1966, Washington became an Agreement State with the NRC. The State has assumed responsibility for licensing the possession and disposal of source and by-product material, while the NRC retained responsibility for licensing the possession and disposal of special nuclear material (SNM). SNM is defined by Title I of the Atomic Energy Act of 1954 as plutonium, uranium-233, or uranium enriched in the isotopes of uranium-233 or uranium-235. The definition includes any other material that the Commission determines to be special nuclear material, but does not include source material. The NRC has not declared any other material as SNM. The NRC licensed the site to “not possess unburied at any time at the facility . . . more than 5,000 grams of special nuclear material.” The NRC SNM license was terminated in 1996.

From 1976 to 1979 the US Ecology disposal facility was the only commercial facility accepting Transuranic (TRU) waste for disposal. This practice ended by State and NRC license condition in November 1979. The license condition that became effective January 1, 1980, prohibited the disposal of radioactive waste contaminated with TRU in excess of 10 nCi/g. The limit was reflective of the sensitivity level for measurements made to determine the presence or absence of TRU isotopes but was not based on the risk of disposal.

1.2.2 LLW Program History:

Much of the information regarding the evolution of the LLW program in the U.S. in the paragraphs that follow comes from NUREG-1853, “History and Framework of Commercial Low-Level Radioactive Waste Management in the United States” (NRC, 2007) and Walker “The Road to Yucca Mountain” that provide useful historical perspectives (Walker, 2009). In 1973, the AEC, predecessor to the NRC and DOE, asked the National Academy of Science (NAS) to independently review the shallow-land disposal practices at its facilities. The AEC requested the review because routine monitoring at some of the AEC sites had begun to reveal that the disposal trenches were not containing the wastes and that radionuclides were being released. At the time, the AEC was also particularly concerned about the long-term management of TRU constituents of its wastes. In 1976, the NAS published its findings and recommendations following the review of solid LLW management practices at AEC facilities. Although the NAS found no serious deficiencies in past Federal disposal practices, it did make numerous administrative, as well as technical recommendations for the NRC to consider.

The Energy Reorganization Act of 1974 gave the NRC the authority to regulate certain Federal high level waste (HLW) storage and disposal activities. However, a number of other Federal radioactive waste activities were exempted from this independent regulatory authority. In its 1976 report, the NAS recommended greater Federal leadership in the management of radioactive wastes. In a later review, the U.S. Government Accountability Office (GAO) (1977) noted several continuing problems, including gaps in the NRC's regulatory authorities; the lack of demonstrated technologies for managing certain defense, commercial and TRU wastes and technical concerns within the scientific community regarding the feasibility of long-term geologic disposal. Based on recommendations for improved coordination of waste management policies and programs, the Federal Government subsequently intensified its efforts to coordinate through the U.S. Office of Management and Budget (OMB).

NRC and the AEC, prior to its reorganization, originally regulated LLW commercial disposal sites through a patchwork of rules consisting of generic regulations specified in 10 CFR Part 20 – "Standards for Protection Against Radiation", 10 CFR Part 30 – "Rules of General Applicability to Domestic Licensing of Byproduct Material", 10 CFR Part 40 –"Domestic Licensing of Source Material" and 10 CFR Part 70 – "Domestic Licensing of Special Nuclear Material". In response to the needs and requests expressed by the public, the States, Congress and industry, the Commission developed a set of comprehensive requirements for licensing the land disposal of commercial LLW.

The NRC began to develop its LLW regulation in 1978 by relying on an extensive National Environmental Policy Act (NEPA) scoping process. In deciding to develop a LLW regulation, the NRC determined that the promulgation of 10 CFR Part 61 qualified as a major Federal action, as defined by NEPA. The staff determined that the most viable regulatory approach would be to develop a regulation generally applicable to land disposal of most types of commercial LLW. The challenges included the ability of the regulation to apply to a broad range of geographical conditions within the U.S. as well as to disparate waste streams, and the need to consider the inadvertent human intrusion into a LLW disposal area.

The staff explored ways of classifying LLW for use in standardized exposure scenarios as a method of predicting potential doses to receptors. The staff considered both generic and specific disposal methods in the context of a FEIS that examined the costs, benefits and impacts of a base-case and alternative disposal concepts. These analysis and studies informed the staff's proposed performance objectives and technical criteria in proposed 10 CFR Part 61 (NRC, 1981b).

The Commission issued a final 10 CFR Part 61 rule in December 1982 (NRC, 1982b). The regulation covered all phases of shallow, near-surface LLW disposal from site selection through facility design, licensing, operations, closure, and post-closure stabilization to the period when active institutional controls end. The regulation requires the use of engineered features in conjunction with the natural characteristics of the disposal site to contain and isolate the wastes. The regulation established the procedures, criteria and terms and conditions on which the Commission would issue and renew licenses for the shallow land burial of commercially generated LLW. Included in 10 CFR 61.55 was "Waste Classification" that introduced a three-tier waste classification system for LLW based on the concentrations of the longer lived radionuclides. These classes include Class A, Class B, Class C and greater than Class C in ascending order of potential radiological hazard.

Because the US Ecology site was sited prior to the Part 61 rulemaking, not all of the Part 61 regulations are applicable. The application of the requirements in the rule to existing sites was intended to be a case-by case determination. In response to public comment on the draft rule, the draft Part 61 rule was modified to clarify the applicability to existing sites and address concerns for instant noncompliance. The back-fitting provisions are included in 61.1(b) in the final rule and are reproduced below:

> *Applicability of the requirements of this regulation to Commission licenses in effect on the effective date of this part will be determined on a case-by-case basis and implemented through the terms, and conditions of the license or orders issued by the Commission.*

This provision is in the final rule in 61.1(b). The Washington State regulations contain similar provisions in 246-250-001:

> *Purpose and scope: (1) The regulations in this chapter establish procedures, criteria, and terms and conditions upon which the department issues licenses for land disposal of low-level radioactive wastes received from other persons. (Applicability of the requirements in this chapter to department licenses for waste disposal facilities in effect on the effective date of this regulation will be determined on a case-by-case basis and implemented through terms and conditions of the license or by orders issued by the department.)*

The closure plan for US Ecology indicates that not all of the Part 61 requirements (and associated WAC code 246-249 and 246-250) are directly applicable, but states that the requirements are as a matter of practice treated as guidance in developing operating procedures and designing the closure plan (1996). Applicability is determined on a case by case basis at the discretion of Washington DOH.

<u>Evolution of TRU Definition:</u>

Although TRU waste is not specifically defined in NRC regulation, Class C limits for TRU nuclides are currently provided in 10 CFR 61.55. However, TRU solid waste classification came into existence as early as the late 1960s and evolved over time. The AEC originally established a policy that solid radioactive waste with concentrations of alpha-emitting radionuclides greater than 10 nCi/g was not acceptable for shallow land burial but required storage and/or burial in a retrievable manner. TRU wastes are the byproducts of fuel assembly, weapons fabrication and reprocessing operations. These wastes contain isotopes higher than uranium, which is number 92 on the Periodic Table of Elements and characteristically have long half-lives and high radiotoxicity. The AEC originally defined this waste stream as solid waste with: “known or detectable contamination of transuranium radionuclides.” Congress gave TRU waste its first legislative definition in the Low-Level Waste Policy Act of 1980 (LLWPA) (Public Law 96-425), but the definition was later rescinded in 1985 when the act was amended. Before 1982, AEC Manual Chapter 0511 defined TRU waste as having greater than 10 nCi/g of the long-lived alpha-emitting TRU radionuclides. It also stated that solid wastes contaminated with certain alpha-emitting radionuclides to greater than 10 nCi/g should be stored in such a way as to allow the packages to be readily retrieved. As this directive was implemented, the 10 nCi/g limit

gradually was construed as a concentration limit that defined the distinction between LLW and other radioactive material destined for disposal in a more secure mode (e.g., deep geologic disposal). In 1982, Federal agencies concurred with a recommendation to increase the existing transuranium radionuclide concentration limit from 10 to 100 nCi/g for this class of wastes. In 1985, the U.S. Environmental Policy Act (EPA) finalized its standards and defined TRU waste within 40 CFR 191.02, "Definitions," in the following manner: "wastes containing more than 100 nanocuries of alpha-emitting transuranium isotopes, with half-life greater than twenty years, per gram of waste, except for (1) high-level radioactive wastes; (2) waste that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this Part; or (3) waste that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.." (50 FR 38084).

In 1980, Congress authorized DOE to build a full-scale research and development (R&D) facility to test the safe management and disposal of defense-generated TRU wastes at Los Medaños near Carlsbad, New Mexico. This R&D facility was later renamed the Waste Isolation Pilot Plant (WIPP). In association with the WIPP development program, DOE prepared a number of NEPA-related documents. All of these documents used the prevailing definition of TRU waste at the time of their respective publication. NRC considers TRU waste as a higher activity form of LLW (i.e., Greater Then Class C waste) subject to disposal in an HLW repository or some other disposal facility approved and licensed by the NRC. Kocher (1990, p. 67) notes that the NRC has not developed a regulatory definition of TRU waste because only small quantities are produced in the civilian sector and EPA currently regulates its disposal.

1.3 Background:

In August of 2009, Washington DOH was seeking assistance from the NRC on issues associated with historical disposal of transuranics at the US Ecology, Inc. commercial LLW disposal facility and the potential radiological risk to workers if waste was exhumed. Native American Tribes have previously expressed interest and concerns with the disposal practices at US Ecology, the State of Washington's oversight and NRC's Trustee responsibilities with the Native American Tribes.

In July of 2008, the Confederated Tribes and Bands of the Yakama Nation sent a letter to the NRC Chairman seeking clarification regarding the NRC's trustee responsibilities to the Confederated Tribes and Bands of the Yakama Nation and raising serious concerns regarding disposal of radioactive wastes at the US Ecology LLW disposal site. The Yakama Nation expressed specific concerns with TRU wastes disposed of at US Ecology's site with concentrations in excess of 100 nCi/g.

In October 2008, the NRC Chairman responded to the Yakama Nations letter explaining that consistent with the Federal courts views on the trustee responsibilities of individual agencies, the NRC fulfills its responsibility in the context of its statutory authorities given through the Atomic Energy Act. The Chairman's response went on to explain that the NRC's programs and regulations under these authorities are designed to ensure adequate protection of public health and safety, promote the common defense and security, and protect the environment for all members of the public. The letter further stated that the NRC enters into Agreements with States after ensuring that the State regulatory programs are adequate to protect public health and safety and compatible with NRC's regulatory requirements. Under Section 274 of the

Atomic Energy Act, thirty-seven (37) States have entered into such agreements with the NRC and Washington had become an Agreement State on December 31, 1966. The State assumed regulatory authority over LLW disposal sites in its agreement with the NRC. Through this authority, Washington State regulates the US Ecology site and the NRC encouraged the Yakama Nation to engage the State of Washington.

In December 2008, the NRC responded to the Yakama Nations with an additional letter. The letter further clarified the NRC role and responsibilities. Under Section 274(j) of the Atomic Energy Act, NRC must periodically review existing Agreement State programs to ensure continued adequacy and compatibility. The NRC may terminate or suspend all or part of its agreement with a State if the NRC finds that these actions are necessary to protect public health and safety or that the State has not complied with the provisions of Section 274. The NRC's Integrated Materials Performance Evaluation Program (IMPEP) implements this requirement by evaluating the Agreement State radiation control programs, to ensure that they are compatible with NRC's regulatory programs and adequately protect the public health and safety. One of the performance indicators used during the IMPEP review is an evaluation of the State's LLRW Disposal Program, which includes a yearly inspection of any LLW disposal facilities.

The NRC explained that the most recent review of the Washington Agreement State Program was in May of 2008 and determined that the State Program was adequate to protect public health and safety and compatible with NRC's regulations. The IMPEP review found that the State of Washington performs a comprehensive inspection of the US Ecology Site on an annual basis. The IMPEP review team also observed the state inspectors in April 2008 performing an inspection of the US Ecology Site and concluded that the inspectors were well prepared and thorough in their evaluation.

In October 2009, the Confederated Tribes and Bands of the Yakama Nation sent a letter to NRC and DOE voicing concerns regarding historical disposal at US Ecology and the production of nuclear material at the Hanford Site. In 2004, the State of Washington completed an Environmental Impact Statement, in which the preferred option for disposition of the site is the installation of an evapotranspiration (ET) cover with the waste remaining in the trenches. The Yakama Nation was concerned about capping long-lived radioactive waste that could potentially contaminate the vadose zone, reach the water table, and eventually reach the Columbia River. In December 2009, the NRC responded to the Yakama Nation letter. The response reiterated that the NRC understands the concerns raised; however, under Section 274 of the Atomic Energy Act of 1954 the NRC, by agreement with a State, relinquishes its regulatory authority over specified radioactive materials and activities after finding that the State program is adequate to protect public health and safety and is compatible with the NRC's regulatory program.

In August 2009, the State of Washington, DOH, Confederated Tribes and Bands of the Yakama Nation and the Confederated Tribes of the Umatilla Indians met to discuss the Tribes concerns with the possible disposal of TRUs in excess of 100 nCi/g prior to 1980. The Yakama Nation, in August 2009, also outlined their issues in a letter to Washington DOH. The issues outlined in the letter are as follows:

1. The US Ecology disposal facility has one of the largest amounts of buried TRU wastes in the U.S. It has more than 40% of the total buried TRU waste on the Hanford Site and contains as much as 220 lbs (99.79 kg) of plutonium.

2. The US Ecology disposal facility appears to contain about 95 percent of the total amount of uranium disposed of in soil at the Hanford Site. According to a 2006 study by Nuvotec and Pacific Northwest National Laboratory, approximately 453,000 pounds (205909.1 kg) of uranium had been discharged to soil by DOE's Hanford operations. By comparison, approximately 9.3 million pounds (4,230,000 kg) of uranium had been disposed of in the US Ecology disposal facility.

3. The Yakama Nation opposes the Washington DOH's decision to not remove TRU wastes and to cap the US Ecology disposal facility upon closure. In their opinion, this decision sets a bad precedent for the cleanup of large amounts of long-lived radioactive wastes at the Hanford Site. Moreover, the Yakama Nation believe there is a need for a comprehensive cleanup of buried transuranic and uranium wastes at the Hanford Site, including the US Ecology disposal facility.

In August 2009, Washington DOH and the Native American Tribes met to discuss the US Ecology disposal facility and discussed the following issues:

1. The possibility of disposed TRUs at the US Ecology disposal facility in concentrations greater than 100 nCi/gram.

2. The incomplete characterization of waste in the early trenches.

   The choice of an evapotranspiration (ET) cover because they have heard that the EPA has determined that ET covers are failing.

The Native American Tribes' consistent message to the State of Washington was for development for a comprehensive clean-up plan across the Hanford Site, including US Ecology, and exhumation of all transuranic waste.

In response to this meeting, the Washington DOH requested technical assistance from the NRC on the safety of the early trenches on August 30, 2009. Washington DOH posed two questions in its technical assistance request:

1. Did waste licensed by the NRC for disposal at the US Ecology disposal facility during the period 1965 to 1980 meet the four performance objectives of 10 CFR 61 (and WAC 246-250), even though it may have contained TRUs in excess of 100 nCi/gm?

2. What is the potential radiological risk to worker heath and safety if waste is exhumed? Exhumation of waste would encompass seven[1] trenches which contain approximately 1,267,000 cubic feet of waste. These trenches are pre-Part 61.

[1] Only six Trenches were evaluated that were in operation prior to 1980 as a license condition prohibited disposal of TRU waste after 1980 and prior to the Part 61 rulemaking.

2 Technical Assistance Request--Question 1:

Chapter 2 presents NRC staff's analysis and results for Technical Assistance Request (TAR) Question 1. TAR Question 1 reads as follows:

> *Did waste licensed by the NRC for disposal at the US Ecology disposal facility during the period 1965 to 1980 meet the four performance objectives of 10 CFR 61 (and WAC 246-250), even though it may have contained TRUs in excess of 100 nCi/gm?*

NRC staff clarified with Washington DOH after receiving the TAR, that the scope of the TAR request was in fact *SNM* disposals authorized by the NRC from 1965 to 1980. This clarification was necessary as the definition of TRU (referenced directly in the TAR question) and SNM (or "waste licensed by NRC for disposal" also referenced in the TAR question) are not equivalent. For example, TRU waste also includes radionuclides such as americium-241 and neptunium-237 that are not considered special nuclear material. Likewise, SNM includes isotopes such as U-233 and U-235 that are not TRU. NRC staff also reached agreement with Washington DOH on the approach to be used to answer TAR Question 1. NRC staff would evaluate Washington DOH's FEIS and associated PA that assessed the risks associated with the entire disposal facility to bound the risks associated with the early SNM disposals. Special emphasis would be placed on early SNM disposals and if necessary, NRC staff would perform supplemental modeling and analysis.

To answer TAR Question 1, NRC staff began by collecting and reviewing licensing information and other records obtained from the US Ecology facility in Richland and Washington DOH offices in Olympia, Washington. While at the site and Washington DOH offices, NRC staff interviewed key personnel from US Ecology involved with disposals and Washington DOH personnel involved in the development of the FEIS (staff were primarily from the Waste Management Section of the Office of Radiation Protection). After clarifying the scope of TAR Question 1 and collecting information, NRC staff reviewed Washington DOH's FEIS performance assessment documentation and supporting references, conducted literature reviews, and conducted its own independent evaluation and modeling. The results of NRC staff's review and evaluation to answer TAR Question 1 are provided in Chapter 2.

In general, Chapter 2 is organized as follows: inventory and other general information about disposal facility operations over time is provided in Section 2.1. Section 2.2 presents information about Washington DOH's performance assessment to demonstrate compliance with 10 CFR Part 61, Subpart C performance objectives. Section 2.2 begins with basic information about performance assessments in general and a listing of the Part 61 Subpart C performance objectives (Section 2.2.1). A summary description of specific features of Washington DOH's performance assessment and results is provided in Section 2.2.2. To help focus its review, NRC staff conducted independent modeling and calculations, and relied on the results of Washington DOH's sensitivity and uncertainty analysis to identify risk-significant aspects of facility performance, which are also described in Section 2.2.2. Washington DOH's general performance assessment approach is evaluated by NRC in Section 2.2.3. Sections 2.2.4 through 2.2.15 describe in more detail specific aspects of Washington DOH's PA and

compliance demonstration with dose-based performance objectives 10 CFR 61.41 and 61.42 and NRC staff's associated evaluation. NRC staff review areas are organized as follows[2]:

- Infiltration and cover assumptions (Sections 2.2.4 and 2.2.5).
- Near-field modeling (or source term modeling—Sections 2.2.6 and 2.2.7).
- Hydrology and far-field modeling (or unsaturated and saturated zone modeling—Sections 2.2.8 and 2.2.9).
- Dose methodology (general approach to translating environmental concentrations to dose--Sections 2.2.10 and 2.2.11).
- Protection of the public (10 CFR 61.41 or offsite receptor compliance demonstration—Sections 2.2.12 and 2.2.13).
- Protection from inadvertent intrusion (10 CFR 61.42 or onsite intruder compliance demonstration—Sections 2.2.14 and 2.2.15).

Although not part of Washington DOH's FEIS and supporting PA, Sections 2.2.16 through 2.2.19 present information and NRC staff's evaluation of compliance with the two remaining (non-dose-based) performance objectives in 10 CFR Part 61, Subpart C and WAC-246-250. Protection of individuals during operations (10 CFR 61.43) is described and evaluated in Sections 2.2.16 and 2.2.17, and stability of the disposal facility after closure (10 CFR 61.44) is described and evaluated in Sections 2.2.18 and 2.2.19.

As described in more detail in specific sections of Chapter 2, NRC staff identified a number of potential issues associated with Washington DOH's FEIS analysis. Many of these issues were resolved after further discussion with Washington DOH staff and others were not. Potential issues identified during NRC staff review include the following:

- lack of documentation or clarity with respect to the development of the inventory for key radionuclides,
- non-conservative assumptions regarding homogeneity of the waste across the disposal facility,
- limited support for key modeling assumptions such as cover longevity and performance,
- potentially non-conservative assumptions regarding distribution coefficients (related to contaminant mobility in the subsurface) for key groundwater constituents,
- lack of evaluation of waste release conceptual model uncertainty, and
- potentially optimistic assumptions regarding radon emanation and transport through the waste zone/trenches and cover.

[2] A description of each technical review area is followed by NRC staff evaluation of the review area. Thus, there are two sections for every technical review area.

In general, potential issues associated with development of the inventory for key radionuclides were resolved through additional documentation (see Sections 2.1.1 and 2.1.2). Additional support for the conservatism of Washington DOH's vadose zone modeling (and specifically source term) calibration process was provided (see Sections 2.2.6 and 2.2.7). Additional radon transport calculations performed after development of the FEIS were also provided (see Sections 2.2.14 and 2.2.15). The radon transport calculations addressed many of the potential issues or uncertainties identified during NRC's review of the radon transport modeling. With respect to the remaining potential issues including key modeling assumptions such as distribution of contamination within the disposal facility, distribution coefficients, and cover performance (as reflected in the in-tact cover infiltration rates and assumed times to failure), Washington DOH's uncertainty analysis did not include many key parameters and conceptual model uncertainty was not evaluated. NRC staff evaluated the risk-significance of all remaining issues and disposal facility performance uncertainties and documents the results in Section 2.3.

Based on this review, NRC staff was able to conclude the following:

1. NRC has reasonable assurance that the US Ecology disposal facility can be operated and closed to meet the performance objectives in 10 CFR Part 61, Subpart C (and associated WAC-246-250) provided certain key assumptions in site performance assessments are met. Key assumptions include the following:

    - The inventory of key radionuclides such as isotopes of U is similar to or less than assumed in the PA analyses.
    - Lack of explicit consideration of certain early (pre-Part 61) waste disposal practices (e.g., less stringent controls on waste segregation, waste form stability, and other controls based on waste classification system) does not lead to a significant underestimation of risk due to a greater potential for increased infiltration, leaching, and waste concentrations.
    - Mobility of key radionuclides such as U isotopes is not significantly under-estimated (e.g., distribution coefficients, solubility limits, and mobile release fractions are appropriate).
    - The as-emplaced engineered cover will perform as well as assumed in site performance assessment analyses with respect to infiltration and radon mitigation.

Other NRC staff conclusions include the following:

2. Washington DOH efforts to refine the inventory for the disposal facility are expected to lead to reduced uncertainty and better estimates of facility risk.

3. In general, the methodology used in Washington DOH's groundwater modeling and risk assessment are technically sound.

4. Remaining uncertainty in disposal facility risk is considered acceptably low to allow closure decisions to be made.

5. Based on Washington DOH's risk assessment calculations, installation of a Phase 1 cover is expected to minimize future dose to potential receptors for more mobile constituents predicted to impact groundwater earlier in the compliance period.

2.1 Inventory and Disposal Characteristics:

2.1.1 Inventory:

Inventory is risk-significant as it is linearly related to dose with the exception of solubility limited radionuclides through the groundwater pathway. Thus, Washington DOH placed special emphasis on updating the inventory for key risk drivers and inventory was a focus of NRC staff's review. Much of the information that the inventory is based on comes from radioactive shipping records called waste manifests. In early years of facility operation, these shipment records or waste manifests were not standardized and generally contained a dearth of information compared to present day records. As discussed in Section 1.2 above, issues arose at a number of disposal facilities in the 1960s and 1970s that led to increasing regulatory oversight and requirements over time that led to better recordkeeping and disposal practices. For example, current regulations found in 10 CFR Part 20, Appendix G and WAC 246-249-090 require that radioactive waste shipments sent for disposal be thoroughly classified and described. Information on modern shipping documents is required to be exhaustive in order that the disposal facility operator can both qualitatively and quantitatively ensure that waste is acceptable for disposal, that it can be safely handled, and that the facility can effectively isolate the waste material as designed (Carpenter, 1990a). On the other hand, early waste manifests provide much less detail regarding the packaging, characteristics of the waste, and isotopic breakdown, which led to ambiguities regarding the activity of key risk drivers. Furthermore, waste shipments that occurred prior to February 1982 were simply recorded on paper records and existed in no other form. After February 1982, a computerized database was used to track shipments to the site as they were made.

The detail and quality of inventory estimates for the US Ecology disposal facility have evolved over time. Perhaps the first attempt to develop a comprehensive inventory of all waste disposed of at the facility occurred as a result of a license condition, known as "Condition 58." Condition 58, associated with a January 1987 amendment to the facility license, required a complete record of the type, activity, and location of all radioactive waste disposed at the site. To complete the inventory estimate required by Condition 58, data contained on manifests were categorized by isotope and entered into the computerized database. Data entry was completed and a report issued in 1990 to address Condition 58.

Several years after the issuance of the Condition 58 report, the licensee reviewed the early waste manifests again for the purpose of evaluating the transfer of information from the shipping records to the database, confirming the accuracy of isotope assignment assumptions, and correcting any discrepancies (Palmer, 1994). This review was performed out of a population of over 10,000 shipping records for over 1 million waste packages for disposals that occurred between 1965 and 1982. Due to the sheer volume of information to be reviewed, criteria were established to focus the review [e.g., higher activity shipments, records with missing information, records with 10 CFR 61.55 listed radionuclides (to get up to 20 percent of such records), and higher activity Pu shipments were targeted]. Several waste generators were contacted to supplement missing or ambiguous information on radioisotopic breakdown of special nuclear

material including Babcock & Wilcox, Kerr-McGee Nuclear Corporation and Westinghouse Electric Corporation. This process resulted in the redistribution of SNM mass and the assignment of previously unassigned SNM mass. In some cases, errors were also made in assigning activity to individual isotopes when more than one isotope was listed. For example, mixed fission products (MFP) might be listed with SNM. In some cases, the total activity was split between the MFP and SNM material, when grams of SNM were clearly provided. In these cases, the SNM activity was calculated, subtracted from the total activity and the remainder of the activity assigned based on data of isotopic breakdown. All told, approximately 20 percent of the higher activity waste manifests were reviewed, corrected and reported in Palmer (1994), which led to the removal of over 42,000 Ci (1.5 PBq) of activity, principally due to reassignment of uranium and plutonium isotopes for large activity waste manifest reviews[3]. An increase of over 35,000 Ci (1.29 PBq) was made based on review of manifests with missing information that needed correction. Review of manifests to target §61.55 radionuclides resulted in the decrease of around 1000 Ci (0.37 PBq). Review of additional records with >10 Ci (0.37 TBq) of Pu isotopes listed led to the reduction in Pu inventories by around 3000 Ci (0.11 PBq).

Isotopes of U and Pu are significant risk drivers for the groundwater pathway. These isotopes may have a relatively large uncertainty in the inventory estimates and are also the focus of the TAR. A summary of the evolution of the inventory for these constituents is listed below. As can be seen in the Table, most of the Pu corrections were made during the Palmer review (1994) with no significant changes between Palmer (1994) and the inventory used in Washington DOH FEIS (2004). Differences in the Pu inventories between Palmer and the FEIS are most likely due to the level of precision of inventories reported for the FEIS, which were estimated from figures provided in the FEIS for the purpose of reporting the inventories in the table below, rather than due to true differences between the two sources of information. On the other hand, significant changes to the U inventory occurred after Washington DOH worked with the licensee to clean-up database errors to support closure plan and FEIS PA calculations. The update to the uranium inventory from the Palmer report was performed using information provided by the licensee that categorized U-238 waste by generator and type (e.g., natural, depleted, or enriched). Although some of this information was verified by the licensee, assumptions were necessarily made regarding the type of uranium waste, the isotopic break-down of uranium isotopes in the waste (e.g., due to assumption regarding enrichment level or due to variations in ratios of various depleted uranium sources). The following table summarizes inventory information for Pu and U isotopes for pre-1982 waste (1965-1981) from these various reports:

[3] Note that additional refinement of the uranium inventory took place following the Palmer study.

Table 2-1 Evolution of Inventory of Key Radionuclides Over Time (Ci)

Report	Trench Report 1965-1981 (Carpenter, 1990b)	Palmer 1965-1981 (Palmer, 1994)	FEIS 1965-1981* (Washington DOH, 2004)
Pu-238	7E+03	1E+04	1E+04
Pu-239	8E+04	4E+03	5E+03
Pu-240	2E+04	2E+03	2E+03
Pu-241	1E+04	2E+04	ND
U-234	1E+02	2E+01	7E+01
U-235	8E+04	7E+03	1E+01
U-238	1E+03	1E+03	3E+02

*Inferred from groundwater modeling disposal rate histories provided in Appendix IV of Washington DOH's FEIS (see Figures 13 and 14). Values are approximate (estimated from FEIS figures). No data was provided for Pu-241 as it was not modeled in the groundwater analysis. To convert Ci to Bq multiply by 3.7E+10.

The inventory listed below for select radionuclides was taken from Washington DOH FEIS (2004) and includes estimates of radioactive waste disposed of at the site just before the publication of the FEIS (through 2002) as well as projections of waste disposal into the future. Washington DOH based future inventory projections on waste activity from 1993 through 1996, plus the Trojan and Washington Public Power Supply System reactor vessels. Because the initial inventory contains about 622 separate isotopes and a majority of these radionuclides are short-lived or of minimal activity, Washington DOH used screening tools to cut the list down to a more manageable set. Twenty-one radionuclides passed the initial screening criteria of a half-life greater than 5.5 years and a total activity of at least 1 Ci (37 GBq). The twenty-one radionuclides have a combined activity of 1.1 million Ci (150 PBq). Future estimates of the inventory from 2002 through 2056 for the twenty-one retained radionuclides were around 4,500 Ci (167 TBq). Table 2-1.1 shows that the inventory for the future years of operation is not expected to be significantly higher than the first 50 years of operation for many radionuclides. Washington DOH conducted separate screening analyses for the groundwater pathway using a tiered process (i.e., tier 1 was based on half-life to vadose zone travel time comparisons using what was described as conservative assumptions regarding radionuclide mobility and tier 2 was based on comparison of estimates of potential radionuclide contributions to drinking water dose versus regulatory standards). The radionuclides that are considered in the groundwater analysis are H-3, C-14, Cl-36, Tc-99, I-129, U-234, U-235, U-238, Pu-238, and Pu-239 (Washington DOH, 2004).

Table 2-1.1. Selected Radionuclide Inventories Used in FEIS (Ci). Adapted from Table 2.D in the Deparment(2004)

Radionuclide	Inventory 1965-2002 (Ci)	Total 1965-2056 (Ci)^
Am-241	464	467
C-14	3970	5090
Cl-36	3.12	3.23
Co-60	1.53E+06	1.53E+06
Cs-137	1.21E+05	1.21E+05
H-3	7.99E+05	8.6E+05
I-129	5.63	5.98
Pu-238	1.06E+04	1.06E+04
Pu-239	4500	4510
Ra-226	233	323
Tc-99	50	55
U-234	279	279
U-235	30.5	30.6
U-238	1510	1510

^Based on projections of future inventory. To convert Ci to Bq multiply by 3.7e+7.

2.1.2 Inventory Evaluation:

As detailed above, US Ecology and Washington DOH have continued to refine inventories for the LLW facility to address uncertainties in waste manifests due to errors, ambiguities in reported values, and missing information. Refinements have also been made to address errors in record-keeping, including data transfer from paper to electronic formats. Recent revisions to inventory estimates include Palmer (1994), Ahmad (2002 and 2003)[4], and updates to the uranium inventory for use in the FEIS PA calculations based on information provided by US Ecology and calculation of isotopic ratios of U for natural, depleted, and enriched U (Thatcher, 2010a). Washington DOH took a graded approach to developing the inventories and used early PA results were used to determine key risk drivers in the performance of the facility and then worked to address the uncertainties in the inventories for these key radionuclides. Although Palmer (1994) reviewed only a small percentage of the waste manifests, corrections to the inventories over an order of magnitude were made for certain key isotopes such as Pu-239. Given the historical trend, continued review of a larger fraction of waste manifests from the time period from 1965 to 1982 would likely lead to even lower inventory estimates for Pu.

NRC evaluated the process that was used to derive the inventory for the disposal facility and found that the approach was generally acceptable. During the review, NRC found that referenced documentation provided insufficient information on how the uranium inventory was derived to evaluate the risks of early trench disposals. In response to NRC staff inquires on the development of the U inventory, Washington DOH provided additional documentation including a memo that details the process by which the uranium inventory was developed (Thatcher,

[4] Ahmad (2002 and 2003) was tasked with refining the inventory for key groundwater pathway constituents including U, Tc, I, and Cl.

2010a). The process used to refine the uranium inventory was similar to a process used to provide more accurate estimates of Pu inventories in previous estimates performed by the licensee (Palmer 1994). Namely, the database was sorted by waste generator and efforts were made to contact waste generators to get more detailed information about the characteristics of the waste, including isotopic ratios of primary radionuclides. In the case of uranium, however, the first step was to classify the waste as natural, depleted, or enriched and then to assign isotopic activities based on the class of uranium present. This procedure was necessary because in many instances the inventory was either ambiguous (e.g., elemental but no isotopic information is provided) or certain conservative assumptions had been made in assigning a percentage of the inventory when more than one radionuclide or radionuclide class was listed. In the face of limited information, what appear to be overly conservative assumptions were made in assigning activity that led to gross over-estimates for certain radionuclides in original estimates. In fact, the latest review resulted in a decrease of about three orders of magnitude in the U-235 inventory compared to original estimates provided in Palmer (1994).

Despite this well-thought out and well-executed process to refine the uranium inventory, uncertainty still remains as errors in information provided on early waste manifests cannot be readily corrected and assumptions must be made when information is lacking. Although the uncertainty in the uranium inventory has been significantly reduced, some measure of uncertainty remains and should be evaluated when evaluating potential compliance with early SNM disposals, which is the subject of this TER. For example, it was not possible to confirm the class of uranium for all disposals and not all errors on waste manifests are readily correctable. Table 2-1.2 below provides information regarding the range in activity percent for U isotopes based on the class of uranium (e.g., natural, depleted, enriched). Most of the uranium inventory is expected to be in the form of depleted uranium. The values used in the table are not necessarily consistent with those used in the FEIS, as variability in the activity percentages for depleted uranium, for example, exists based on the source of information. As a starting point, the uncertainty in the U-238 inventory was first considered. The uncertainty in the U-238 inventory was assumed to be less than a factor of 2 given the great deal of effort spent on refining the inventory for this constituent but to be in the ball park of the recent factor of three to four reductions in the uranium inventory based on recent analyses. Due to the low variability of U-235 activity based on enrichment level and the assumption that a much smaller percentage of slightly enriched uranium was disposed of in the disposal facility, the uncertainty in the U-235 inventory is expected to be tied to the uncertainty in the U-238 inventory at around a factor of 2. Finally, given the relatively large range of potential U-234 activity percentages compared to U-235, this radionuclide was assumed to have a relatively larger uncertainty (factor of four was assigned). The uncertainty range assumed is expected to provide risk insights with respect to the impact of U inventory on the dose results but is not expected to represent a rigorous analysis of the potential uncertainty in U inventory. Additionally, it is important to note that U is assumed to be solubility limited in the FEIS. Use of a uranium solubility limit constrains the peak dose from U-238 due to increases in the U inventory. The impact of lower or higher U inventories with and without solubility control is discussed further in Section 2.3

Table 2-1.2. Activity Percent of Uranium Isotopes in Various Classes^

	U-238	U-234	U-235
Natural	49%	49%	2%
Depleted	85%	14%	1%
Enriched (3.5%)	14.7%	81.8%	3.4%

^ Activity percentages obtained from http://www.wise-uranium.org/rup.html

While U isotope inventories can be higher (or lower) than estimated in the FEIS (from Table 2.E of the FEIS reported above), plutonium inventories are expected to be biased high as the same process used to refine the plutonium inventory was only applied to approximately 20 percent of the waste manifests reviewed prior to 1982. However, the bias is not expected to be large, as any manifest with greater than 10 Ci (0.37 TBq) of reported Pu inventory was reviewed and corrected. Therefore, Pu inventory uncertainty was not evaluated.

It is significant to note that the activities for disposals that occurred between the years of 1965 and 1996 were summed as if they all occurred on the same date and were not decay-corrected until after 1996. Although this is generally a conservative assumption in that decay was not considered, in-growth was also not considered. The roughly 30 year time period where in-growth was not considered is not expected to be significant given the period of institutional control (assumed to be 107 years after closure) and due to the large time frames over which compliance must be demonstrated. For projected activities beyond 1996, in-growth is only considered from the closure date although the inventory is decay-corrected for each year of additional activity estimated (Thatcher, 2010b). In-growth between 1996 to 2215 may be more significant, but generally the amount of radioactivity in later disposal years will be minor compared to initial activity estimates.

Washington DOH assumed a homogenous concentration across the disposal facility in calculating potential doses for the groundwater pathway as well as the intruder analysis. As most of the Pu inventory was disposed of prior to the effective date of the Part 61 rule, the inventory and concentration of Pu is significantly higher in trenches 1-6 than in the other trenches that operated in the 1980s and later. In fact, most of the Pu was disposed of in the early trenches before concentration and other more stringent controls related to depth and layering of higher activity waste was put in place. Based on the relative volumes of the trenches, the potential concentrations of key Pu isotopes in the waste zone could be almost an order of magnitude higher compared to the assumption that the inventory is distributed homogeneously across the disposal facility. The impact on the Pu inventory used for the groundwater analysis is less, as all trenches were expected to be the same thickness and the leachable area of the early trenches is about twenty-percent of the modeled domain (inventory could be a factor of five higher). The actual downgradient concentrations of Pu from the early disposal trenches are expected to be less than a factor of five higher as greater dilution from clean or cleaner groundwater from the remainder of the disposal facility would occur. NRC analytical and numerical calculations estimate that the Pu concentrations in groundwater could be a factor of three higher due to a smaller but more concentrated source. Additionally, the well would have to be located directly downgradient of trenches 1 through 6 to see the expected higher concentrations of Pu from these earlier trenches which is less likely than assuming the well could be located anywhere along the long dimension of the disposal facility boundary. The

concentrations of U-234 and U-235 in trenches 1 through 6 could also be slightly higher but the slight increase is not expected to be risk-significant. Additional discussion regarding the impact of the increased Pu concentrations in early trenches is discussed in Section 2.3.

2.1.3 Disposal Characteristics:

Disposal practices have changed over time and can be risk-significant as these practices may impact for example, the leachability of the waste, stability of the disposal facility, and accessability of the waste to a potential receptor. Although detailed information regarding disposal practices and worker doses in the early days of operation is not available, some useful information that may shed light on the characteristics of early disposals that is pertinent to facility performance is summarized below. Information in a Condition 58 report (Carpenter, 1990a) provides useful information on disposal practices at the US Ecology facility. The following practices were noted:

1. During periods of overlap when one trench was nearing closure and the next trench had just been opened or was preparing to open, shipments were segregated according to operational convenience and prudent handling and disposal practices. For example, shipments of liners (right circular cylinder containers), boxes or heavy containers received during the overlapping period were either placed on the floor of the new trench or set into storage for later placement into the new trench when finished. Liners, boxes and heavy containers cannot be safely set upon randomly placed drums because of their weight, configuration and the increased potential to create unfillable void spaces.

2. Similarly, drum and small package shipments were placed into the trench nearing closure because their smaller size allowed for more accurate placement with regard to requisite disposal depths.

3. Disposal depth requirements were attached to a package's external radiation levels; therefore, the higher the radiation level, the more likely the waste was disposed of at a lower depth in order to take advantage of shielding provided by other waste packages on top of it and backfill. If, for example, a liner had a radiation reading of 50 R/hr (0.5 Gy/hr) and weighed 6,000 pounds (2721.55 kg), it would have been placed into the new trench where it could be quickly covered to reduce exposures to facility workers.

The Site Stabilization and Closure Plan (US Ecology, 1996) also provides useful information on disposal practices in the early days of operation.

1. In general, wastes buried in trenches 1 through 4 were received in metal drums, fiberboard drums and cardboard boxes and were placed in the trench by hand. Liners from casks were handled in one of two ways. The first method used for liners reading up to approximately 50 R/hr (0.5 Gy/hr) was to place the liner at or near the bottom of the trench (approximately 35 feet {10.67 m}). After confirmation of the radiation levels, the liner was shielded with other waste or sand until the radiation levels were acceptable. The second method, used with liners reading in excess of 50 R/hr (0.5 Gy/hr) was to place the liner in a slit trench cut into a sloping wall of the trench and then cover the liner with 3 to 5 ft (1 to 1.5 m) of site soil. Most liners in slit trenches are 20 feet (6.1 m) or more below grade. The shallowest liner was buried approximately 10 to 15 feet (3.05 to

4.57 m) deep in the extreme west end of trench 4. Some boxes were placed in the trenches by cranes using box hooks or slings. If the box weight exceeded the capacity of the crane, the boxes were maneuvered down the operating face of the trench until the trench bottom was reached. The utilization of these trenches (defined as the total volume of waste placed in the trench divided by the total volume of the excavation with no adjustment for the cap) was approximately 25 to 30 percent. The other 70 to 75 percent is sandy backfill. Backfilling was completed by bulldozing the native sandy soil over the working face as the face reached its final height of 3 feet (0.91 m) below the ground surface. Additional soil was placed to ground surface and mounded over the closed trenches to a height of 2 feet (0.61 m) above the ground surface at the trench center line. This was covered by a layer of six inches (0.15 m) of pit-run gravel.

2. Starting with trench 5, drums were placed in the trench by crane, two at a time. However, these containers were still considered randomly placed. As of the date of the Site Stabilization and Closure Plan (US Ecology, 1996) this practice was still being used. Cardboard containers were no longer accepted for burial. Acquisition of a larger crane made box-stacking possible, although a low box inventory generally held box stacks to two high and two deep. Trench utilization increased to approximately 35 percent. Cask liner handling, backfilling, mounding and gravel cover were the same as earlier trenches.

3. Starting with trench 6, box hooks were no longer used. Boxes were handled exclusively with slings and were used to construct stacks or cells by stacking them two to three high and two to three deep with an open space in the center. Cask liners with high radiation levels are placed in these cells and then covered with sand to reduce radiation levels. All other activities remained the same as described for trenches 1 through 5.

Another important disposal practice that significantly impacts the doses associated with radon discussed more in Section 2.2.14 is related to the placement of radium sealed sources in the disposal trenches (Elsen, 2003).

1. Based on information obtained from licensing files, trenches 1 through 6 were only required to have 3 feet (0.91 m) of earth to separate the waste from natural grade.

2. Beginning with Amendment 10 of the facility license dated November 21, 1979, wastes were required to be at a minimum depth of eight feet (2.44 m) below grade[5].

3. Beginning in 1984 additional requirements related to depth (minimum of 16.5 ft {5 m} below grade) and packaging (double containment generally with metal liners and concrete) for Class C radium waste came into effect.

[5] It is important to note that trench 6 was opened in August 1979 and closed in June 1980. Thus, it is not clear if the new requirement that came into effect in November 1979 would have been applied to trench 6.

A photograph of an open, early trench (circa 1979) is reproduced in Figure 2-1 below.

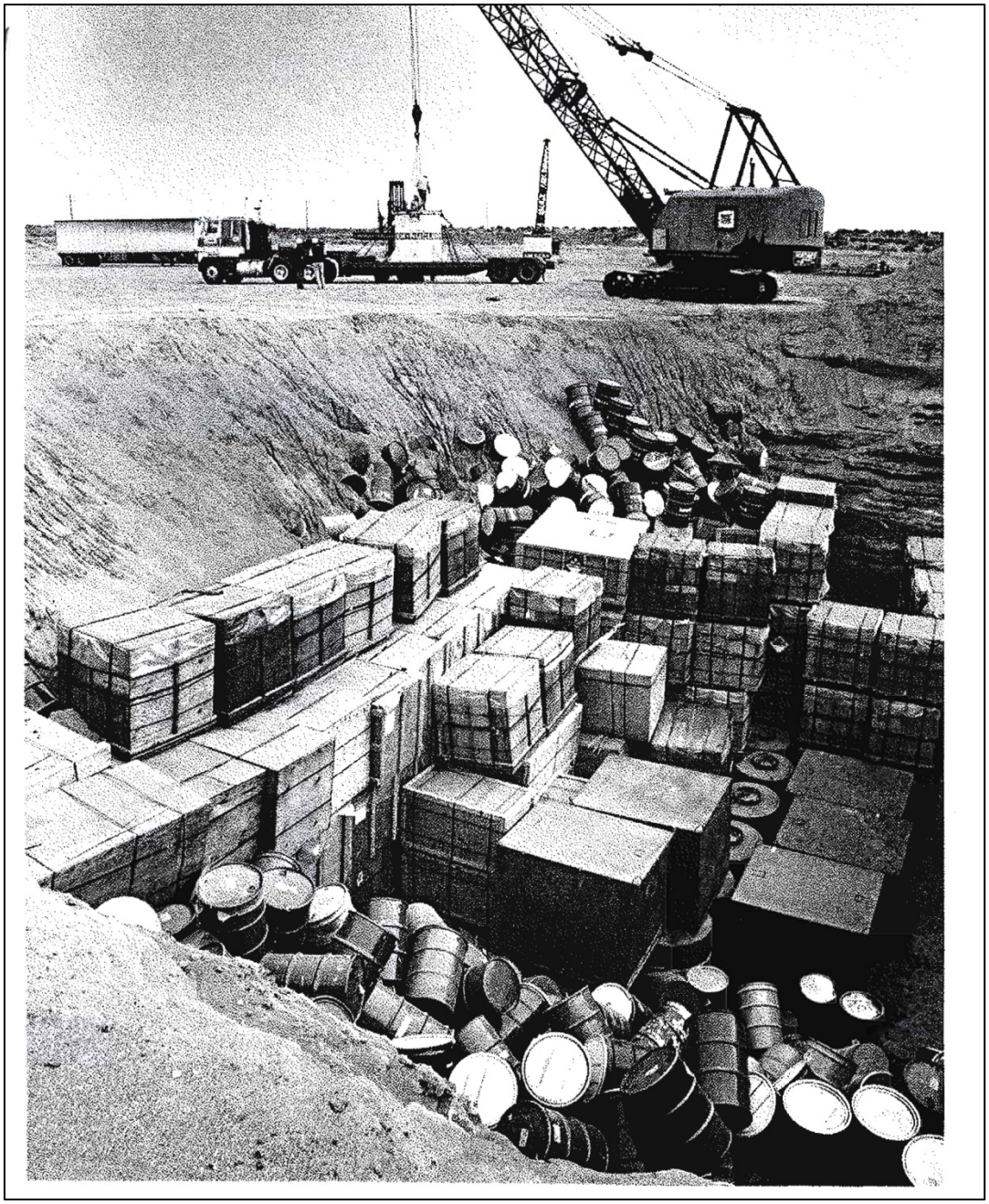

Figure 2-1 Photograph of Early, Open Trench (Circa 1979)

Less restrictive disposal practices and requirements in place at the US Ecology disposal facility in the early years of operation (1965 to 1980) may have led to relatively higher risks from early trenches due to the potential for greater leachabiity of waste (e.g., due to presence of higher liquid fractions or chelating agents), higher relative activity and less than optimal control of the distribution of waste within the disposal trenches and facility (e.g., depth of higher activity waste)), and stability and segregation of higher activity waste that has the potential to affect infiltration rates through the disposal trenches due to subsidence. Requirements related to Class B and C waste form stability did not come into effect until the Part 61 rulemaking in the early 1980s to make waste forms more recognizable and non-dispersible to a potential intruder for a minimum of 300 years (see 10 CFR 61.7(2)). The potential impact of less stringent early disposal practices is evaluated in more detail, as appropriate, in the sections that follow (e.g., Section 2.2.7 on near-field modeling, 2.2.19 on compliance with stability requirements, and Chapter 3 on worker risks associated with waste exhumation).

2.2 PA to Demonstrate Compliance with Performance Objectives in 10 CFR Part 61:

PAs are normally prepared to demonstrate that dose-based performance criteria found in 10 CFR Part 61, Subpart C, can be met for LLW disposal facilities. Washington DOH prepared an environmental risk assessment or PA to support its FEIS on licensing and closure of the US Ecology disposal facility (see Appendix II in Washington DOH, 2004). As stated in Section 2.0, DOH's FEIS analysis (and specifically its PA) is being relied on by NRC staff to evaluate potential compliance of early waste disposals against WAC 246-250 and 10 CFR Part 61 performance objectives for LLW disposal. When necessary, additional calculations and modeling are performed to supplement DOH's analysis. NRC attempted to evaluate the potential uncertainty in dose predictions with presentation of "bounding" risk estimates in Section 2.3. This report evaluates DOH's PA models for the sole purpose of determining whether early waste disposals can meet performance objectives for LLW disposal even if those disposals contain waste with concentrations above the Class C limits defined in §61.55. When important differences in the characteristics of early waste disposals exist, NRC staff makes an effort to evaluate the potential risk-significance of these differences. Thus, comments in this report should not be interpreted as passing judgment on the adequacy of Washington DOH's FEIS itself, which serves a different purpose and answers different questions related to facility licensing and closure and to satisfy state environmental protection regulations.

Various approaches to PA calculations (e.g., deterministic, probabilistic) have their advantages and disadvantages. A deterministic approach can be very valuable when compliance can be easily demonstrated with parameters and models that clearly tend to over-predict the potential risk posed by the disposal facility. These types of analyses require little support of model and model parameters and thus can save a lot of time and money. However, compliance demonstrations can be difficult for evaluations that rely on more complex models that have many interdependent parameters with large or unknown uncertainty in simulations that attempt to demonstrate compliance over thousands to tens of thousands of years. A probabilistic approach can have distinct advantages when there are a number of uncertainties that may significantly influence the results of a PA. Although the compliance demonstration in DOH's PA is deterministic, efforts were made to study the sensitivity of results to key parameters (see discussion in "Parameter Uncertainty Analysis" section of Appendix IV of DOH's FEIS) as well as to study the uncertainty or variability in dose estimates over time through a probabilistic uncertainty analysis (see discussion in Section 6.0 of Appendix II to DOH's FEIS).

Model support (i.e., data or information that supports the model or parameters used in the model) is necessary to provide confidence in the predictive capability of the PA model being evaluated. Because of the long time periods involved with most PA analyses, PA models cannot be validated in a traditional sense. However, the results of laboratory and field experiments, monitoring data, natural analogs, expert elicitation, model benchmarking and verification, and other forms of model support can increase confidence in the predicative capability of the PA model(s). The amount of support provided should be commensurate with the risk significance of the parameter, feature, or process being modeled. Efforts were made in DOH's analysis to better understand disposal facility performance via supporting modeling simulations, implementation and evaluation of various alternatives for engineered barriers, and through probabilistic sensitivity and uncertainty analysis. Key models were verified and calibrated to monitoring data to provide additional confidence in future predictions.

2.2.1 Summary of Performance Objectives:

The primary dose-based performance objectives in 10 CFR Part 61, Subpart C evaluated in Washington DOH's PA are §61.41 related to the protection of the general population from releases of radioactivity and §61.42 related to the protection of individuals from inadvertent intrusion (see text of regulations below).

> 10 CFR 61.41, "*Protection of the general population from releases of radioactivity*. Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."

The 0.25-mSv/yr (25-mrem/yr) limit applies to the post-closure period of a disposal facility. Total effective dose equivalent (TEDE) is used instead of the limit for "whole body" and organ doses listed in the Part 61 regulation, which is based on outdated ICRP 2 methodology. In the final rule addressing disposal of spent nuclear fuel and other high-level radioactive waste at Yucca Mountain, Nevada (66 FR 55752), the Commission stated that it considers 25 mrem (0.25 mSv) TEDE as the appropriate dose limit within the range of potential doses represented by the older limits found in regulations, such as § 61.41, that were published prior to the adoption of a dosimetry system capable of accounting for the radio-sensitivity of different organs.

> 10 CFR 61.42, "*Protection of individuals from inadvertent intrusion*. Design, operation, and closure of the land disposal facility must ensure protection of an individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."

In the Draft Environmental Impact Statement for Part 61 (NRC, 1981), NRC used a 500-mrem [5-mSv] annual dose limit to an inadvertent intruder to establish the concentration limits and other aspects of the waste classification system. This limit is typically used by NRC staff when evaluating compliance with §61.42 (or WAC-246-250-180). Washington DOH uses a limit of 100 mrem/yr (1 mSv/yr) when evaluating compliance with chronic exposures from inadvertent

intrusion based on a recommendation in a National Commission on Radiation Protection Report (1993) for continuous or frequent exposure and to be consistent with the limit for the radionuclide cleanup standards for radioactive material licensed sites found in WAC Chapter 246-246 (Washington DOH, 2004). While §61.42 does not specify a time when active institutional controls are assumed to be removed, the regulations in §61.59(b) specify that institutional controls may not be relied upon for more than 100 years following transfer of control of the disposal site to the Federal or a State government. Thus, this regulation provides a basis for the requirement for a 100-year post-transfer active institutional control period and a time frame for when institutional controls are assumed to fail. Washington DOH assumes that institutional controls fail 107 years after the assumed closure date (2 year active monitoring period, 5 year stabilization period, and 100 year institutional control period) when demonstrating compliance with §61.42.

The two remaining performance objectives found in 10 CFR Part 61, Subpart C and WAC-246-250 are not specifically evaluated in Washington DOH's FEIS and associated PA. These performance objectives include protection of individuals during operations §61.43 and stability of the disposal site after closure §61.44 (see text of regulations below).

> 10 CFR 61.43, "*Protection of individuals during operations*. Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable."

This performance objective applies to both the public and to disposal facility workers.

> 10 CFR 61.44, "*Stability of the disposal site after closure*. The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

The stability performance objective is consistent with a premise of Part 61 that the facility must be sited, designed, used, operated, and closed with the intention of providing permanent disposal and should not require long-term maintenance and care.

Generally, a 10,000-year evaluation period is sufficient to demonstrate compliance with the 10 CFR Part 61, Subpart C, performance objectives. This time period is normally sufficient to capture the peak dose from the more mobile, long-lived radionuclides and to demonstrate the influence of the natural and engineered systems in achieving the performance objectives (NRC, 2000). However, assessments beyond 10,000 years may be necessary to ensure that radioactive waste disposal does not result in markedly high doses to future generations for certain types of waste or to ensure that overly optimistic assumptions regarding the performance of engineered or natural barriers do not mask the potential risks of long-lived constituents (e.g., Pu isotopes). For purposes of modeling the risks associated with the US Ecology site under the groundwater pathway, predicted concentrations and doses presented in the report go well beyond a 10,000 year compliance period. The purpose of extending the

calculations beyond 10,000 years was to understand the overall behavior of the release and transport model. Radionuclide fluxes to the aquifer were calculated out to 100,000 years and then set to zero. Radionuclide concentrations in the aquifer were calculated out to 200,000 years in the FEIS (Washington DOH, 2004).

2.2.2 Washington DOH's PA Approach and Results:

As stated in Section 2.0, NRC staff reviewed Washington DOH's FEIS and associated PA for the purpose of relying on its assessment to bound impacts associated with SNM licensed for disposal by NRC at the US Ecology site from the period 1965 to 1980. To facilitate use of DOH's PA in answering TAR Question 1, it was first helpful for NRC staff to understand the overall risk drivers for the facility and what features of the disposal facility are relied on most for performance. As such, key results are presented in Table 2-2 and discussed in the text below. Additionally, the models and calculation approaches used by Washington DOH are described in summary fashion below and in more detail in the sections that follow.

Results of Washington DOH's (and NRC staff's independent PA modeling) were enlightening in that key aspects of disposal facility performance were identified and certain assumptions and modeling parameters were found to be more risk-significant than others. The following bullets summarize some of the key findings from Washington DOH or that were inferred by NRC staff during its review:

1. Radon doses dominated the intruder scenarios; consequently, assumptions related to the depth of disposal of radium sources, cover thickness, and other radon transport parameters (e.g., moisture content, emanation rates, time to containment failure) were found to be important.

2. Doses associated with late construction of a cover are significantly higher than they are for doses associated with placement of a cover in the immediate future. Increased infiltration rates in the next forty plus years leads to higher groundwater related doses from H-3[6] and mobile fractions of uranium and plutonium.

3. Doses for the Native American scenarios are generally higher than they are for the Rural Resident scenarios due to differences in behavioral parameters (e.g., use of a sweat lodge and higher plant and animal ingestion rates). Given the risk significance of the sweat lodge scenario, the higher fluxes of mobile Pu and U to groundwater for the late construction alternative leads to higher doses from these two constituents through the inhalation pathway (e.g., flashing of contaminated groundwater to steam which is subsequently inhaled in the sweat lodge).

4. Interactions of key radionuclides with the subsurface materials at the US Ecology site (i.e., sorption and solubility) is important to the timing and magnitude of the overall peak dose with respect to the 10,000 year compliance period.

[6] More recent work shows the doses from H-3 were overestimated (Rood, 2008; Thatcher, 2008).

Table 2-2. Summary of Washington DOH's PA Results

Scenarios	Site Soils	US Ecology Proposed Cover	Enhanced* Cover Design	Enhanced Synthetic Cover Late Construction
Public (Offsite)	**Dose mrem/yr ^** Limit: 25 mrem/yr TEDE			
Rural Resident	20	8	8	39
Native American^	81	18	22	130
Columbia River	NA	NA	11	NA
Intruder (Onsite)	**Dose mrem/yr** Limit: 100 mrem/yr TEDE#			
Rural Resident	384	87	82-105*	105
Native American	336	94	89-107*	171
Upland Hunter	NA	NA	2	NA

^100 rem = 1 Sv
^Doses reported for Native American scenarios are the highest between the Native American adult and child.
*Range of doses provided for bentonite, asphalt, and geosynthetic enhanced cover designs for onsite analyses. Differences represent differences in intruder cover performance (e.g., thickness of clay affecting radon flux). All enhanced cover designs are assumed to perform similarly with respect to infiltration.
#A dose limit of 100 mrem/yr is used by Washington DOH when evaluating compliance with the §61.42 (or WAC-246-250-180) performance objective related to protection of the inadvertent intruder (onsite receptor). Precedent in NRC review documentation is use of a higher 500 mrem/yr (5 mSv/yr) dose limit.

DOH's FEIS PA provides an evaluation of the types of radioactive releases that could occur as a result of disposal of radioactive waste at the US Ecology facility, the transport of the contaminants released into the environment, the potential exposures to humans, and the resultant consequences from these exposures. Washington DOH presented the results of a series of models performed sequentially (e.g., UNSAT-H, First Order Leach and Transport [FOLAT], GWSCREEN, and exposure assessment modeling) to estimate potential doses for comparison against the performance objective (25 mrem/yr {0.25 mSv/yr} TEDE dose standard) in §61.41. In some cases, Washington DOH conducted modeling to simply provide insights regarding parameters to be used in key PA models or insights regarding system performance (e.g., modeling was used to provide insights regarding potential cap or cover performance [in the form of infiltration rates] for use in subsequent vadose zone modeling; HYDRUS 2D was used to simulate the change in moisture content over time during the active period of disposal facility operation and after closure and cap installation). In other cases, Washington DOH used key model output from one model directly in a downstream model (e.g., FOLAT vadose zone modeling results were used in saturated zone modeling with GWSCREEN; and GWSCREEN modeling results were used to provide exposure point concentrations for use in biosphere modeling). Some models were used to verify results of other models (e.g., DUST-MS was compared to FOLAT vadose modeling results). Washington DOH used data to calibrate models (e.g., analytical data from vadose zone borehole sampling was used to calibrate near-field model) to provide additional confidence in the predictive capability of the models. Uncertainty in model parameters was propagated through the series of computational models (e.g., the

uncertainty in transport parameters, and background infiltration rate was propagated through the groundwater model to determine the impact of these parameters on groundwater pathway dose). Finally, Washington DOH presented results from deterministic analysis, as well as results of a probabilistic uncertainty analysis.

The sections that follow discuss each of the major process models or calculations used in this study. As discussed in Section 2.1, inventories were developed based on information provided in waste disposal records, information provided by waste generators, and in some cases calculations (i.e., calculations of isotopes of uranium based on relative weight percentages for natural, depleted, and enriched uranium). Waste disposals (including future, projected waste disposals) were homogenized over the disposal facility for the purposes of dose modeling calculations. Waste packaging is assumed to be ineffective in controlling contaminant release and partitioning from the waste form into infiltrating water[7]. A single partitioning coefficient is used to describe partitioning between the waste, back-fill, and infiltrating water. The entire site is modeled as if it was a single trench and the cross-sectional area for waste release was the sum of the areas of all of the individual trenches. Infiltration through an open trench is assumed to be greater than infiltration through a closed trench. Therefore, infiltration through the composite trench represents an area-weighted infiltration that is based on the number of open trenches at a given time. Figure 2.2 shows the conceptual models for cover performance and contaminant flow and transport out of the disposal facility.

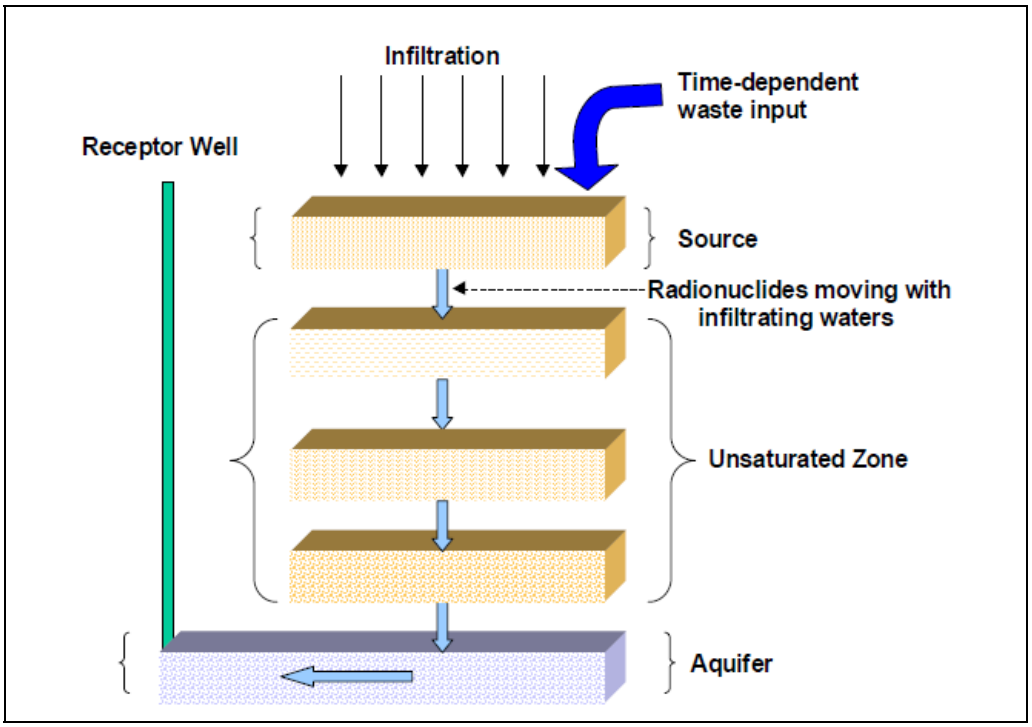

Figure 2-2. Conceptual Model for Waste Release and Contaminant Transport (From Washington DOH, 2004, Appendix IV)

[7] This assumption is true for the groundwater analysis. Radium sealed sources were assumed to degrade after 500 years for the purpose of the intruder calculations.

Washington DOH modeled the transport of contaminants through the vadose and saturated zones with FOLAT and GWSCREEN, respectively. FOLAT is a mathematical model used for the simulation of vadose zone transport and can accommodate changes in moisture content over time as well as radioactive decay and in-growth. GWSCREEN was used to model contaminant transport in the saturated zone. The public receptor was assumed to be a residential farmer who could locate a well at the boundary of the disposal facility. The well is assumed to be used to withdraw water for personal consumption and for watering a small garden, as well as other domestic purposes. Separate Native American scenarios, including a Columbia River water user, and an upland hunter were also simulated. The offsite groundwater pathway scenario assumed that a receptor received radiation doses by consuming contaminated groundwater, contaminated animal products, and contaminated leafy vegetables and produce. Of particular note, an additional pathway of exposure not evaluated in the resident farmer scenario includes use of a sweat lodge for the Native American scenario. Washington DOH used spreadsheets to convert radionuclide concentrations in environmental media into annual doses following internal dosimetry methodology in ICRP 72 and external dosimetry methodology used in the Microshield computer code and in Federal Guidance Report 12 to estimate risks for both adults and children.

Washington DOH performed a parametric uncertainty and sensitivity analysis for the groundwater pathway to evaluate the variability in the model predicted concentrations and doses due to variability in model inputs; and to identify key model inputs. Although Monte Carlo techniques were used, Washington DOH's analysis was not considered a probabilistic risk assessment. Simple random sampling was used to propagate sampled parameters values through the transport model yielding distributions of predicted groundwater concentrations and doses at specified output times that corresponded to the times of maximum dose in the 0-10,000 year time frame based on uncertainty analysis results. The pre-cover and design-basis infiltration rate of the enhanced cover design (only cover evaluated in the uncertainty analysis), calibrated mobile release fractions (and associated inventory), exposure scenario parameters (e.g., drinking water ingestion rate), and dose conversion factors remained fixed (i.e., they were not varied in the uncertainty analysis). Additionally, releases from waste to soil were conservatively assumed to be instantaneous because data was lacking on waste form performance. Washington DOH developed parameter distributions based on analyst interpretation of relevant data. The parametric uncertainty analysis was not intended to be comprehensive, because time and resources limited what could be accomplished in an uncertainty analysis. The data from the uncertainty analysis was used to identify the most important parameter values based on the degree of correlation between the parameter and the output variable (predicted dose). Parameter distributions are listed in Table 2-2.1 below.

Output from Washington DOH's groundwater uncertainty analysis is presented in Figure 2-2.1 below. The results show that the drinking water dose[8] can vary by over three orders of magnitude at 10,000 years. Less uncertainty surrounds the dose at early times which is dominated by the mobile tritium radionuclide. These results are not surprising as a greater number of radionuclides contribute to dose over longer time periods and the mobility of key

[8] While the drinking water dose was the intermediate endpoint for the groundwater analysis, the ultimate endpoint for dose modeling presented in Appendix II considers all pathways related to groundwater contamination.

radionuclides is generally one of the single-most important parameters leading to variability in the magnitude and timing of peak dose for individual radionuclides. When this type of uncertainty is not present (e.g, for known mobile constituents), the uncertainty in dose predictions is substantially less.

Results of Washington DOH's sensitivity analysis indicated that the sensitivity of a given parameter is time dependent. Sixty years after the start of operations, drinking water doses were most sensitive to Darcy velocity in the aquifer and to aquifer porosity because of the importance of groundwater dilution and decay of short-lived radionuclides such as H-3 during transport through the aquifer. At 800 years, drinking water doses were most sensitive to cover longevity, Darcy velocity in the aquifer, and background infiltration. The mean cover failure time was 500 years after installation of the cover in 2005 and therefore, failure would have a significant impact on more mobile radionuclides that dominate the dose at 800 years, such as the mobile fraction of uranium and plutonium isotopes, and to a lesser extent, Tc-99. At 2000 years, drinking water doses are most sensitive to Darcy velocity in the aquifer and to background infiltration. Drinking water doses also show sensitivity to the iodine and uranium Kd values as well as the uranium solubility as doses during this time period are dominated by Tc-99, I-129, and U-238. At 10,000 years, drinking water doses are most sensitive to uranium Kd values, background infiltration, Darcy velocity in the aquifer, and carbon and iodine Kd values. Doses at 10,000 years are dominated by U-238 and C-14 (Washington DOH, 2004).

Table 2-2.1. List of Uncertain Parameters Varied in Groundwater Modeling Analyses (Adapted from Table 22 in Appendix IV of Washington DOH's FEIS [2004])

Parameter	Distribution^	Comments/Reference
Background infiltration rate m/yr	Triangular 0.0025, 0.005, 0.01	Rood 2000a
Longevity of cover yr	Triangular 250, 500, 750	Assumed
Longitudinal dispersivity in aquifer m	Triangular 13.75, 27.5, 41.25	Rood 2000a
Transverse dispersivity in aquifer m	Triangular 2.5, 5.0, 7.5	Rood 2000a
Darcy velocity in aquifer m/yr	Truncated Lognormal 32.9, 2.33, 3.0, 250	Rood 2000a
Bulk density g/cm^3	Triangular 1.58, 1.97, 2.36	Rood 2000a
Aquifer porosity	Triangular 0.097, 0.010, 0.103	Rood 2000a
Uranium Kd* L/kg	Log triangular 0.6, 3.0, 79	Kincaid et al. 1998
Thorium Kd* L/kg	Log triangular 40, 1000, 2000	Kincaid et al. 1998
Radium Kd* L/kg	Log triangular 8, 20, 173	Kincaid et al. 1998
Lead Kd* L/kg	Log triangular 2000, 6000, 7900	Kincaid et al. 1998
Carbon Kd* L/kg	Log triangular 0.25, 0.5, 5.0	Kincaid et al. 1998
Iodine Kd* L/kg	Log triangular 0.3, 0.5, 15	Kincaid et al. 1998
Uranium solubility mg/L	Triangular 1.0, 25, 50	Rood 2000a

^For triangular or log triangular distributions, the distribution is defined by the minimum value, mode, and maximum value, respectively. For the truncated lognormal distribution used to define the Darcy velocity, the distribution is defined with the geometric mean, geometric standard deviation, minimum value and maximum value, respectively.

*The mode of the distribution was taken to be the "best estimate" Kd value reported in Kincaid et al. (1998) used in the deterministic analysis. The minimum Kd was taken to be the conservative estimate of the Kd as reported in Kincaid et al. (1998). The maximum of the distribution was taken to be the highest value reported in the range of possible Kd values in Kincaid et al. (1998).

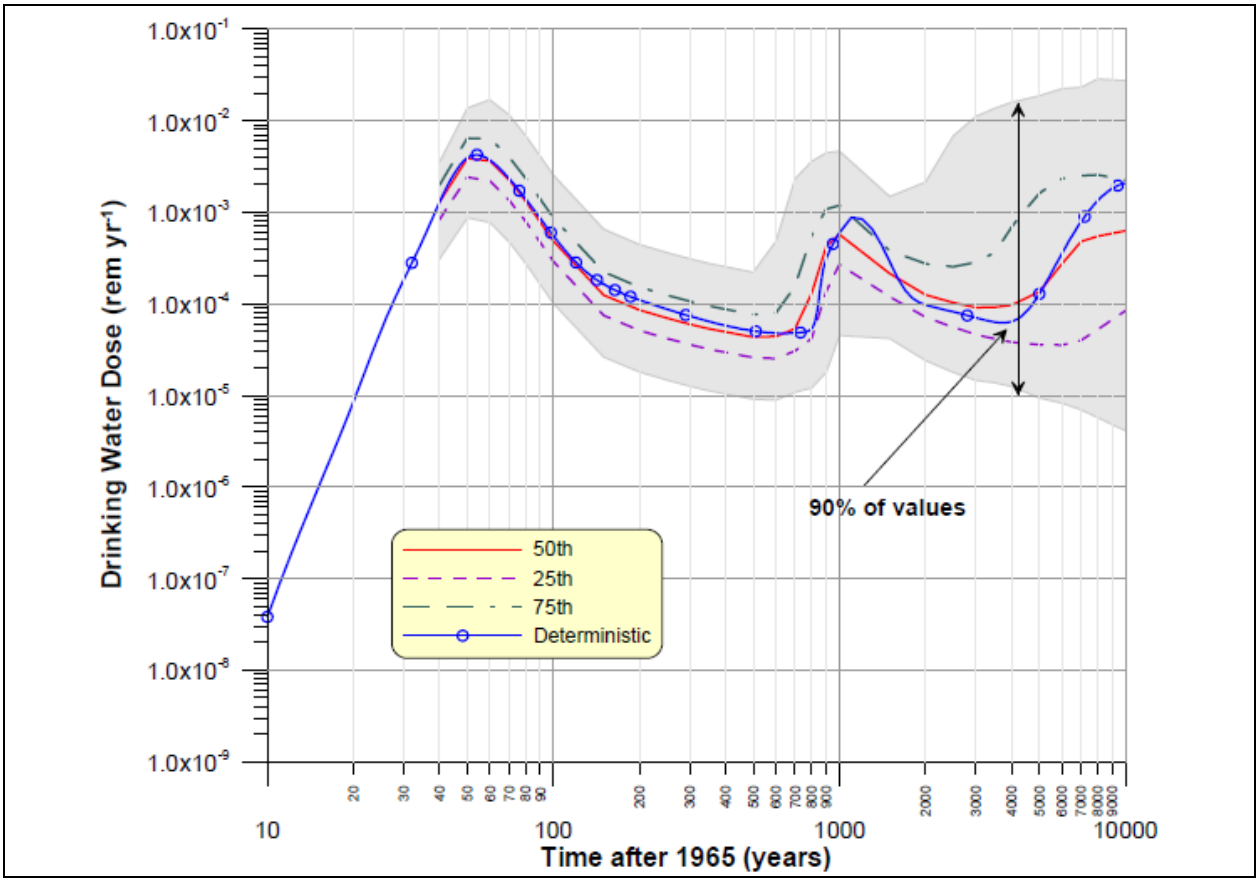

Figure 2-2.1. Results of Probabilistic Uncertainty Analysis for Groundwater Analysis Presented in Washington DOH's FEIS, Appendix IV (2004)

Washington DOH conducted a limited probabilistic uncertainty analysis with respect to the risk assessment presented in Appendix II (i.e., the biosphere modeling conducted to estimate dose and risk after groundwater concentrations from upstream models were calculated in groundwater analyses presented in Appendix IV). Uncertain parameters included those associated with human exposure assessment (e.g., consumption rates, biosphere distribution coefficients, soil to plant transfer factors, wet to dry conversion factors, and parameters related to external dose); a parameter related to radon dose (e.g., degradation times for sealed sources), and uncertainty related to radiation dosimetry (e.g., translated to uncertainty in dose conversion factors). Relevant sensitivity information inferred from the results of the groundwater analysis presented in Appendix IV of DOH's FEIS (2004), the risk assessment presented in Appendix II, as well as NRC staff's own independent evaluation is provided in Table 2-2.2.

Table 2-2.2. Summary of Probabilistic Sensitivity Analysis Results—Key Parameters and Risk Drivers Inferred from Appendix II [Dose Modeling] and Appendix IV [Groundwater Modeling] of Washington DOH's FEIS (2004)

	Time Period			
	0-500 years	**500-1500 years**	**1500-10,000 years**	**>10,000 years**
Key Parameters	Darcy Velocity	Parameters important to Radon flux*	Parameters important to Radon flux*	Kds U, Pu Solubility U
	Cover Longevity & Performance	Darcy Velocity	Darcy velocity	Darcy velocity
		Cover Longevity & Performance	Kds U, Tc, I, C-14	
Dominate Radionuclides	H-3 U mobile Pu mobile	Rn-222+D U mobile Pu mobile	Rn-222+D Tc-99 I-129 C-14 U	U immobile Pu immobile

*In addition to cover thickness, which is perhaps the single-most important parameter related to radon flux based on FEIS and follow-up calculation results (Daniel B. Stephens & Associates, 2007), emanation rates, moisture content, diffusion rates, Ra-226 inventory, and depth of waste (related to cover thickness) are also important.

2.2.3 NRC Evaluation of Washington DOH's PA Approach:

Washington DOH used reasonable methodologies for demonstrating potential compliance of the US Ecology disposal facility with performance objectives for low-level waste disposal in 10 CFR Part 61 (and WAC-246-250). The FEIS presents a range of scenarios and alternatives that provide insights on facility performance. Washington DOH developed exposure scenarios based on a comprehensive evaluation of relevant sources including Part 61 rulemaking documentation, the Hanford Site Risk Assessment Manual (DOE, 1995) and DOH Hanford Guidance for Radiological Clean-up (1997). Washington DOH prepared probabilistic uncertainty and sensitivity analyses to identify risk-significant aspects of facility performance. Washington DOH also performed model verification and calibration using monitoring data collected from the site, albeit limited and without its own uncertainty[9], to provide additional confidence in the predictive capability of the PA groundwater models and the ability of the facility to meet performance objectives in 10 CFR Part 61, Subpart C. The Washington DOH PA presents the logical development of the types of exposure pathways important for potential receptors at the Hanford site. Several Native American Tribe scenarios were analyzed and

[9] Calibration uncertainty results from measurement error or limited data to constrain the problem. For example, available data may be explained by more than one conceptual model with calibration to different conceptual models producing different end results; or results of an optimization (calibration) process may produce non-unique solutions. Additionally, model complexity was increased in the calibration process. Model complexity led to additional parameters that with limited constraining calibration data led to additional parameter uncertainty. Thus, for this problem, both conceptual model and parameter uncertainty are thought to exist.

presented in the FEIS, although updated information on the scenarios has been provided.[10] The receptor characteristics and exposure scenarios are reasonable; and the dose limits, dose methodology, point of compliance, compliance period, and institutional control period are all acceptable.

2.2.4 Washington DOH's Infiltration and Cover Assumptions:

As shown in Figure 2-2, the first input to Washington DOH's performance assessment model is the infiltration rate which is a function of various factors including site climate, precipitation rates, vegetation, runoff potential (e.g., slope) and use of engineered barriers. Infiltration is risk-significant in Washington DOH's model because it is directly related to the flux of contamination to a potential drinking water aquifer and affects timing of release to the aquifer which is particularly important for short-lived radionuclides such as H-3 and Pu-238. In fact, Washington DOH's PA results show that timing and cover selection are particularly risk-significant. Because of this, US Ecology plans to use an engineered cover to limit infiltration through the waste.

Appendix III of DOH's FEIS provides information on cover performance modeling (Washington DOH, 2004). UNSAT-H Version 2.03 was used to model the performance of various cover designs including the following:

1. site soils cover,
2. US Ecology proposed cover,
3. homogenous cover, and
4. three enhanced covers (low permeability layer consisting of (i) asphalt, (ii) geosynthetic and (iii) bentonite).

UNSAT-H uses a fully implicit, finite difference method for solving water flow using Richards' equation. Plant water uptake is introduced as a sink term at each node and is calculated as a function of root density, water content and potential ET. The computer code is described in Fayer and Jones (1990). Slight modifications were made to the code in Washington DOH analysis to increase precision, to mitigate problems with the time stepping algorithm and to modify the Ritchie equation to manage uncertainties with the leaf area index for plants grown in desert communities. Several modeling limitations, simplifications, and assumptions were noted with respect to the UNSAT-H modeling including the following:

1. Modeling reflects design or in-tact conditions (i.e., degraded performance of layers due to settlement, cracking, oxidation, cation exchange, clogging of drainage layers, burrowing, fire, disease, succession, deep root intrusion into synthetic materials, accumulation of windblown materials, or wind erosion was not considered[11]).

2. The same vegetative density and growth pattern was assumed for all covers and all time periods.

[10] See discussion in Section 1.3 above and Section 2.2.13 below regarding updated scenarios and parameters for Native American Tribes.
[11] Degradation assumptions were made for the subsequent groundwater analysis.

3. The model is one dimensional and therefore, cannot be used to model lateral drainage at the capillary break above the impermeable layers.

Degraded cover conditions were assumed for the groundwater analyses after some assumed service-life had expired. Differences in vegetative density and growth patterns are expected to have a minor influence on performance compared to other uncertainties (e.g., seasonal variations in plant growth and leaf area index application) and all covers are expected to be subject to the same processes affecting all covers (e.g., deposition of windblown material, fire, intrusion and succession). Because UNSAT-H is one-dimensional, ponding takes place above the low permeability layers due to inability of the model to consider lateral flow out of the drainage layer. As a result, only the upper layers are modeled and no credit is taken for the drainage layer and low permeability layers of the enhanced designs and homogenous cover.

Five closure and cover design options (see Table 2-2.3 below) were simulated in the groundwater assessment presented in Appendix IV of DOH's FEIS (2004). Water fluxes through the three engineered cover designs were based on information provided in Appendix III of DOH's FEIS, along with three closure scenarios. As discussed above, because the UNSAT-H code used to evaluate the performance of the covers only considered the upper layers above the low permeability layer, all three enhanced designs were grouped together with respect to infiltration performance in the groundwater analysis presented in Appendix IV. The engineered covers considered consisted of (i) a site soils cover, (ii) the US Ecology proposed cover, and (iii) the lumped enhanced cover design group (asphalt, bentonite, and synthetic). The FEIS considered closure options with disposal operations terminating (i) in year 2003, (ii) in year 2056, and (iii) in year 2215[12]. Not all covers were evaluated for each closure option. In all cases, the cover was assumed to be installed in the year 2005 over the existing trenches and infiltration in open trenches for future site operations would be controlled to no more than the cover design. Covers were assumed to begin to fail 500 years after placement in the year 2505 based on the typical cover design lifetime for Hanford Site facilities. Cover failure was assumed to occur at this time (500 years after placement) regardless of the closure option considered. The time for the cover to degrade to natural infiltration is assumed to be the lifetime of the cover. For example, if the cover lasts 500 years, then the cover degrades to natural infiltration in 1000 years (Washington DOH, 2004).

The site soils cover has an initial infiltration rate (20 mm/yr) greater than natural recharge rate (5 mm/yr) which is assumed to decrease to the background recharge rate due to settlement, re-vegetation, and creation of structure in the site soils cover over a 500 year stabilization period. For all other engineered covers, the covers are assumed to begin to fail at 500 years and return to natural recharge rates after another 500 years. That is, infiltration through the cover increases linearly from 0.5 to 5 mm/yr between 500 and 1000 years after installation.

[12] It is important to note that the alternatives analyzed in Appendix IV differ from those presented in Appendix II. Most notably, the *late* enhanced cover construction (construction in 2056) alternative was not presented in Appendix IV.

Table 2-2.3. Cover and Closure Options Evaluated in Groundwater Analysis

Cover/Closure Option	Design Infiltration Rate mm/yr
Site soils cover/waste disposal ceasing in 2056	20
Enhanced cover/ waste disposal ceasing in 2003	0.5
Enhanced cover/ waste disposal ceasing in 2056	0.5
Enhanced cover/ waste disposal ceasing in 2215	0.5
US Ecology proposed cover/ waste disposal ceasing in 2056	2.0

2.2.5 NRC Evaluation—Washington DOH's Infiltration and Cover Assumptions:

Washington DOH generally used reasonable approaches for evaluating performance of engineered covers for the purposes of evaluating various alternatives for US Ecology facility closure. However, documentation was lacking in certain key areas. For example, as cover longevity and performance has a significant impact on the results of the analysis based on sensitivity analysis results presented in Appendix IV of Washington DOH's FEIS (2004), support for key modeling assumptions related to cover performance were expected to be more robust. Although the cover designs and associated performance assumptions in the FEIS are conceptual in nature, support for key assumptions is needed to ensure engineered barrier performance is not over-estimated and can be achieved in the field. Lack of documentation and support places the facility at greater risk of not being able to meet performance objectives in the future.

Perhaps, the greatest benefit of early construction of a cover is that it limits releases of more mobile constituents into the environment. Although FEIS documentation was limited, additional intermediate groundwater modeling results were obtained to allow comparison of an early versus late construction cover alternative. NRC review of this documentation coupled with interviews with FEIS analysts confirmed that late construction of a cover significantly increases the dose for several key radionuclides and in particular, long-lived, mobile fractions of U and Pu. While short-lived isotopes such as H-3 also benefit from construction of a cover earlier in 2005 versus later in 2056, the benefit of early construction is not as great as it is for other key radionuclides given the fact that (i) the peak H-3 dose is dominated by the earliest disposals when infiltration rates through the open trenches and flux are the highest (see Figure 2-2.5 in Section 2.2.8.2) and (ii) early releases have reached significant depths in the vadose zone prior to construction of a cover. The effects of reduced infiltration rates on deeper layers of the vadose zone from construction of a cover are not realized until much later (several decades to hundreds of years later) than surface layers (see discussion in Section 2.2.8). The end result is that the H-3 dose peaks significantly earlier (owing to its short half-life and higher flux early on) than other longer-lived radionuclides (e.g., U and Pu-239) whose individual peaks are truncated more significantly by construction of a cover earlier (assumed to be in the year 2005 in the FEIS) rather than later (e.g., assumed to be in the year 2056 in the late construction alternative in the FEIS). The benefits of early cover construction for any particular radionuclide is, therefore, a complex function of many factors including historical disposal rates, variability in infiltration rates/fluxes over time based on operations and timing of cover construction, cover performance assumptions, and radionuclide dependent factors such as half-life and mobility. In another example, the impact of timing and cover performance on less mobile constituents such

as the immobile U fraction, C-14 and I-129 is negligible. Thus, individual and overall peak doses that occur later in the compliance period are not sensitive to cover timing and performance.

Because the FEIS (Washington DOH, 2004) assumed that a cover would be in place in the year 2005[13] and the benefits of early cover construction for mobile constituents such as mobile fractions of U and Pu is clearly evident when comparing overall peak doses from early versus late construction in the FEIS, construction of an early cover is expected to be risk-significant. The interim-cover should be just as effective as assumed in the FEIS to ensure that the overall peak dose is similar to or less than estimated in the FEIS. An interim cover has been proposed that contains a high-density polyethylene (HDPE) geomembrane and overlying protective soil layers (Pachernegg, 2010). The HDPE geomembrane will need to perform as well as assumed for the enhanced cover designs evaluated in the FEIS for a minimum of around fifty years prior to final closure proposed in the year 2056 when a final cover will be installed. Depending on the final design, the upper layers of the final cover system (e.g., evapotranspirative and drainage layers) will also need to be designed to meet performance standards for the enhanced cover designs established in the FEIS for the assumed 500 to 1000 year performance period (cover assumed to be completely in-tact up to 500 years and completely degraded after 1000 years). It is expected that the geomembrane will undergo antioxidant depletion over time such that the service life for this cover component will be limited to less than 500 years assumed for in-tact cover performance in the FEIS based on recent studies (e.g., Benson, 2010). Thus, design optimization for the upper layers of the final cover will be critical to ensuring the doses remain similar to or less than assumed in the FEIS. The impacts of late cover construction or less than optimal interim cover performance is evaluated further in Section 2.3.

With respect to performance of evapotranspirative cover systems, in August 2009 Washington DOH and the Native American Tribes had a meeting to discuss the US Ecology disposal facility. At this meeting, they discussed the choice of an ET cover because the Native American Tribes had heard that the EPA had determined that ET covers are failing. Surface covers employ a variety of functional mechanisms to divert water and contain waste, however most covers are of two types: conventional and ET. Conventional covers rely on the resistive properties of one or more components of the cover, such as a geomembrane, to halt downward movement of infiltration water and allow a drainage layer with high hydraulic conductivity to channel the water to the sides of the cover where it is discharged from the system. The resistive properties can be used to prevent water from reaching the waste, or radon from escaping into the atmosphere. Examples of materials with resistive properties include compacted soil or clay, sheets of synthetic material such a geomembranes, and geosynthetic clay liners. Geotextiles and geonets are often used in conjunction with granular drainage layers to provide a drainage pathway out of the cover system. Although ET removes water from conventional covers, it is the layers of low permeable material that hinder water from reaching the waste. In contrast, ET covers rely more on natural processes to remove water and would not fully function without vegetation. ET is usually the most important process removing water, sometimes removing over half of the total water input (i.e., precipitation). Water is allowed to enter the outer portion of the cover, a non-compacted soil layer with a saturated hydraulic conductivity value close to that of the

[13] While the FEIS assumes a cover is in place in the year 2005, additional supplemental analyses conducted more recently (Rood, 2008) evaluate the impact of cover construction later (i.e., year 2012), as the year 2005 has come and past.

surrounding environment, during periods of elevated precipitation and minimal ET. Stored water is subsequently pulled back to the surface by a network of plant roots and removed from the system by ET during drier periods. ET covers are effective when the upper soil layer has sufficient storage capacity and when sufficient evapotranspirative demand exists to remove the stored water. Engineered surface barriers may combine the features of both conventional and ET covers, e.g., installation of synthetic material below the water storage unit of an ET cover.

All components of an engineered surface barrier are subject to some form of degradation over the tens or hundreds of years in service, however overall performance has not shown to be significantly poorer than conventional covers (Dwyer, 2003). The EPA has put together a fact sheet describing advantages and disadvantages of ET covers (http://www.epa.gov/tio/download/remed/epa542f03015.pdf). Although there are potential shortcomings with ET covers, in many aspects, advantages sometimes outweigh the disadvantages. In addition to being potentially less costly to construct, ET covers have the potential to provide equal or superior performance compared to conventional cover systems, especially in arid and semi-arid environments. In such environments, they may be less prone to deterioration from dessication, cracking, and freezing/thawing cycles. The coarser-grained layer can act as a biointrusion layer to resist root penetration and animal intrusion, due to its particle size and low water content. Disadvantages for ET cover systems include applicability in areas that have arid or semi-arid climates only (e.g., western United States). Local climatic conditions, such as amount, distribution, and form of precipitation, including amount of snow pack, can limit the effectiveness of an ET cover at a given site. If gas collection is required at the site, it may be necessary to modify the design of an ET cover to capture and vent the gas generated in the landfill. However, in general, ET covers perform as well as other cover designs if climate and characteristics of the disposal site are considered.

2.2.6 Washington DOH's Near-Field Model:

The near-field model is that portion of Washington DOH's larger PA model representing the source zone (e.g., inventory and source release) depicted in Figure 2-2. The near field model is risk-significant because it determines the rates of release of radioactivity from the disposal trenches into the surrounding environment. The driving force for these releases is infiltration of rainwater into the disposal trenches described in the preceding Section 2.2.4. The source term and unsaturated zone transport models (modeled together using the FOLAT code) are discussed in Appendix IV to Washington DOH's final FEIS (2004). The models were updated from previous analyses by incorporating transient infiltration rates and historical waste disposal rates into the model. Radionuclide inventories were re-evaluated and important radionuclides identified through a two-phase screening approach. Fifteen radionuclides were identified as being important in terms of their potential for groundwater ingestion dose: C-14, Cl-36, H-3, I-129, Pu-238,-239,-240,-242, Ra-226, Tc-99, Th-230, Th-232, U-234, U-235, and U-238. Ni-63 and Sr-90 were used for model calibration but were ultimately screened out of the detailed groundwater analysis based on their low risk significance to drinking water dose. Assumptions regarding partition coefficients and cover longevity were also revisited and modified as necessary from previous analyses (Washington DOH, 2004).

Radionuclide release rates from the trenches and their transport in the unsaturated zone were calibrated to measured concentrations taken from borehole data beneath trench 5. The distribution of contamination under trench 5 could not be explained by purely aqueous phase transport considering the current level of understanding of the relative mobility of these constituents in similar Hanford soils and environments (i.e., the contamination should not have been as deep in the vadose zone using recommended Kd values in modeling calculations). A colloidal transport model was, therefore, proposed. The colloidal transport model assumes a fraction of the radionuclide inventory moves at the velocity of groundwater. The fraction of the inventory that moves at the velocity of groundwater was used as a calibration parameter and represents the "mobile fraction" of the inventory. Calibrated radionuclide mobile fractions ranged from 6.2E-04 to 4.6E-06 for Ni-63, U-238, Sr-90, and Pu-239; and 0.047 for Tc-99. The higher mobile fraction value for Tc-99 is reflective of the relatively greater mobility of this constituent. However, for Tc-99 the analyst concluded that it was necessary to limit the radionuclide release rate from the trenches so that model-predicted radionuclide inventories below the trenches matched inventories extrapolated from the borehole data.

As explained in Section 2.2.4, the cover was assumed to perform at the in-tact or design-basis infiltration rates presented in Table 2-2.3 for 500 years and linearly degrade to background infiltration rates over an additional 500 year time period (i.e., background infiltration was achieved by year 1000). Sorption was only assumed to occur on the fines in subsurface materials. Changes in infiltration rates are reflective of periods of active operations (higher than background infiltration rates at a magnitude reflective of the number of open trenches), post-closure period (lower infiltration rates for engineered covers), and period following degradation of the covers (gradually higher infiltration rates over time). Figure 2-2.2 below shows Washington DOH's conceptual model for waste release over time. Simulations with the 2D HYDRUS code were also run to better understand the progression of the drying and wetting front through the entire thickness of the vadose zone as a function of time (see Figure 2-2.2). These changes were found to have a significant impact on the results of the analysis (see discussion in Section 2.2.5).

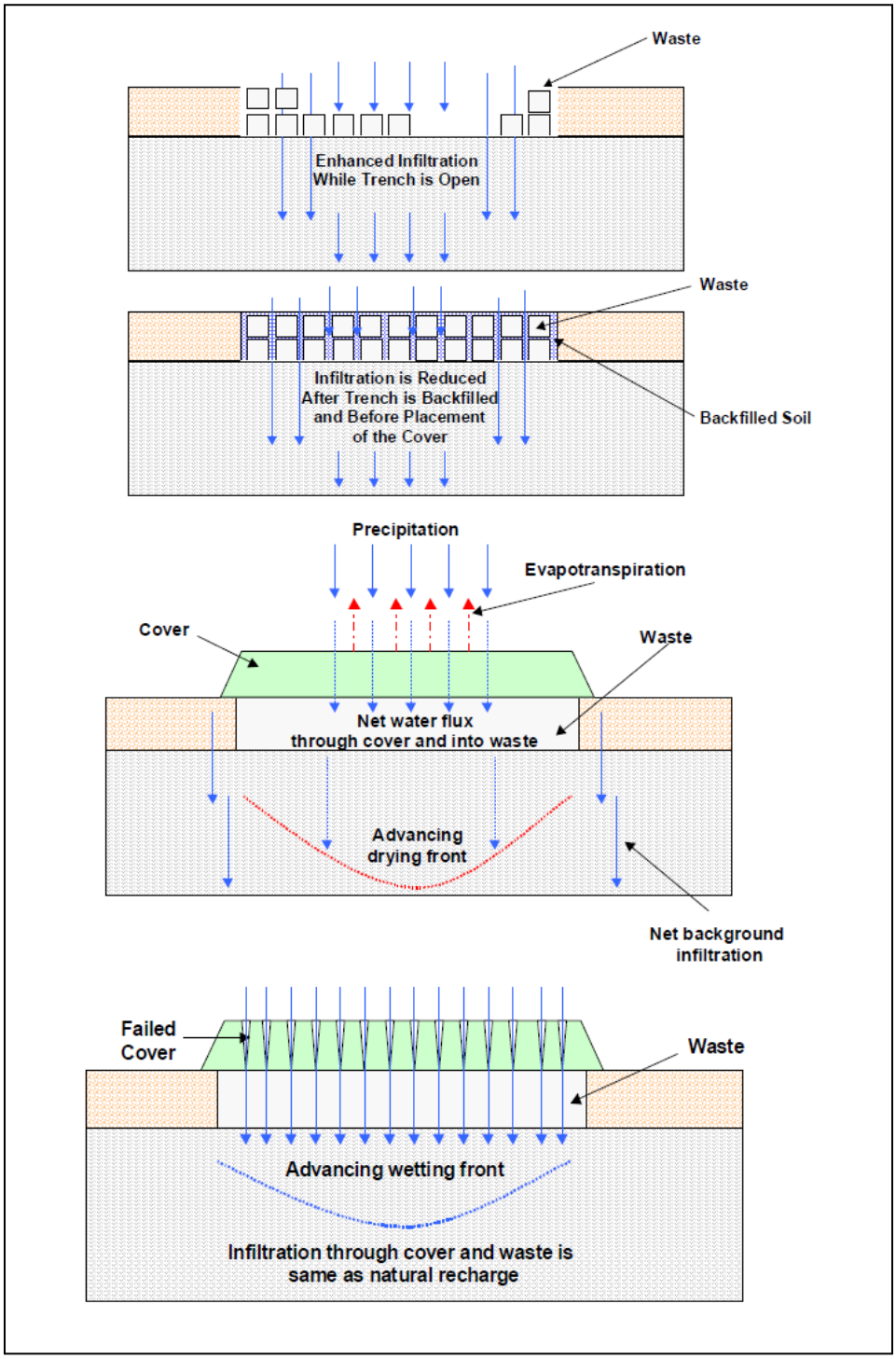

Figure 2-2.2. Conceptual Model for Infiltration and Moisture Content Changes (i) During Operations, (ii) After Cover Installation and (iii) After Cover Degradation. Taken From Appendix IV in Washington DOH's FEIS (2004)

2.2.6.1 Source Term Modeling:

As discussed in Section 2.2.6, time varying waste disposal rates were considered in the source and vadose zone modeling for the radionuclides that were not screened out of the detailed analysis. For scenarios involving operation of the site beyond the year 2003, waste disposal rates were assumed to remain constant for the duration of site operations (to year 2056 or to year 2215). Disposal rates from the period of 1965 through 1981 were also assumed to be constant as information on the inventory for these early disposals were not detailed enough to differentiate these disposals on a more time discrete basis.

FOLAT was used to model source release and vadose zone transport (Rood, 2002). The FOLAT model treats the source and unsaturated zones as a series of compartments where interchange between the compartments is described by advection-driven first-order (e.g., leaching) or solubility-limited processes. The conceptual model for FOLAT is relatively simple. The subsurface environment is envisioned to be composed of a series of "compartments". Within each compartment, radionuclides enter, mix, sorb, decay, and are eventually removed by the downward movement of water. Each compartment may have its own unique qualities that include horizontal and vertical dimensions, bulk density, porosity, hydraulic conductivity, net water flux through the compartment, and sorptive properties. Water flux and moisture content through each compartment may change as a function of time. Radionuclides sorb on to the solid matrix as described by a partitioning coefficient or Kd. Sorption delays the overall downward movement of radionuclides compared to the velocity of water. Variable transport rates of parents and daughters are considered.

Radionuclides may be present in each of the compartments at the start of the simulation, or alternatively, the parent member of the decay chain may be placed over time in the uppermost compartment. Concentrations of radionuclides in pore water are not allowed to exceed their solubility limit[14]. Unit gradient conditions are assumed to apply to each compartment (i.e., only gravity driven flow is considered). Ordinary differential equations describe the mass balance of radionuclides in each of the compartments. Radionuclide concentrations in pore water and the radionuclide fluxes from each compartment are determined from the radionuclide inventory within each compartment.

2.2.6.2 Source Term Parameters:

Washington DOH initially took partitioning coefficients from the Composite Analysis for the 200-Area (Kincaid et. al., 1998). Recent measurements of radionuclides in boreholes beneath trench 5 were used to refine the partitioning coefficients and estimate mobile release fractions. The 200 Area Composite Analysis (Kincaid et al. 1998) provided estimates of element specific Kd values for six different geochemical environments identified as A through F. In general, the A environment (described as high organic and very acidic) had the lowest Kd values and the F environment (described as low organic, low salt, and near neutral) had the highest Kd values. Geochemical environments were then assigned to three zone categories; high impact, intermediate impact, and low impact groundwater.

[14] Only a solubility limit for U was used in this analysis.

The high impact zone category was defined as the area in the unsaturated zone near the source that is impacted by the chemical composition of the waste, particularly any contaminated liquids that were disposed. Organic compounds, pH, and salt, when present in the source may affect the Kd values. The high impact zone category has the lowest Kd values. The intermediate impact zone category was assigned to the unsaturated zone where the excessive acidic or basic nature of the waste has been neutralized by the buffering capacity of the natural soil and no pH effects of the plume remain. The low impact/groundwater zone category was defined in the unsaturated zone and unconfined aquifer where Kd values are not affected by the chemical composition of the contaminant plume. The groundwater zone category has the highest Kd values. In the 200 Area composite analysis (Kincaid et. al.. 1998), the US Ecology site was assigned a geochemical environment described as low organic/low salt/near neutral (geochemical environment F) for all soils in the unsaturated zone and in the aquifer. Consequently, the same Kd values were assigned to all geologic media (although Kd values were modified for the percent gravel in each model layer based on lithographic information used to construct the model).

In light of borehole data that suggested greater mobility of certain key radionuclides, Washington DOH recognized that radionuclide transport may be affected by colloid transport, presence of complexing agents, and preferential flow paths not considered in the Kincaid et al., composite analysis (1998). Therefore, borehole data collected at the site was used to calibrate the source term model—specifically the mobile-release fraction and waste release Kds parameters of the model. For the immobile fraction, the Kd values reported in Kincaid et al. (1998) for geochemical environment F were used without modification.

2.2.6.3 Calibration of Source Term Model:

In 1999, US Ecology conducted a comprehensive facility investigation (US Ecology, 1999) hereafter referred to as the Phase I and II investigation. Part of the investigation was to examine radionuclide migration from the disposal trenches, which entailed the drilling of four boreholes to a depth of about 21.3 m (70 feet) below the trench bottom. Two boreholes were drilled adjacent to trench 5 (boreholes C and D) and two adjacent to the chemical disposal trench (boreholes A and B). These two trenches were considered the most likely to provide evidence of waste constituent migration beyond the physical limitations of the trench; scintillation-vial solvents benzene, toluene, and xylenes were known to be disposed of in trench 5 along with some of the other trenches at the facility. These solvents were, in fact, quantified at very low concentrations in soil gas samples withdrawn from wells near the west end of trench 5 and near the chemical trench (US Ecology, 1999). Additionally, the occurrence of Freon, organic chemicals, and carbon dioxide in soil gases (and depleted oxygen levels indicative of aerobic degradation) near the west end of trench 5 was also noted. It was hypothesized that decomposition of organic material in the trenches along with density driven gas phase transport of solvents out of the trench and into the vadose zone beneath the trenches was potentially occurring (US Ecology, 1999).

Radionuclides were measured as a function of depth below the boreholes and included Ni-63, Sr-90, Tc-99, Pu-238,239/240, U-234,235,238, Th-230,232, and Ra-226. Much of the information provided in this section is summarized from Appendix IV of Washington DOH's FEIS (2004). Ni-63 and Sr-90 had soil concentrations above the minimum detectable concentration (MDC) in almost all the samples and showed relatively uniform concentration with depth. These

results included the samples taken beneath the chemical trench, which presumably received no radionuclides. This distribution reflects relatively rapid transit times in the unsaturated zone. In fact, to produce the observed depth distribution, the radionuclides would have to travel at the rates of infiltrating water with essentially no sorption occurring, which is inconsistent with laboratory data on the mobility of strontium and nickel.

Pu-239/240 concentrations at or above the MDC were found in samples taken below the chemical disposal trench. Uranium, thorium and radium isotopes all had soil concentrations above the MDC. US Ecology (1999) cites conclusions of Minor that indicate "...the analytical results of nine vadose zone samples agree well with local background concentrations and/or represent data whose quality appear to be reliable—K-40; Ra-226- and 228; Th-228, 230, and 232; and U-234, 235 and 238." Analysis of uranium isotopic ratios in the borehole samples, however, suggested that some of the uranium detected was anthropogenic in nature (e.g., the mean U-235 weight percent in borehole samples was substantially higher than that for natural uranium and closer to that of enriched uranium, although this conclusion was not consistent with U-234 measurements which may imply a potential positive bias in the U-235 measurement).

The measured concentrations in boreholes C and D (taken below trench 5) and the estimated radioactivity disposed of in trench 5 provided data to construct a source term model for the trench. The chemical trench presumably received no radionuclides and therefore, no model calibration to data taken from below the chemical trench was performed. The calibration process considers radioactive waste disposed of in the trench in 1978–1979 when trench 5 was open. During active disposal, the trench is open and there is no runoff. An infiltration rate of 7.5 cm/yr is assumed during active disposal, consistent with the estimate of Kincaid et al (1998). During the period the trench was open (April 1978 to September 1979), 22.9 cm of precipitation was recorded at Pasco according to precipitation records obtained from the National Climatic Data Center, so the assumed infiltration rate during this period is reasonable. After closure of the trench, infiltration is assumed to be reduced to 3 cm /yr.

Soil concentrations beneath trench 5 were averaged by depth and numerically integrated. The activity disposed of in trench 5 was estimated from the total radioactivity disposed of from 1965 to 1981. It was assumed that each trench that was open during the 1965 to 1981 time frame received an equal amount of radioactivity. Because seven trenches were operating during this time, the total 1965 to 1981 disposed radioactivity was divided by seven. Measured concentrations of Pu-239 and Pu-240 were not segregated, and were reported as a single value; therefore, inventories of Pu-239 and Pu-240 were summed.

The calibration exercise did not assume the entire contaminant plume was captured by characterization data. Rather, the mobile fraction of the inventory was calibrated to the distribution of soil concentrations below the trench within the depth range sampled by matching radionuclide concentrations in the borehole samples taken below trench 5 to the model-estimated concentrations in corresponding unsaturated layers 1–3 which lie between 10.6 m and 29.5 m (35 ft and 96.8 ft) below ground surface. Measured concentrations were averaged across the thickness of each unsaturated layer. The three unsaturated layers correspond to following depths below the ground surface:

1. UZ Layer 1--10.6 to 16.9 m below grade
2. UZ Layer 2--16.9 to 23.26 m below grade, and
3. UZ Layer 3--23.26 to 29.6 m below grade

Measured concentrations that were below the MDC were assumed to be equivalent to the MDC for this calculation, which provides a conservative estimate of the radioactivity below the trench. Radionuclide pore water concentrations output from the FOLAT model in each layer were converted to soil concentrations via calculation. Contamination below trench 5 is assumed to be vertically transported from the trench to the unsaturated zone. For comparison, simulations were run with the DUST model (Sullivan, 1996), which uses a finite-difference approximation to the advection-dispersion equation, for verification purposes.

The release fraction calculations are sensitive to the estimated initial inventory. Evaluation of the uncertainty in the inventory estimate was stated to be beyond the scope of the analysis but was recommended for future work. Based on the results of model calibration, a fraction of each radionuclide in the inventory was assumed to be mobile; the fraction was only applied to the 1965-2002 inventory. Future disposals were assumed to be controlled so as to minimize mobile-fraction releases. The mobile fraction was based on assumed similarity to other isotopes and/or sorption characteristics. Table 2-2.4 provides information on mobile release fractions and Kds.

Table 2-2.4. Summary of mobile release fractions and partitioning coefficients

Isotope	Mobile Release Fraction	Distribution Coefficients+
U	3.5E-04	3 L/kg (all isotopes of U) 25 mg/L solubility limit (only affects U-238)
I-129 and C-14^	6.2E-04	0.5 L/kg (I-129 and C-14)
Pu, Th, Ra	4.6E-06	200 L/kg (Pu) 1000 L/kg (Th) 20 L/kg (Ra)
H-3 Cl-36 and Tc-99*	1.0	0 L/kg (H-3) 0.75 (Cl-36 and Tc-99—waste zone) 0.0 L/kg (Cl-36 and Tc-99—UZ and SZ)

+The values reported in this table are prior to gravel-fraction corrections that lower the Kds further. The values apply to the immobile fraction (mobile fractions have a Kd=0 L/kg), except for H-3, Cl-36 and Tc-99 which only have one fraction (mobile).
^Not measured in borehole data; assigned same value as Ni-63 that was measured in borehole data but screened out of list of radionuclides for detailed groundwater analysis. Ni-63 was chosen as a surrogate for I-129 and C-14, because it had the second highest value after Tc-99
*Calculated a mobile release fraction of 0.05 for Tc-99 but instead used a value of 1.0 for mobile release fraction (see discussion in the text).

Calculating the mobile release fraction for Tc-99 was stated to be more complicated due to the fact that all Tc-99 is relatively mobile and it would be difficult to differentiate mobile versus the less mobile fraction for this constituent. Thus for Tc-99 and the other mobile radionuclide, Cl-36, an "effective" Kd in the source zone was calculated by calibrating the predicted Tc-99 activity below the trench down to 21 m to the measured data considering the total activity of Tc-99 in trench 5. This "effective" Kd represents partitioning from the waste form into infiltrating water to reduce the leaching rates of Tc-99 to better match monitoring data (the calibrated model only showed a 5% mobile fraction rather than 100% that would have nominally been assumed for Tc-99). For the remainder of the radionuclides (excluding Tc-99, Cl-36, and H-3), immobile fraction leaching from the trench and transport in the unsaturated zone and aquifer used partition coefficients for geochemical environment F provided in Kincaid et al. (1998).

2.2.7 NRC Evaluation of Washington DOH's Near-Field Model:

As discussed in Section 2.1 above, Washington DOH spent a great deal of effort evaluating previous waste disposal records and refining the inventory for certain key radionuclides. This work is expected to significantly reduce the uncertainty associated with the source term (or waste release) estimates, although some amount of uncertainty is still expected to exist despite Washington DOH's best efforts. The approaches used to evaluate waste release from the disposal facility with exceptions noted below were generally conservative in the absence of information to constrain modeling predictions. For example, no waste form performance was assumed in the analysis due to waste packaging that might delay or retard the release of constituents in the environment.[15]

NRC staff did have concerns regarding the lack of consideration of conceptual and parameter uncertainty in the source term model. While calibration of the source term model to data was undertaken by Washington DOH and the approach is generally supported by NRC staff, due to the limited amount of data available, uncertainty in the calibration process and near-field model remains. Calibration uncertainty may result from measurement error or due to limited data. For example, borehole data used in the calibration process may be subject to error or extrapolation of the data spatiallymay introduce errors in the calibration process. In another example, results of an optimization (calibration) process may produce non-unique solutions or available data may be explained by more than one conceptual model with calibration to different conceptual models producing different end results.

Additional model complexity was introduced in the revised FEIS source term modeling in the form of a non-mechanistic mobile release fraction parameter to help explain the apparent high mobility of certain key radionuclides. However, neither the inventory used to determine the mobile release fraction, nor the mobile release fraction were evaluated in the uncertainty analysis due to limited scope. With respect to conceptual model uncertainty, potential mechanisms for what appears to be enhanced release of radioactivity out of early disposal trenches do not appear to be well understood. While various mechanisms were hypothesized including potential colloidal transport, it was beyond the scope of the study to investigate the controlling mechanism(s) further. NRC staff was initially concerned that the source term model

[15] Radium sealed sources were not assumed to degrade until after 500 years in the intruder or on-site receptor analysis. However, no credit was taken for delayed release of radium sealed sources in the groundwater analysis. Discussion regarding radon release models is discussed in Section 2.2.15 below.

was either unrealistic or potentially non-conservative. In other words, without a clearly supported mechanistic model(s) for enhanced radionuclide release, the right results (during model calibration) could have been obtained for the wrong reasons, which would compromise the predictive power of the model for longer timeframes or even for a larger area beyond the scope of the calibration exercise—which in this case was a single trench with data representing a small fraction of a single trench. Several scenarios that could lead to higher doses are discussed in the paragraphs that follow along with potential mitigating factors that were considered in evaluating source term conceptual model uncertainty.

NRC noted that contamination was found below the chemical trench but no known sources of radioactivity are assumed to exist in the chemical trench. This uncertainty was not specifically addressed in the analysis (calibration was focused around trench 5 releases). If any of the detections below the chemical trench are valid, contamination located underneath the chemical trench either came from the chemical trench or from another nearby trench. In either case, the conceptual model for waste release used in the calibration process either (i) is not entirely consistent with or (ii) does not entirely consider all of the available data. Consider for instance that lateral transport of contamination from another trench(s) to the vadose zone underneath the chemical trench occurred. In this case, the conceptual model of one-dimensional vertical transport and associated assumption that contamination directly underneath a trench is a good representation of leaching of contamination from the trench located directly above the contamination comes into question. Calibration efforts based on this conceptual model may lead to a potential underestimation (or overestimation) of the higher mobility fraction or the general mobility of a particular constituent. Analysis of inventory data for the early trenches indicates that the majority of the inventory of key radionuclides is concentrated in trenches 4 and 5, somewhat limiting the impact of an invalid 1-D vertical transport assumption as co-located trench 4 (along the long dimension) contains similar inventories of key radionuclides as trench 5 (the same cannot be said about nearby trench 6). In another hypothesis, if the contamination below the chemical trench is in fact attributable to contamination in the chemical trench, then the assumption that the chemical trench contains no radioactivity is invalid. In this case, the amount of radioactivity that may be presumed to be located in the chemical trench could be back-calculated from available data, although this approach would likewise be fraught with uncertainty in the face of limited data to constrain modeling predictions. Considering the two scenarios and given (i) the relatively higher concentrations of Sr-90 in samples taken below the chemical trench compared to trench 5, (ii) the distance of the chemical trench to other trenches, and (iii) the increased risk of enhanced mobility due to potential complexation of chemical with radioactive constituents, it is perhaps more likely that the chemical trench contained some limited amount of radioactivity that led to contamination directly below the chemical trench. Because no records of any radioactive waste disposals exist for this trench, the presence of radioactivity in the chemical trench cannot be confirmed; however, given the limited volume of the trench and its primary purpose (to receive chemical, not radioactive waste) the impact of a scenario where the chemical trench contains radioactivity is expected to also be limited.

After interviews with Washington DOH staff, it became clear that DOH places little weight on the borehole data collected from the Phase I and II investigation used to calibrate the groundwater model, and in particular Pu found below the chemical trench due to potential issues associated with data quality, difficulties with separation chemistry (e.g., Pu and Th separation), and analysis of radioisotopic distributions within the subsurface (e.g., lack of co-location of similar radionuclides). A chemical trench inventory report submitted by the licensee in response to Condition 58 was also used to support the assumption that the chemical trench contains no radioactivity. Additionally, subsequent Phase III sampling associated with the Washington Department of Ecology's Model Toxics Control Act (MTCA) investigation revealed little to no contamination in boreholes advanced vertically downward in several locations around the perimeter of early trenches (Washington DOH, 2010). Samples were taken at two depth discrete locations near the bottom of the trench and approximately 20-27 m below grade. While the information provides compelling evidence of the limited amount of radioactivity presumed to have leached out of the disposal trenches, the information provided cannot completely rule out the potential for risk-significant quantities of radioactivity to have migrated out from the early trenches, including the chemical trench, in localized areas or along preferential pathways especially if the releases were driven by higher infiltration rates expected for open trenches or due to the presence of greater liquid waste fractions or chelating agents than allowable under today's standards.

With regard to preferential pathways, clastic dikes have been observed in the Hanford formation beneath the 200 East Area and more specifically at the US Ecology disposal facility. The vertically oriented clay skins within clastic dikes may have formed an impediment to lateral flow (Last et al., 2006) in localized areas during periods of higher infiltration through open trenches or due to the presence of liquid waste. If flow is or was primarily vertically oriented due to clastic dikes or otherwise, it would be difficult to draw definitive conclusions regarding the presence or absence of contamination based on data from sample locations at the periphery of the trenches. There is also a potential for preferential horizontal flow due to sublinear channel-cut scour and fill features that occur within the Hanford formation (Last et al., 2006). Both the Ringold and the Hanford formations also contain thin fine-grained stringers that can result in lateral spreading. Most notably, low permeability layers within the sand-dominated facies of the Hanford formation are generally thicker and more continuous than those in the gravel-dominated facies over a range of approximately 100 m (Last et. al, 2006). If flow is or was more laterally oriented, perimeter sampling locations would be more likely to detect contamination from the trenches if located in close proximity to vertical discontinuities. Constraining model predictions is hampered by the difficulty in obtaining additional sampling data from directly underneath the trenches and given the potential complexities in contaminant transport that makes efficient selection of sampling locations difficult. However, any future sampling events should consider any available hydrostratigraphic information to optimize sampling locations. Furthermore, information about both contaminant and moisture content distributions obtained from the Phase I and II investigation should also be considered because it may provide information on the most likely flowpaths for contamination away from the trenches.

Another source of conceptual model uncertainty is the assumption in the source term model that all radionuclides other than Tc-99, Cl-36 and H-3 have a high and low mobility fraction, while Tc-99, Cl-36, and H-3 only have a mobile fraction. If this assumption is not valid, the implication is that radionuclides assumed to have both a mobile and immobile fraction may rather be simply more mobile than anticipated, thereby leading to higher doses earlier in the compliance period than estimated by the PA model. This is significant because the peak dose for many of the more strongly sorbing radionuclides does not occur until after the end of the 10,000 year compliance period (e.g., immobile fractions of U and Pu). Uncertainty in the assumed mobility of U is evaluated further in Section 2.3.

With regard to the uncertainty in Pu mobility, Pu geochemisty is very complex as this radionuclide can be present in five different oxidation state with many of these states able to co-exist simultaneously. Pu(III) and Pu(IV) are, in general, relatively insoluble, whereas Pu(V) and Pu(VI) are, in general, more soluble. At neutral to alkaline pH (>7), dissolved plutonium forms very strong hydroxy–carbonate mixed ligand complexes, resulting in desorption and increased mobility in the environment (Prikryl and Pickett, 2007). In oxidation state IV, plutonium strongly hydrolyzes (reacts with water), often to form colloidal solids which can increase the mobility of Pu (Clark, 2000). Pu (V) has also been observed to sorb strongly to colloids albeit at lower fractions than Pu (IV). Evidence of redox cycling occurring on mineral surfaces has also been observed (Clark, 2000). A number of studies indicate that iron hydroxides adsorb and reduce Pu(V) and Pu(VI) to its tetravalent state at the solid surface. Fjeld, et al. (2003) have described a conceptual model for plutonium transport through sediment columns representative of the Savannah River Site in Aiken, SC, where plutonium transport is controlled by the net rate of reduction of adsorbed Pu(V) to adsorbed Pu(IV). In this model, oxidized plutonium can mobilize as Pu(V), and the Pu(V) can re-adsorb onto iron bearing minerals and be slowly reduced to Pu(IV). In this way, plutonium transport is kinetically controlled with a small fraction able to move more rapidly, while the bulk of plutonium is largely immobile. Fjeld et al. (2001) also conducted column experiments to simulate contaminant transport in sediments at the Idaho National Engineering and Environmental Laboratory and found that both mobile and immobile fractions of Pu could exist simultaneously. In the neutral to slightly alkaline and oxidizing environment of the Hanford site, Pu is expected to exist in the Pu(V) and Pu(VI) oxidation states. Pu Kd estimates vary from 0.4 to 200 L/kg in Hanford soils based on the source term characteristics (e.g., acidity, complexing agents, chelates, and salts) provided in Kincaid et al. (1998). While US Ecology was deemed to be a low risk site, given results of monitoring from underneath the early chemical trench, the expected variability in disposal practices over time, and relatively higher inventory of Pu in the early trenches, perhaps the greatest risks associated with Pu transport are for early trenches and unknown sources. However, it is unlikely that the sorption characteristics for the immobile fraction of Pu were so grossly overestimated in the FEIS that the peak dose from Pu would be expected to occur during the 10,000 year compliance period (i.e., the Kd would have to be at the very minimum reported for Hanford soils under any chemical condition). Nonetheless, the timing and magnitude of peak dose from Pu beyond the 10,000 year compliance period is not well understood. Therefore, additional studies should be conducted and information collected, as practical, to elucidate Pu mobility in the US Ecology subsurface for the purpose of informing closure decisions.

Two radionuclides are assumed to have only a mobile fraction but with a distribution coefficient larger than zero indicating some nominal amount of attenuation in the waste zone; Tc-99 and Cl-36 were assumed to be attenuated in the waste zone using an effective Kd for Tc-99 calibrated to monitoring data. If the monitoring data used to calculate the effective Kd for Tc-99 are not representative of the total amount of Tc-99 leached from the trench or the inventory of trench 5 is less than assumed, with the latter appearing to be the case based on evaluation of available trench data and considering the fact that the Tc-99 inventory is expected to be significantly over-estimated for all trenches (see discussion in Section 6.1 of Appendix II to [Washington DOH, 2004]), Tc-99 mobility (and by association Cl-36) could have been underestimated. However, because the inventory of Tc-99 in all of the trenches is expected to be significantly over-estimated, the impact of overly optimistic assumptions regarding the attenuation of Tc-99 in trench 5 is mitigated. Additionally, Cl-36 is not expected to be a risk driver in the PA. Therefore, the impact of Tc-99 and Cl-36 waste zone mobility is not addressed further.

A source of parameter uncertainty is the starting inventory of radioactivity in trench 5, which was used to determine the waste zone Kd and mobile fraction parameters during the model calibration process. Given limited information on the inventory in trench 5, the analyst assumed that the entire inventory from 1965 to 1981 came from seven trenches and that the inventory was equally distributed between the trenches. This assumption may lead to either an over- or under-estimation of the mobile fraction or waste zone mobility based on the particular key radionuclide in question. NRC staff evaluated this uncertainty based on trench by trench data provided in response to Condition 58 of the license (Carpenter, 1990b) in Section 2.3 of the TER. It is important to note that the trench-specific inventory data is not without its own uncertainty and so a basic assumption that allows use of this data to study uncertainty in the mobile release fractions is that any uncertainty is relatively similar between early disposal trenches.

NRC staff thinks that uncertainties in the mobile fractions have been partially managed by the collection of additional borehole data in the Phase III investigation which suggests that the extent of contamination in the subsurface is limited. Although the potential exists for preferential pathways and un-evaluated mechanisms for enhanced radionuclide transport exists, the approach used in the FEIS is perhaps more likely to over-predict the potential doses associated with more mobile radionuclides or radionuclides that are subject to enhanced transport given the conservative assumption that the *entire* disposal inventory (prior to 2002) contains a high mobility fraction when only a small fraction of the inventory in early trenches may be affected. While uncertainty in the mobile fractions for trench 5 or other early trenches is expected to be relatively large and variability across the disposal facility is expected, the average risk for the entire disposal facility is expected to be much smaller and managed with conservative assumptions (assumption that the mobile fractions calculated for trench 5 apply to newer trenches with more stringent controls on waste form in place is expected to be conservative). Additionally, it may be overly conservative to assume that the mobile fraction remains mobile at longer time and distance scales if the mechanism of enhanced transport is due to chemical affects that may be buffered along the flow path from the disposal trenches or if colloidal transport is hampered by a threshold moisture velocity or filtration along the flow path.

Nevertheless, conceptual model uncertainty is more difficult to assess and evaluate because of the large number of variables and limited amount of constraining information which would otherwise make the problem more tractable. For this problem, conceptual model uncertainty is not readily reducible because of the limited amount of information available and the difficulty in obtaining additional information to help constrain the problem. NRC recommends that the Washington DOH (or the licensee) collect additional information to better understand disposal facility performance and monitor activities at the larger DOE site to ensure that conceptual model uncertainties are appropriately managed and constrained to the extent practical.

2.2.8 Washington DOH's Hydrology and Far-Field Transport:

Far-field modeling includes that portion of Washington DOH's PA model downstream of the source zone and following source release (i.e., portions of the unsaturated zone as well as saturated zone modeling shown in Figure 2-2 above). The far-field model is risk-significant as it determines the potential natural attenuation of contamination along flow paths away from the source zone and in the underlying aquifer. Contaminants are assumed to travel vertically approximately 80 m through the unsaturated zone underneath the footprint of a "composite trench" that represents the area of all of the trenches at the disposal facility as illustrated in Figure 2-2.3. After transport through the vadose zone, radionuclides enter the aquifer and migrate horizontally in the direction of saturated groundwater flow. The aquifer is assumed to be a homogeneous, porous media of infinite lateral extent and finite thickness. Aquifer flow is assumed to be at steady-state and unidirectional (parallel to the short-length of the disposal facility), with no appreciable sources or sinks within the footprint of the facility. A drinking water well screened from the top of the aquifer down to 15 m below the water table surface is assumed to be drilled on the downgradient edge of the US Ecology facility property line. Pumping is assumed to be minimal and have little impact on the overall flow in the aquifer. In-growth of progeny is not considered during transport in the saturated zone to the well. This simplifying assumption was stated as being reasonable for this site given the short transport times to the well (Washington DOH, 2004).

2.2.8.1 Model Construction:

DOH took most of its model input from Rood (2000a), Rood (2000b), and Kincaid et al. (1998); model input is presented in Table 2-2.5 below. Analyses in Kincaid et. al. (1998) were used to support the assumption that the two-dimensional aquifer solution used in Washington DOH's FEIS with a 15-m mixing thickness results in a conservative estimate of aquifer concentrations compared to the more realistic three-dimensional model used in the 200 Area Composite Analysis. This assumption was supported by the analyst's interpretation that vertical dispersion would lead to a plume that bypassed part of the well screen. Washington DOH determined the number of unsaturated layers in the FOLAT model based on calculations to mimic the amount of plume spreading or dispersion expected based on solution of the advection dispersion equation. Comparisons of GWSCREEN, which uses an analytical solution to the advection dispersion equation, and FOLAT results were made and showed no meaningful differences.

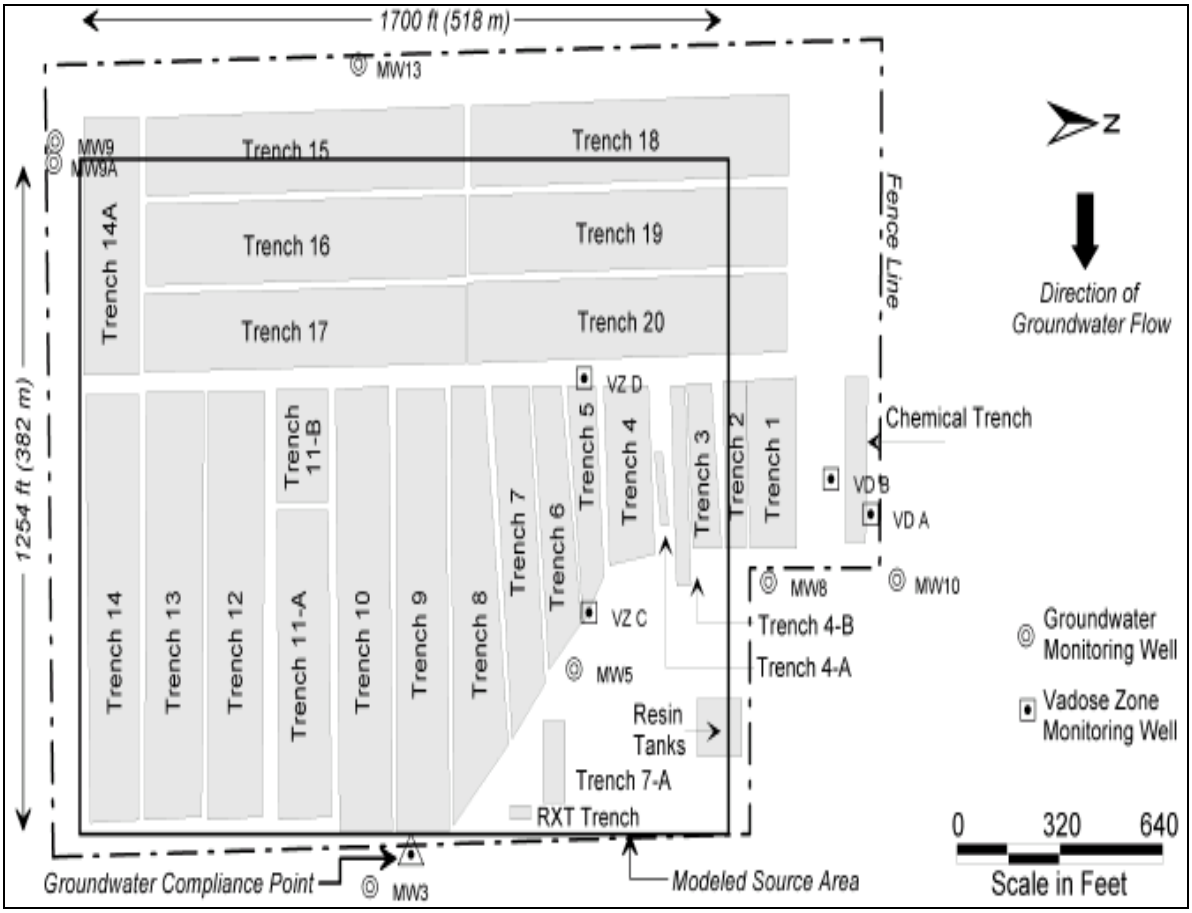

Figure 2-2.3 Groundwater Modeling Extent Indicated in Black Outline Taken from Washington DOH's FEIS, Appendix IV (2004).

Table 2-2.5 Groundwater Model Input Parameter Values

Parameter Name	Nominal Value	Reference
General		
Length of source parallel to aquifer flow	382 m	Rood (2000a)
Width of source perpendicular to groundwater flow	518 m	Rood (2000a)
Cover Longevity	500 yr	Assumed
Source Zone Properties		
Source thickness	10.6 m	Rood (2000a)
Bulk density	1.97 g/cm^3	Kincaid et al 1998
Saturated hydraulic conductivity	555 m/yr	Kincaid et al 1998
van Genuchten fitting parameter α	0.811	Kincaid et al 1998
van Genuchten fitting parameter *n*	1.58	Kincaid et al 1998
Residual moisture content	0.015	Kincaid et al 1998
Total porosity	0.119	Kincaid et al 1998
Vadose Zone Properties^		
Vadose zone thickness	82.3 m	Rood (2000a)
Number of vadose zone layers	13	Calculated
Thickness of vadose zone layers	6.3 m	Calculated
Bulk density (layer 1) (layers 2-13)	1.78 g/cm^3 1.97 g/cm^3	Kincaid et al 1998
Saturated hydraulic conductivity (layer 1) (layers 2-13)	3753 m/yr 555 m/yr	Kincaid et al 1998
van Genuchten fitting parameter α (layer 1) (layers 2-13)	1.3 0.811	Kincaid et al 1998
van Genuchten fitting parameter *n* (layer 1) (layers 2-13)	2.1 1.58	Kincaid et al 1998
Residual moisture content (layer 1) (layers 2-13)	0.026 0.015	Kincaid et al 1998
Total porosity (layer 1) (layers 2-13)	0.337 0.119	Kincaid et al 1998
Aquifer Properties		
Longitudinal dispersivity	27.5 m	Rood (2000a)
Transverse dispersivity	5 m	Rood (2000a)
Well screen thickness	15 m	Rood (2000a)
Aquifer porosity	0.1	Rood (2000a)
Darcy velocity	32.9 m/yr	Rood (2000a)
Bulk density	1.6 g/c m^3	Rood (2000a)

^Material properties for layers 2-13 are the same as for the source zone. Layer 1 has properties slightly different.

2.2.8.2 Boundary Conditions:

As discussed in Section 2.2.6, water fluxes in the unsaturated zone were based on data in Gee et al. (1992), Kincaid et al. (1998), and the estimated infiltration rates for the three covers. Natural recharge in the 200 Area was estimated in Kincaid et al. (1998) to be about 0.5 cm/yr.

Gee et al. (1992) estimated natural recharge to range from near zero for vegetated soils containing silt loam, to up to 10 cm/yr for unvegetated coarse sediment soils. For the Washington DOH FEIS assessment, the natural recharge rate was assumed to be 0.5 cm/yr (2004). As discussed conceptually in Section 2.2.4 above, the presence of an engineered cover is assumed to limit infiltration through the waste and influence water fluxes through underlying unsaturated layers. During active disposal, a fraction of the site is excavated and water infiltration through open trenches is enhanced. Water infiltration through an open trench was assumed to be 7.5 cm/yr based on data in Kincaid et al. (1998). Closed trenches within the US Ecology property boundary during operations from 1965 to 2005 are assumed to be lower than an open trench but enhanced over natural background rates at 3 cm/yr, as the soil is still in a disturbed state. Infiltration across the modeled source area is area-averaged based on the number of open and closed trenches over time.

At the start of the simulation (1965), water fluxes in all layers are initialized at the trench infiltration rate of 7.5 cm/yr. Water fluxes in subsequent years are calculated using a preprocessor to the FOLAT program which calculates the water balance in each layer based on the user-provided water flux at the surface and the hydrologic characteristics of each soil layer. The water flux at the surface encompasses three phases (i) pre-cover times, (ii) the design-based cover infiltration rate while the cover is intact, and (iii) the background infiltration rate after the cover has failed. Once the cover is installed, the unsaturated zone dries over time and moisture contents eventually reach an equilibrium value that is determined by the amount of infiltration through the cover. After cover failure, the unsaturated zone beneath the trenches is re-wetted and moisture contents eventually reach an equilibrium value determined by the natural recharge rate.

Washington DOH first examined drying and wetting processes using the HYDRUS 2D code (Washington DOH, 2004). The simulation used a simplified homogeneous representation of the unsaturated zone consisting of sandy loam. Initial conditions were based on the equilibrium water contents assuming a recharge rate of 2 cm/yr. Boundary conditions included a 200 m long cover in the center of the model domain, which limited infiltration to 0.5 mm/yr. Free drainage was assumed at the base of the unsaturated zone. This simulation was run until water contents reached an equilibrium throughout the domain; equilibrium conditions were achieved after about 400 years. A second simulation was performed where the equilibrium water contents with the cover in place at 500 years were the initial conditions for the simulation. The cover was assumed to fail instantaneously with an upper boundary condition set to a recharge rate of 2 cm/yr. The results of the two simulations are reproduced in Figure 2-2.4. The frames to the left of the figure show the advancement of the drying front following placement of the cover, while the frames on the right show the advancement of the wetting front after the cover is assumed to instantaneously fail. The HYDRUS simulation results show that the infiltration shadow beneath the composite trench extends vertically down to the aquifer. The results also show that drainage from the unsaturated zone takes much longer than re-wetting following cover failure. This information supported Washington DOH's decision to add additional model complexity to the vadose zone modeling in the FEIS to more accurately reflect the changes in moisture content and flux through the vadose zone over time.

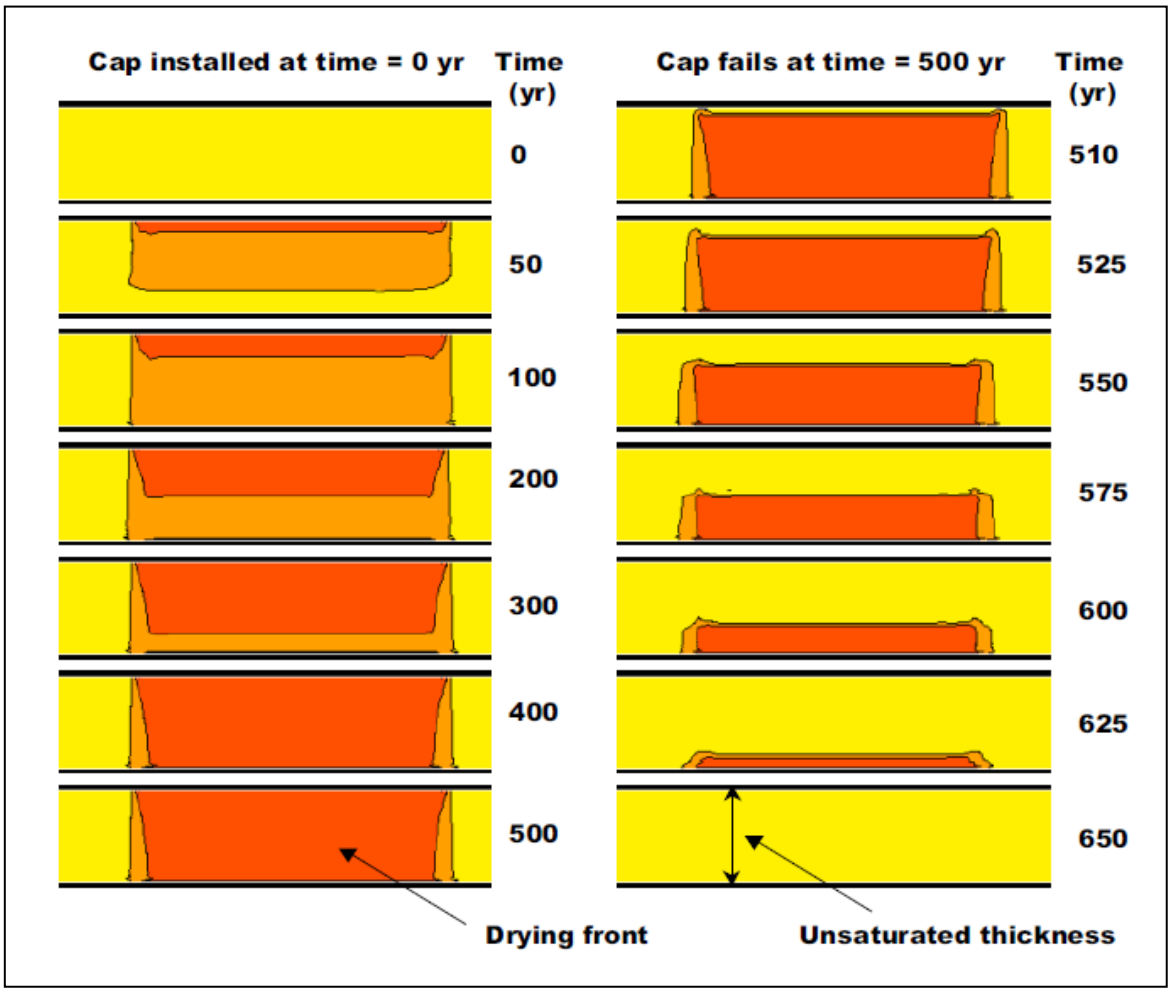

Figure 2-2.4 Simulation of drying and wetting front due to cap installation and failure. Taken from Washington DOH's FEIS, Appendix IV (2004)

With respect to Washington DOH's FEIS vadose zone modeling, installation of the cap first limits infiltration into the waste and eventually throughout the "infiltration shadow". After *engineered* cover failure, re-wetting of the unsaturated zone occurs relatively rapidly[16]. Net water flux at several depths in the unsaturated zone, as calculated by the FOLAT preprocessor, (FOWL) are illustrated in Figure 2.2-5 for the site soils, enhanced, and US Ecology proposed covers modeled in the FEIS. These illustrations depict the major effects of drying and re-wetting of the vadose zone caused by changes in the infiltration rates at the surface. Note that eventually all layers revert back to the same flux rates which are consistent with the background infiltration rate assumed in the modeling after 1000 years, 5 mm/yr.

[16] This observation only applies for the enhanced and US Ecology proposed covers. The site soils cover does not degrade. Instead, infiltration is actually reduced to 5 mm/yr over time.

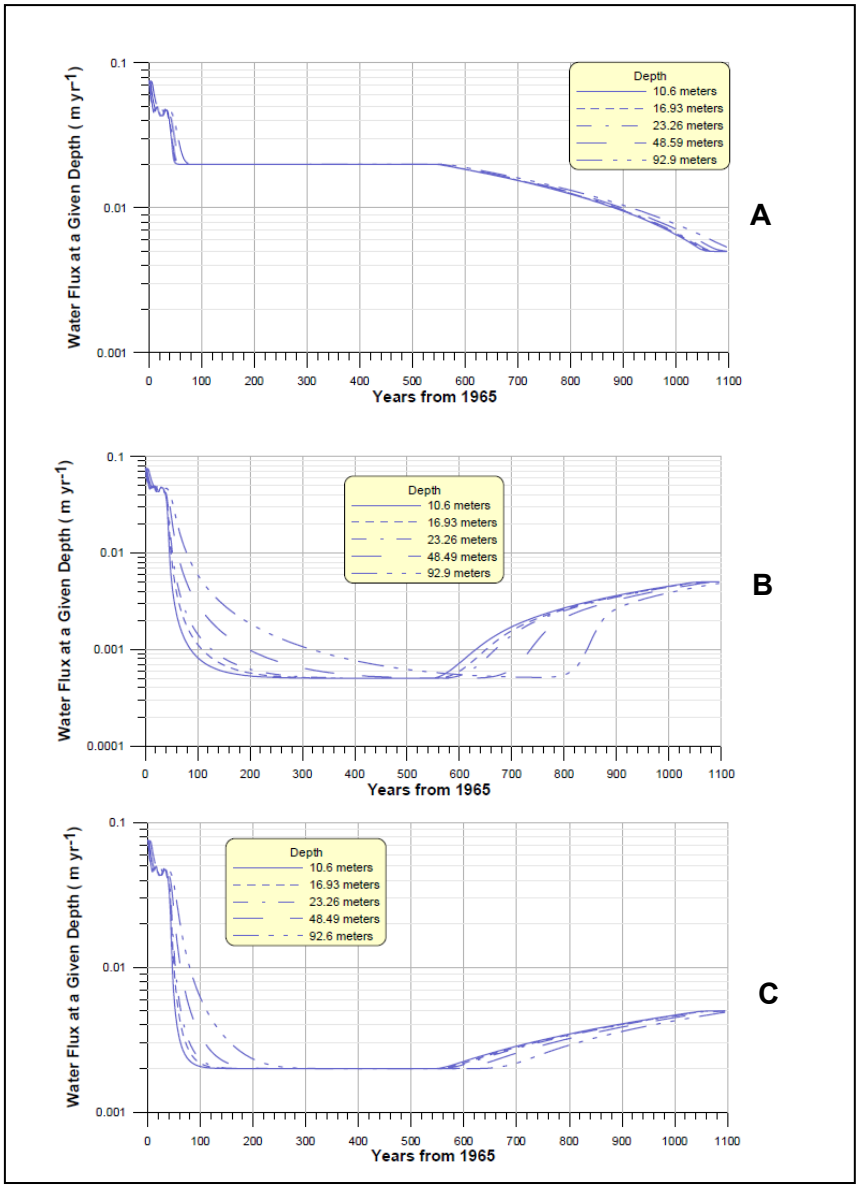

Figure 2-2.5 Water Flux Over Time for Various Covers (a) Site Soils, (b) Enhanced, and (c) US Ecology Proposed Cover and for Various Depths (11, 17, 23, 48, and 93 m)

2.2.8.3 Material Properties:

Material properties include bulk density, saturated hydraulic conductivity, residual moisture content, total porosity and the van Genuchten fitting parameters, α and n. The van Genuchten fitting parameters are used to determine the moisture content for a given water flux. In the original assessment (Rood 2000a), both the source and unsaturated zone had essentially the same properties. The FOLAT model allows for unique material properties assigned to the source and each unsaturated layer. Lithology of the unsaturated zone and surface soils where the trenches are located were provided in Kincaid et al (1998) for the US Ecology site and were used in these simulations without modification. Partition coefficients were adjusted for the percent gravel content—unsaturated layer 1 was assumed to have a gravel content of 17.3% and the aquifer was assumed to have the same percent gravel composition as unsaturated layers 2–13, 42%. The unadjusted Kds used in Washington DOH's analysis are reported in Table 2-2.4 in Section 2.2.6.

2.2.9 NRC Evaluation—Washington DOH's Hydrology and Far-Field Model:

With respect to key transport parameters, Kds are taken from Kincaid et al (1998) for the benign chemical environment assumed to be present below the trenches. Given the apparent high mobility of at least a small fraction of certain key radionuclides in the subsurface at US Ecology and uncertainties in the source term conceptual model, it is not clear that these Kds are realistic or conservative. For example, the Kd for U could be significantly lower than 3 L/kg based on site-specific information for different chemical environments. If the Kd for U is, in fact, lower than assumed for the immobile fraction, the peak dose from U isotopes could occur within the 10,000 year compliance period. Additionally, the minimum Kd of 0.6 L/kg used to define the parameter distribution in Washington DOH's uncertainty analysis is similar to the conservative or "best estimate" value but larger than the minimum value assumed for the range of U Kds in other site assessments (ORP, 2006; Last et al., 2006; Kincaid et al., 1998). Nonetheless, Washington DOH found the U Kd to be risk-significant in probabilistic sensitivity analyses performed for the groundwater pathway (2004). Independent NRC staff analysis also showed a strong correlation of U Kd to peak dose. Given the risk-significance of this constituent for the US Ecology and larger Hanford site, the mobility of this constituent should continue to be studied and monitored to ensure that the PA does not significantly under-predict the potential dose from this constituent. Solubility control of U[17] is also subject to uncertainty. Wood (1995) reports a solubility limit of 2.7E-04 for UO_2^{+2} controlled by schoepite (or a solubility limit of around 75 mg/L for U) based on thermodynamic data in MINTEQ that are described as "fair." The impact of lower Kds and no assumed solubility control for U peak dose is evaluated further in Section 2.3.

Lithology of the unsaturated zone was taken from Kincaid et al (1998) for the US Ecology site. Kincaid et al. (1998) shows that the well logs relied upon to construct the lithology for the US Ecology site were relatively far away compared to well logs from site wells reported in CH2M HILL, Inc. (1986) presented in Attachment A of the Closure Plan (US Ecology, 1996). Development of model lithologies using well log data from the CH2M Hill report would appear to

[17] A solubility limit of 25 mg/L for U was assumed in the analysis. The solubility limit only affects U-238 dose due to its low specific activity (compared to U-234 and U-235).

be more appropriate. Changes in lithology could affect moisture contents, water fluxes, and partitioning coefficients. However, the impact of any slight changes to the lithology is expected to be of relatively minor risk-significance compared to other PA model and parameter uncertainties (e.g., source term model, Kds, and cover performance) and is therefore, not evaluated further.

As discussed in the inventory section above, Washington DOH also made certain assumptions regarding the homogeneity of the waste disposed of in the disposal facility trenches. If higher concentrations of certain key risk drivers were assumed in early trenches, groundwater concentrations could be significantly higher (e.g., Pu disposals in early trenches constitute much of the Pu inventory for the disposal facility). If the infiltration rates, Kds and mobile fractions for Pu are realistic or are conservative, higher Pu concentrations in the early trenches alone is not expected to drive the doses significantly above the dose standards within the 10,000 year compliance period; the maximum Pu dose is less than 25 mrem/yr [0.25 mSv/yr] for the Native American adult when considering higher concentrations of Pu in the early disposal trenches alone.

A concern expressed verbally to NRC staff during a meeting with the Confederated Tribes and Bands of the Yakama Nation included a geological connection of the liquid waste source area of the BC cribs with the LLW disposal site by means of a downward dipping Cold Creek formation. Boreholes have shown that the Cold Creek unit does not exist in the LLW waste site area (CH2M HILL, 1986). However, downward movement of infiltrating water from the surface through the unsaturated layers of the Hanford formation can be strongly influenced by the relative amounts of sand, silt, and clay found in any particular horizon of the Hanford formation. Zones of lower permeability would cause some lateral spreading, which would result in a delayed arrival at the water table (Bergeron et al., 1987). However, most layers of this type are expected to have limited lateral extent, and water movement would eventually return to a vertical direction. If this were not the case, clastic dikes in the Hanford Sands are known to exist in the southern part of the Hanford Site. Laminar features potentially causing lateral flow within the Hanford formation would be intersected by clastic dikes, disrupting stratigraphic horizons and any accompanying lateral flow. Therefore, NRC staff considers a hydraulic connection in the unsaturated zone between the US Ecology Site and the BC Cribs unlikely.

NRC staff evaluated Washington DOH's hydrology and far-field models and found them to be generally adequate and appropriately implemented with the possible exceptions noted above. A number of assumptions regarding natural attenuation processes operable at the site were necessarily made. In most cases, these assumptions are supported by previous analyses and studies. In other cases, it is not clear that the most appropriate values were selected in the face of limited data and uncertainty (e.g., uranium Kds). NRC staff recommends that information and data from continued characterization, studies, and research activities regarding natural attenuation processes at the site continue to be collected and evaluated. When significant deviations exist between PA model assumptions and future studies on what are expected to be risk significant parameters or processes, PA calculations should be updated to evaluate the risk significance of the deviations on site performance.

2.2.10 Washington DOH's Dose Methodology:

The dose methodology used by Washington DOH in the PA process was the application of dose conversion factors to an all-pathways exposure scenario. This methodology is widely used in PAs and consists of multiplying the radionuclide concentration in air, water, or soil (that a receptor might be exposed to through any of the various pathways) by the dose conversion factor specific to that ingestion or inhalation process and radionuclide.

The calculation process and the dose factors used for the all-pathways exposure PA are described in Appendix II to Washington DOH's FEIS (2004). The exposure pathways include drinking water dose from groundwater and other groundwater related pathways (e.g., use of contaminated water for irrigation, animal consumption, and sweat lodge use for Native American scenarios), air dispersion pathways, and intruder pathways resulting from home excavation and drilling a well into the waste zone with contaminated drill cuttings being brought to the surface. The primary mechanism for transport of radionuclides from the US Ecology disposal facility to a human receptor is expected to be leaching to the groundwater and subsequent human consumption and use of well water for domestic or more traditional Native American uses. Gaseous transport of radon from the waste zone upwards through unsaturated soil and cover materials to the surface where a potential receptor could be exposed is also expected to be a main transport mechanism for radionuclides in the disposal facility.

ICRP 72 dose conversion factors were used to calculate doses to adults and children from internal exposures to radioactivity. Microshield uses ICRP 51 methodology in calculating effective dose equivalents for the external dose pathway. Concentrations of parents and progeny calculated by Microshield are also used as input for analysis using external dose conversion factors for an infinite plane source 15 cm in depth provided in Federal Guidance Report (FGR) No. 12 (Eckerman and Ryman, 1993).

Regulatory Guide 3.64 methodology was used to calculate radon fluxes through the waste zone and cover. Concentrations in indoor air were calculated based on assumptions regarding flux through cracked concrete foundations, the location of a receptor in the living space, and building ventilation rates. Concentrations in outdoor areas are based on radon flux, wind speed, and assumed mixing height with additional dispersion considered for downgradient (offsite) locations. After radon concentrations are calculated, assumptions regarding equilibration of radon with its daughters are made to estimate working level months (WLMs). A WLM is a commonly used term related to radon exposure and is defined as any combination of short-lived radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy (NCRP, 1998). The effective dose to an individual is then estimated by using an effective dose per unit exposure conversion factor of 830 mrem/WLM (Porstendorfer and Reineking, 1999). This value is based upon ICRP 66 (ICRP, 1994) lung dosimetry, and estimates of 'normal' indoor particle concentrations.

Washington DOH intended to have the dose calculations reported in its PA analysis for the US Ecology facility represent (i) the maximally exposed individual (MEI) for the rural resident scenarios, and (ii) the average exposure for the Native American scenarios. All of the calculations were performed using a single-point estimate of dose. The assumptions supporting

the single-point estimates were stated to be conservative and were intended to ensure that the dose projections are sufficiently protective of human health (Washington DOH, 2004).

2.2.11 NRC Evaluation—Washington DOH's Dose Methodology:

NRC staff evaluated Washington DOH's dose methodology and found it to be acceptable. The calculation approaches used were sound and appropriately implemented. Key exposure and radiation dosimetry uncertainties were addressed or evaluated. Variability in the population doses due to differences in behaviors, lifestyles, and potential use of resources at the larger Hanford site were appropriately studied and evaluated through the development of various exposure scenarios, critical groups and through uncertainty analysis as described in greater detail in Section 2.2.12. Use of ICRP 72 to calculate potential doses to children provides additional information regarding the potential variability of dose across the population. A great deal of information from the literature related to radiation dosimetry was brought to bear in Washington DOH's PA and is expected to have significantly improved the accuracy of deterministic dose estimates. Consideration of uncertainty in dosimetric parameters was also undertaken by Washington DOH with a thoughtful evaluation of potential sources of uncertainty and with development of associated parameter distributions. The probabilistic uncertainty analysis conducted by Washington DOH is expected to have improved the overall understanding of the impact of dosimetric uncertainties on PA model-predicted doses.

2.2.12 Washington DOH's Demonstration of Compliance with the Protection of the Public Performance Objective:

Washington DOH demonstrated compliance with the §61.41 performance objective listed in Section 2.2.1 (protection of the public) through development of exposure scenarios, and using the dose methodology discussed in Section 2.2.10. Exposure scenarios are discussed in Appendix II to the FEIS (Washington DOH, 2004) and include the following:

1. Offsite Rural Resident Scenario
2. Offsite Native American Scenario
3. Intruder Rural Resident Scenario (see discussion in Section 2.2.14 below)
4. Intruder Native American Scenario (see discussion in Section 2.2.14 below)
5. Intruder Native American Upland Hunter Scenario (see discussion in Section 2.2.14 below)
6. Native American Subsistence River Resident

The basis for the general population scenarios included environmental impact statements supporting the 10 CFR 61 rulemaking (U.S. NRC, 1981, 1982), as well as the Hanford Site Risk Assessment Manual (HSRAM) and the DOH Hanford Guidance for Radiological Cleanup (DOE, 1995; and DOH, 1997). Comparisons of the parameters defined in Washington DOH's analysis, the HSRAM manual, and the state of Washington Model Toxics Control Act (WAC 173-340) were made in Appendix II of the FEIS (Washington DOH, 2004). The Native American Subsistence scenario was modified from the Columbia River Comprehensive Impact Assessment document (DOE 1998) and the Tank Waste Remediation System FEIS (DOE 1996), following consultation with representatives of the Confederated Tribes of the Umatilla Indian Reservation, the Yakama Indian Nation, and the Nez Perce Tribe. Both the Native

American Upland Hunter and Columbia River Subsistence Resident scenarios were obtained from the CRCIA document.

After cessation of disposal operations, the facility begins a multi-year closure and institutional control period that lasts for 107 years. Thus, intruder analyses are not evaluated until 107 years (intruder scenarios are discussed in more detail in Section 2.2.14). Prior to the end of the institutional control period, however, releases of radioactivity from the disposal facility could occur which could lead to potential exposures via the groundwater or air pathways to receptors located at or beyond the facility boundary in downgradient or downwind locations. More likely, releases will take hundreds to thousands of years to migrate to offsite locations (off the US Ecology property) via the groundwater pathway. Radon releases could occur earlier, but most of the risk associated with these releases are from sealed sources that are not assumed to degrade until 500 years after closure and doses at offsite locations are expected to be low.

To evaluate potential compliance of various closure alternatives against the §61.41 (and associated WAC-246-250) performance objective, Washington DOH evaluated a number of exposure scenarios. These exposure scenarios include (i) rural resident, (ii) Native American and (ii) Columbia River user receptors. With respect to the rural resident, all of the receptor's time is spent on-residence. The receptor builds a house, drills a well, and raises crops and animals. Due to the limitations of the quantity produced and variety of fruits and vegetables, only a portion of the produce is grown on the receptor's land. Due to the use of the groundwater well, the individual is exposed to a number of pathways. The pathways analyzed for the rural resident scenario are (Kennedy and Strenge, 1992):

1. External exposure to radiation from contaminated soil while outdoors.
2. External exposure to radiation from contaminated soil while indoors.
3. Inhalation exposure to resuspended soil while outdoors.
4. Inhalation exposure to resuspended soil while indoors.
5. Inhalation exposure to resuspended surface sources of soil tracked indoors.
6. Inhalation exposure to gaseous radionuclides while indoors and outdoors.
7. Direct ingestion of soil.
8. Inadvertent ingestion of soil tracked indoors.
9. Ingestion of drinking water from a groundwater well (including while showering).
10. Ingestion of plant products grown in contaminated soil.
11. Ingestion of plant products irrigated with contaminated groundwater.
12. Ingestion of animal products grown onsite.

The Native American combines both traditional and contemporary activities. Traditional activities include hunting, fishing, gathering plants and materials, and use of a sweat lodge. Contemporary activities include aspects of irrigated farming—the use of a groundwater well for drinking water, showering, plant irrigation, and animal watering. The main exposure routes via the groundwater pathway are drinking water, consumption of irrigated vegetables and animal products, ingestion of irrigated soil, external exposure to soil contaminated with irrigation water, inhalation of resuspended soil, and inhalation of water vapors in the sweat lodge.

Use of a sweat lodge is unique to the Native American scenario. The sweat lodge is similar to a steam bath, where high temperatures are combined with a humid environment. The liquid contaminants are assumed to become airborne during the flashing of the water to steam on the

rocks of the sweat lodge. This assumption is risk-significant because inhalation leads to a greater risk compared to ingestion of the same quantity of the constituent. The occupancy time for the sweat lodge is assumed to be 1 hour/day with approximately one gallon (3.8 l) of contaminated groundwater used per hour in the sweat lodge. Children are known to use the sweat lodge, although less frequently and for shorter durations (only 10-15 minutes). Consumption of an additional one liter of water per day is also assumed to account for the water loss due to sweating in the sweat lodge.

The Columbia River user represents a potential Native American receptor living a traditional lifestyle near the Columbia River on the Hanford site. The individual spends time at the river shoreline, at river seeps and springs, as well as in upland areas away from the Columbia River. The individual drinks water from the seeps, bathes and swims in the river, and uses a sweat lodge supplied by seep water. The individual consumes plant and animal products from the river, from the springs, and from the upland areas. Some of the plant foods are irrigated with contaminated river water. Game and livestock, including organs, are included in dietary meat consumption. The individual is also assumed to gather and use materials for cultural purposes from the shoreline, from the springs, and from the upland areas. The concentrations in the seeps are assumed to be diluted 53% by river water (Guensch,G.R & Richmond, M.C., 2001). The groundwater concentrations in the seeps are conservatively assumed to be the same as the groundwater immediately down gradient from the site with no dispersion or decay assumed during transport from the facility boundary to the seeps.

The results of the PA calculations show that groundwater related pathways provide most of the dose to an offsite receptor with radon also providing a minor contribution to dose. Of all the alternatives analyzed, late construction of the geosynthetic/GCL cover alternative leads to the greatest dose. Resulting doses for this cover range from 0.36 to 1.30 mSv/yr (36 to 130 mrem/yr) for the rural resident and Native American adults, respectively. Thus, the peak individual and overall groundwater concentrations and resultant dose are driven largely by the 40 years of uncovered trenches and corresponding high infiltration rates.

The impact of operating the site until 2056 or until the entire site is filled (estimated to be 2215) appears to have little impact on the final dose estimates given the small inventory expected to be disposed of at the facility in the future. Additionally, the dose from radon due to future disposals is expected to be limited given the current practice of segregating waste in the disposal facility (placing higher-activity waste at the bottom of the trenches).

The US Ecology Proposed cover provides the lowest predicted offsite results at 0.18 mSv/yr (18 mrem/yr) to the Native American Adult. The lower overall peak dose for this cover is due to the greater infiltration rate over a longer period of time. The enhanced covers, in comparison, have a significantly lower infiltration rate while the covers remain intact, but result in a contaminant flux peak after cover failure at a higher value.

Differences in the dose and risk estimates when comparing the Native American results to the rural resident results, aside from the large contributions from the sweat lodge, can be attributed to a number of factors; namely:

1. Enhanced contribution as a result of an assumed increased consumption of fruits and vegetables, as well as a significantly greater assumed fraction grown locally (62.5% grown locally for the Native American, versus 30%-40% for the rural resident).

2. Increased consumption of water to account for the additional water loss while using the sweat lodge.

3. Slight differences in the amount of meats and milk consumed, as compared to the rural resident, and a greater assumed contaminant concentration for the organ meats.

Most of the differences between the rural resident and the Native American scenarios can be attributed to differences in habits and consumption patterns between the two. Several of the differences can simply be attributed to modeling assumptions (greater percentage of locally grown produce, and greater contaminant concentrations in organ meats) that may or may not reflect actual exposure conditions.

2.2.13 NRC Evaluation—Washington DOH's Demonstration of Compliance with the Protection of the Public Performance Objective:

The exposure scenarios developed by Washington DOH represent thoughtful consideration of potential land use scenarios and associated pathways of exposure for receptors who might participate in activities on or near the US Ecology disposal facility after closure. A number of sources of information were consulted to help develop exposure scenarios including DOE and Washington DOH risk assessment guidance. Therefore, NRC staff thinks that the exposure scenarios, pathways, and approaches used by Washington DOH for demonstrating compliance with the §61.41 performance objective related to protection of the general population from releases of radioactivity from the disposal facility are reasonable and adequate. Although outside the scope of this TER, the Confederated Tribes of the Yakama Nation and Confederated Bands and Tribes of the Umatilla provided updates to Native American exposure scenarios to NRC staff for review (Harris and Harper, 2004; Ridolfi, 2007). The scenarios include higher ingestion rates of soil, drinking water, dairy, beef and game, and fruit and vegetables than those used in Washington DOH's PA. Additional pathways of exposure not considered in Washington DOH's assessment include dermal exposure and the fish pathway. US Ecology and Washington DOH should consider the more recent Native American exposure scenario information in future PA updates.

2.2.14 Washington DOH's Demonstration of Compliance with the Performance Objective Related to Inadvertent Intrusion:

Washington DOH demonstrated compliance with the §61.42 performance objective listed in Section 2.2.1 (protection of individuals from inadvertent intrusion) by developing exposure scenarios for potential receptors participating in onsite activities at the US Ecology disposal facility after closure (e.g., exposure to radon emanating from the disposal trenches into the basement of a home or exposure to contaminated drill cuttings brought to the surface after drilling an onsite well). As discussed in Section 2.2.1, after cessation of disposal operations, the facility begins a multi-year closure including a two year active monitoring phase and a five year stabilization period. While the US Ecology facility is located in the DOE Hanford site and the "institutional control" period could last for several centuries, the PA analysis assumes that

institutional controls only last for 107 years following closure of the facility for disposal (two years of active monitoring, five years for the stabilization period and a 100 year institutional control period). During the institutional control period, lapses in land records that would result in inadvertent land purchase and squatting are not presumed to occur. Thus, intruder analyses are not evaluated until 107 years following closure of the disposal facility.

Given the presence of a cover and large depths to waste (greater than 20 ft {6m}), intrusion events such as construction of a building foundation directly into the waste are not considered.[18] Instead an intruder is assumed to drill a well atop the disposal facility which results in exposures to contaminated well water and drill cuttings that are brought to the surface. A 12-inch (30 cm) diameter well is assumed to be drilled to 360 feet (110 m) (50 feet (15 m) past the presumed groundwater table). Of the 360 feet (110 m) of material, 37 feet (11 meters) are assumed to be contaminated with a homogeneous mix of waste from the disposal facility. This contaminated material is uniformly spread over a 16,000 square foot area (1,500 square meters). The depth of the contamination is six inches (15 cm), as the material is assumed to be uniformly tilled. The 16,000 ft^2 (1,500 m^2) source approximates an infinite plane for external dose calculations. Intrusion into a single, discrete source is not evaluated in this analysis due to the low probability of the event, although the results could be significantly higher. The Native American intruder scenario uses the same exposure parameters as the offsite Native American scenario. The Native American intruder assumptions for access to the buried waste are identical to the intruder rural resident.

In order to accurately calculate the in-growth of the progeny (for the intruder) and perform further external exposure calculations, the computer code MICROSHIELD (Grove Engineering, 1998) was used. The MICROSHIELD code calculates the parent and progeny concentrations as well as an estimate of the effective dose equivalent, using ICRP 51 methodology (ICRP 51, 1987).

The external dose contribution analysis for both indoor and outdoor scenarios is performed in the following manner:

1. The concentration in the waste volume was estimated by taking the total source activity per radionuclide and dividing it by the total mass of waste and other fill in the active waste region. The estimate excludes the mass of soil between trenches at the depth of the waste.

2. The volume of waste (0.8 cubic meters) is then removed and uniformly spread over the top 15 centimeters of soil to an area of 16,000 ft^2 (1,500 m^2).

3. This surface concentration is entered into the MICROSHIELD code in the form of a perfect disk source, with the dose point (the individual) in the center. The soil assumed for the analysis is a Nevada Test Site (NTS) dry, sandy soil that was thought to be similar to the cover material that will be used at the disposal facility.

[18] Indirect radon doses due to construction of a residence atop the disposal facility are considered as radon gas can migrate through the soil column into a residence.

4. MICROSHIELD calculates the estimated contribution to dose, using the appropriate buildup and attenuation factors for the soil and air (Grove Engineering, 1988). As a check on results, the concentrations obtained from the output of the MICROSHIELD code are also used as the input for analysis using Federal Guidance Report (FGR) 12.

A whole body dose from external radiation was calculated and added to the effective dose calculated for ingestion and inhalation of contaminated material. The individual was assumed to occupy the 16,000 ft^2 (1,500 m^2) contaminated area 100 percent of the time. It is assumed that 60% of the rural residents' time is spent indoors and 40% of the time is spent outdoors. The Native American intruder is assumed to spend equal amounts of time indoors and outdoors. An indoor shielding factor of 0.33 is used to account for the shielding provided by the structure of the home, the reduction from an infinite plane source because the home is at the boundary of the contaminated area, and a further reduction to account for time spent indoors away from the walls.

Gaseous radionuclides are also expected to diffuse out of the disposal facility into the air where a potential receptor could be exposed through the inhalation pathway. Three radionuclides exist as gases and were assumed to contribute to the gas inhalation pathway—Rn-222, C-14, and H-3. Due to the long half-life of radium-226 (the parent of radon) and C-14, the offsite estimates for these two radionuclides can be applied to any time period during the institutional control period, due to the small amount of decay. On the other hand, H-3 decays considerably during the institutional control period and specific calculations are therefore performed for tritium to estimate the potential impact at the time of maximum exposure, the site closure date.

Ra-226, with a half-life of 1600 years, decays via alpha emission to Rn-222 with a half-life of 3.8 days. A fraction of the radium 226 that decays to Rn-222 escapes the confines of the soil column and migrates toward the surface. This diffuse radon can accumulate in houses through cracks in the floor, around floor penetrations (such as drainpipes), and through the concrete floor. A portion of the radon in the air is respirated and retained in the lung where the radon daughters (Po-218, Bi-214, Pb-214, and Po-214) deliver a dose that is approximately 100 times greater than the dose of Rn-222.

For the proposed alternatives, cover depth and the addition of a clay layer are controllable and were stated to significantly influence the estimated radon flux from the soil. Gravel is assumed to have no impact on radon attenuation but clay is stated to have a tremendous impact on lowering radon emanation. A clay barrier is estimated to reduce the predicted emanation rate by a factor of 2.5. Enhanced barriers such as asphalt or a geomembrane are assumed to be essentially impermeable while intact (Washington DOH, 2004). Radon is predominately a contributor to dose to an on-site (intruder) while indoors, as the gas has a greater opportunity to accumulate in a home without the benefit of the free exchange of air. As a result, the indoor radon calculations are the focus of the PA and of this review.

Given the continued management of the Central Plateau, the Native American Upland Hunter was considered a more realistic exposure scenario. This approach is also consistent with the approach for loss of institutional controls at MTCA sites. This scenario could result in exposures via the ingestion of meat (game), the ingestion of plants and roots, inhalation of radon, C-14 and H-3, and groundwater ingestion. Although the hunter is assumed to bring drinking water to the site that is contaminated from site operations, the hunter is not assumed to bring sufficient water

for use in a sweat lodge while hunting. No direct contact with the waste or contaminated groundwater by a hunter is assumed and the direct ingestion of contaminated soil and external exposure were eliminated as potential pathways for this scenario. The meat and plant ingestion pathways are only considered in light of their uptake of C-14and H-3, as a result of gaseous diffusion through the soil cover.

Parameters for the Native American scenarios were derived from Harris and Harper (1997) including ingestion rates of native foods based on surveys. The EPA vegetable ingestion rate was ratioed into “root” and “leafy” by the proportions referenced from Hunn (1990). Ingestion of animal organs and wild bird meat was accounted for by increasing the total meat and poultry intake rate. Animal organs were assumed to have contaminant concentrations 10 times the concentration of other tissues, and the organ intake rate was assumed to be 10 percent of the intake rate of other animal tissue.

Doses associated with the intruder analysis are generally at or less than the 100 mrem/yr (1 mSv/yr) standard used by Washington DOH to evaluate compliance with §61.42 or WAC-246-250-180 and much less than 500 mrem/yr (5 mSv/yr) used in NRC technical analyses for all engineered cover alternatives (e.g., US Ecology and enhanced cover designs). The one exception is the doses associated with late construction of the geosynthetic/GCL cover with doses significantly above the 100 mrem/yr (1 mSv/yr) standard but still below the 500 mrem/yr (5 mSv/yr) standard for the Native American intruder at 170 mrem/yr (1.7 mSv/yr). The significantly larger dose for this scenario is apparently due to increased infiltration of constituents such as H-3, U and Pu isotopes within the 0 to 500 year timeframe that contribute to sweat lodge and drinking water doses.

Most (around sixty percent) of the dose for the intruder analyses is stated to come from radon contributions for engineered cover alternatives such as the US Ecology proposed cover and the enhanced cover designs. The differences between the engineered designs with respect to radon emanation are not significant and qualitative comparisons were noted in the text related to differences such as clay thickness. Obvious differences in doses between robust engineered and site soils covers were noted. For example, the site soils cover doses from radon were significantly greater than the predicted doses for the enhanced designs (total dose around 380 mrem/yr (3.8 mSv/yr) for site soils compared to around 100 mrem/yr (1 mSv/yr) or less for engineered covers).

2.2.15 NRC Evaluation—Washington DOH’s Demonstration of Compliance with the Performance Objective Related to Inadvertent Intrusion:

With respect to intruder analyses, Washington DOH considered a range of exposure scenarios and critical groups appropriate for an intruder analysis including more realistic and less likely but plausible exposure scenarios. Generally, the approaches used and implementation of these approaches appears sound.

Given its risk significance and due to the complex nature of the analysis that was conducted to calculate radon flux through the soil column, the intruder analysis evaluation focuses on uncertainties with respect to radon transport modeling. For example, it is not clear how waste form and cover degradation over time would affect dose calculations reported in the FEIS. The approach used in the FEIS considered the change in porosity of the clay layers in the enhanced

barrier designs. Diffusion of radon through large cracks that may be created in a dessicated or otherwise cracked resistive layer, such as clay or asphalt material, is expected to differ fundamentally from diffusion through an in-tact porous material where increases in porosity are simply made to account for enhanced diffusion. If relied on for performance in the final design, the potential uncertainty in the risk estimates due to the manner in which degradation is assumed to impact radon flux through a resistive barrier such as clay or asphalt should be considered. Consideration should also be given to how volumetric changes in the waste zone due to waste degradation affect radon flux calculations.

It is not clear how degradation of the radium sealed source itself would affect risk estimates. Sealed radium sources are known to contain pin-hole or larger breaches in containment. Although the radium sealed sources are assumed to be encased in metal and concrete, concrete is subject to cracking and may not remain impervious to fluid flow for 500 years as assumed in the analysis. Concrete degradation will facilitate corrosion by allowing the ingress of deleterious species such as chloride and oxygen or due to the breakdown of the passive oxide film on the steel surface in contact with concrete through carbonation, which lowers the pH and allows corrosion to occur. Corrosion of the metal casing and damage to the sealed source itself due to structural collapse of stabilizing materials or other factors may lead to earlier or higher release rates than assumed in the FEIS analysis. Depending on the condition of the source at the time of disposal, the quality and condition of containment barriers such as concrete and steel, the acceptance criteria in effect at the time of disposal, and environmental conditions in the disposal trench, failure rates of stabilized radium sealed sources are expected to be variable over the disposal facility with perhaps earlier failures and higher flux rates associated with sources disposed of in the early disposal trenches. The implications of assuming shorter lifetimes for radium sealed sources include less decay and potentially higher flux rates out of the waste zone for degraded waste forms.

Important parameters affecting radon flux, such as moisture saturations, diffusion coefficients, and porosity, were not varied in the uncertainty analysis and base case values may not be fully supported. For example, moisture saturations are variable based on cover design, material properties, and changes in infiltration over time due to degradation, or seasonal, or climatic fluctuations. Values selected in the FEIS analysis may not be appropriate or conservative for all cover designs. Changes in porosity or diffusion rates in the waste zone as a result of degradation processes were not considered, as discussed above.

More recent analyses were conducted to support the ninety-percent design for an evaportranspiration final cover (Daniel B. Stephens & Associates, 2007). The modeling approach used in the ninety-percent design was significantly more conservative than the FEIS analysis; the assumed saturation fractions were lower (increases radon flux), higher concentrations of Ra-226 at shallower depths were assumed, no clay layer was assumed to be present, and the entire Ra-226 inventory was assumed to be available for transport at time zero (or 0 years after closure) (i.e., assumed discrete radium sealed sources were degraded and available for transport at the time of closure). The results of this more conservative analysis showed that at the minimum assumed thickness of 5 m, the results were higher than the FEIS analysis and for the average assumed thickness of 6.8 m the results were lower than the FEIS analysis. Basically, a significantly thicker cover is needed for the ninety-percent design cover to perform at the same or better level as the FEIS modeled cover, which was assumed to be 3.4 m thick in the FEIS. As no credit is taken for a clay layer that is potentially more prone to failure

and no performance of the stabilized radium sealed source is taken, these potential technical issues are addressed by the more recent calculations. Additionally, more conservative values for moisture content were assumed in the updated analysis.

For both sets of calculations, Regulatory Guide 3.64, which is traditionally used for uranium mill tailings sites, was used to calculate radon flux from the disposal facility. It is not clear that the default parameter values, such as radon emanation coefficient used in calculations of flux through uranium mill tailings are adequate for the purposes of modeling flux primarily from discrete point sources, such as radium sealed sources. The waste forms differ considerably and emanation from degraded sealed sources may be significantly lower or higher depending on the integrity of the radium sealed source and stabilizing materials. No basis was provided for the emanation coefficient assumed in the analysis for sealed sources or how it might be variable within the disposal facility or over time. Ho (2008) developed a one-dimensional advection, diffusion model that simulates aqueous and gas phase (diffusion only) transport of radon in landfills with various radium sources. Because little information was available regarding the emanation rate of Rn-222 from anthropogenic sources, such as sealed sources of Ra-226, a distribution for the emanation coefficient (or factor) with a minimum value of 1E-06 to a maximum of 1 (representing no containment) was used in the probabilistic analysis. Results showed the strong correlation of this parameter on radon flux and the ability of the facility to meet standards. The emanation factor was found to be the most significant variable influencing the variability in the simulated radon flux. The waste volume, cover thickness, moisture content, and porosity were also shown to be statistically correlated to the simulated radon surface flux, but to a much lower degree (Ho, 2008). While credit was taken for infiltration, a transport mechanism that competes with upward diffusion of Rn-222, this parameter did not significantly influence the results in the semi-arid climate being simulated. While the Ho (2008) analysis was for a landfill, and stabilization materials may slow the release of radon from the US Ecology disposal facility, transient effects including changes to emanation coefficients over time due to container degradation should be considered.

NRC staff recommends that the key parameters in the diffusion calculations be identified and that the uncertainty in these parameters be reduced or managed with conservative assumptions. Variability in material properties such as thickness, moisture content, and porosity of cover layers and the waste zone should be considered in space and time. Consideration of the impact of degradation of radium sealed sources over time on emanation coefficients or rates should also be considered.

To mitigate this risk and as final designs are developed, NRC staff recommends that the key barriers and barrier characteristics most important to performance with respect to radon emanation (e.g., material types, thickness, and emanation) and with respect to infiltration (e.g., porosity and other material properties of storage layers) be identified. Support should be provided for performance assumptions commensurate with the risk significance of those assumptions.

2.2.16 Protection of Individuals During Operations:

This section describes potential disposal facility compliance with the 10 CFR 61.43 performance objective related to protection of individuals during operations. Operational risks include common occupational hazards, which are regulated by Washington Industrial Safety and Health Act standards, as well as potential exposure to radiological materials. Radiological dose limits associated with the US Ecology are subjected to both the NRC dose regulations discussed in 10 CFR Part 20 and those instituted by the State of Washington. NRC regulations in 10 CFR Part 20 dictate that occupational dose limits for workers are not to exceed 5,000 mrem/yr (50 mSv/yr) while members of the public are limited to 100 mrem/yr (1 mSv/yr). According to WAC Chapter 246-221 the State of Washington limits occupational doses for workers 5,000 mrem/yr (50 mSv/yr) while the members of the public are permitted a maximum of 500 mrem/yr (5 mSv/yr) from effluents and external radiation. The US Ecology license establishes a more restrictive limit of 400 mrem/yr (4 mSv/yr) to the public as part of its operational requirements. However, the use of a 25% occupancy factor when calculating doses decreases the public dose limit to 100 mrem/yr (1 mSv/yr). In addition, WAC Chapter 246-250 sets a limit of 25 mrem/yr (0.25 mSv/yr) for doses to the public from effluents migrating offsite.

Initially workers disposing of waste were likely to receive most of their occupational dose when offloading waste packages from trucks. Little occupational dose was attributed to the actual disposal process as the waste was quickly and randomly placed into the trenches. Current disposal practices which include additional time and effort to dispose of waste packages in an orderly pattern may lead to higher doses to workers. A review of annual As Low as Reasonably Achievable (ALARA) reports, however, show that annual worker doses remain well below occupational limits.

US Ecology currently maintains a radiation monitoring program for workers as well as an environmental monitoring program to evaluate potential offsite doses to the public. Data from these programs are collected and analyzed to determine worker and public doses on an annual basis. This information is compiled in the annual environmental monitoring report and ALARA report. Additionally, US Ecology maintains a formal training program, approved by Washington DOH that includes classroom study, on-the-job training, and testing requirements for radiological workers, management, and unescorted visitors (US Ecology, 2009).

2.2.17 NRC Evaluation—Protection of Individuals During Operations:

Regulations in 10 CFR 61.43, “Protection of individuals during operations,” dictate that operations must be conducted in compliance with the radiation protection standards discussed in 10 CFR Part 20 and that every reasonable effort shall be made to ensure exposures are as low as reasonably achievable. WAC regulations must also be considered when evaluating the doses to workers and the public from operational activities. The NRC staff review found that US Ecology follows current WAC and NRC regulations and takes the necessary measures to protect workers and the public during day-to-day disposal activities.

A review of recent annual ALARA reports confirms that occupational doses received from workers were well below regulatory limits (US Ecology, 2008; US Ecology, 2002). The 2008 annual environmental monitoring report further confirms that offsite doses received by members

of the public are also maintained below regulatory limits (Haight, 2009). NRC staff assumes, based on these measured doses and proximity of current disposal activities relative to trenches 1-6, that there is currently no impact from the radiological waste contained in trenches 1-6 to the occupational doses of current workers.

2.2.18 Site Stability:

This section focuses on reviewing factors that could affect the stability of the proposed disposal site, including the potential effects of erosion, flooding, seismicity, and other disruptive processes. This section also addresses stability of the waste and engineered features of a disposal facility. The performance objectives for disposal site stability after closure are provided in §61.44, which states that the disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure.

The long-term performance of the disposal site depends on the stability of the natural environment of the site, the disposal facility design, and the physical stability of waste disposed of at the facility. Disruptive events that are part of the natural environment have the potential to significantly degrade waste isolation by directly or indirectly affecting the engineered barriers or the waste form. In general, disposal sites should not be susceptible to erosion, flooding, seismicity, or other disruptive events to such a degree or frequency that waste isolation is compromised. In addition to natural site instabilities, waste and disposal facilities may also be subject to instability because of waste characteristics (e.g., differential settling caused by voids in the waste) or facility design (e.g., long-term physical instability of covers). The relative importance of these processes may vary from site to site.

<u>Subsidence and Differential Settlement.</u> Subsidence could have the following effects on a future cover at the US Ecology Site: small depressions forming on the cover; differential settlement causing an uneven cover surface; stress cracks forming on the cover surface; and open voids in the cover. Attachment L of the Closure Report (US Ecology, 1996) applied the work done by Sowers (1973) to the US Ecology Site.

Sowers (1973) studied the behavior of municipal landfills under loading and determined that consolidation of the waste materials can be attributed to four mechanisms: mechanical consolidation or void reduction by material crushing or reorientation; biochemical decomposition, including decay and fermentation; physiochemical changes, including corrosion, oxidation and combustion; and shifting of fine materials into large voids. Sowers found that the settlement of a municipal landfill occurred in two phases, similar to those found in the settlement of soils. The first or primary phase, occurs simultaneously with the load placement, and results from the adjustment of the waste materials to changed stresses. Sowers found this settlement phase was completed soon after the load was placed. After a period of primary consolidation, the period of secondary consolidation of the waste begins. This consolidation results from the effects of the first three mechanisms listed above. Sowers found that both phases of consolidation could be described by the equations that describe the respective phases in consolidation of soils. For waste consolidation, the settlement parameters are functions of the waste characteristics and the conditions within the waste trench that affect the rate of waste decomposition.

The following two paragraphs are a summary of the waste characteristics of trenches one through six at the US Ecology Site: trenches one through four contain metal drums, metal boxes, fiberboard drums, wooden boxes, and cardboard boxes. Trench five contains drums, metal boxes, and wooden boxes, but no cardboard boxes, as cardboard containers were not accepted after completion of trench five. Trench six and the newer trenches primarily contain metal drums, metal boxes, and metal liners.

Trenches one through four were filled by hand stacking the wastes and by using a crane to place the wastes. The areas between the wastes were backfilled by bulldozing native sandy soil over the working face. Although the wastes were placed by hand and by crane, they are considered to be randomly placed. Wastes were placed in trench five by crane and were stacked two boxes high and two boxes deep. Wastes were placed in trench six by crane and were stacked two to three boxes high and two to three boxes deep. The areas between the wastes in trenches five and six were backfilled by bulldozing native sandy soil into them.

Subsidence caused by waste decay is semi-quantitative because of the variability of factors affecting the decay rate. The corrosion rate is a function of the drum material, the drum surface protection (paint), soil temperature, soil moisture content, soil pH, soil oxygen levels, drum thickness, and soil electrical resistivity. The biodegradation rate is a function of the soil and waste temperature and moisture content, quantity of organic material, soil pH, waste type, and depth. NRC's NUREG/CR-2101 (NRC, 1981) determined that the biodegradation settlement in trenches at the Sheffield LLW Site in Illinois will probably be negligible. Because conditions are less favorable for decay at the Richland site, biodegradation in the Richland trenches will probably be negligible. Should it occur, settlement caused by biodegradation would be long-term and gradual.

Sowers developed equations for the primary and secondary consolidation of landfills based on field studies of long-term consolidation of these landfills. The Closure Report presented the results of similar calculations for future consolidation and subsidence. Parameter values were adjusted to reflect the waste and soil characteristics of the US Ecology Site. More conservative values were used for the older trenches than for the newer trenches. The estimated total subsidence was calculated at approximately three and one half feet over a 50-year period, and it was concluded that this amount of subsidence was not enough to breach the cover. Further calculations of future subsidence by differential settlement caused by earthquakes, based on work done by Newmark and Rosenblueth (1971), showed minimal to no trench settlement due to the compacted nature of backfill used at the US Ecology Site.

Analyses of the trench foundation soils showed that high-relative density of the foundation soils and the great depth to groundwater provide a foundation capable of supporting heavy loads and eliminate the possibility of liquefaction. Because of their density and dry state, any settlement of the foundation soils that may occur would result from immediate deformation. This settlement would occur almost concurrently with the placement of the waste load, and would not influence the long-term performance of the trench cover since it is placed much later. Because of the character of the foundation soils, significant settlement of the foundation is not anticipated.

Erosion and Mass Wasting. Attachment M of the Closure Report presents an analysis of the erosional stability of the engineered cover proposed for the US Ecology Site. Analyses were documented in the Attachment M of the Closure Plan before NRC's NUREG-1623 was brought out in 2002, but does comport with NRC's 1990 Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites (US Ecology, 1996). The analysis in Attachment M examined the design criteria and erosion parameters of soil properties, geometry, vegetation, and criteria to design for storms.

Vegetation is an important property influencing the ability of an earthen structure to resist erosion. Vegetation binds soil particles together, which effectively increases the size of the soil particles. Vegetation dissipates energy in water flowing over or through it, thus decreasing the erosive potential of the flowing water. Vegetation also prevents the surface of the soil from being struck by raindrops, and so prevents soil particles from being dislodged and moved by the rain itself.

The probability that the vegetation cover will deteriorate because of future drought or disease is low because of the hardiness and diversity of plants that will be established on the cover. Studies show that vegetation at the Hanford Site is strong enough to have a mitigating effect upon erosion of the facility cover and other reclaimed land. Thus, vegetation will provide significant protection to the soil cover. This protection was considered in the performance evaluation of the cover design.

The Probable Maximum Precipitation (PMP) event is the design rainfall used in the analysis to calculate potential erosion. The PMP used represents an upper envelope to the maximum precipitation that can occur in the site area. This design storm was developed according to the procedures in the Hydrometeorological Report Number 57. An intensity-duration relation relating average rainfall rate to duration for the design storm is derived. A runoff model is selected for the ration formula. Conservative parameter values for rational formula were chosen, and the Soil Conservation Service curve number method was selected to calculate time of concentration.

The disposal unit cover is elevated above the surrounding ground surface to prevent the flow of water onto the disposal cover. The cover surface slopes at a minimum one percent to encourage surface water runoff and limit the erosive force of incident precipitation.

The limiting flow for the soil with vegetation was calculated at 1.85 $ft^3/s/ft$ and with gravel mulch and vegetation at 2.07 $ft^3/s/ft$. The cover is resistant to erosion since the limiting flow is three times larger than the calculated flow expected from the cover design.

The expected erosion caused by flowing water was examined using the Universal Soil Loss Equation. The average soil loss is calculated as the product of two quantitative factors (slope length and slope steepness) and four qualitative factors (soil erodibility, rainfall erosivity, cover management factor, and supporting practice factor). The calculated average soil thickness loss for the design life of 1000 years was less than 2 inches.

The effects of wind erosion were examined using the Wind Erosion Equation. The average soil loss is calculated as a function of five factors (climate, soil erodibility, field length, surface roughness, and vegetative cover). The calculated average soil thickness loss for the design life of 1000 years was approximately 11 inches.

Test data provide evidence supporting the use of pea-gravel admixtures to protect the capillary barrier layer. Although the gravel may tend to become buried by plants and surface deposits during normal climatic periods, periods of dry stress may lead to deflationary conditions and cause the gravel to appear on the surface and protect the capillary barrier layer from erosion.

Seismic Activities. Seismicity in the Columbia Plateau is attributed to a north-south compression force regime that has resulted in thrust or reverse dip-slip faulting. Seismic data and observations since 1872 show that most large earthquakes occur farther than 124 miles (200 km) from the Pasco Basin. The 1996 National Earthquake Hazard Reduction Maps concluded that any area west of the crest of the Rocky Mountains is capable of experiencing a 7.0 magnitude earthquake. However, seismic events in the central Columbia Plateau, including the Pasco Basin, have generally been short in duration and less than 3.5 on the Richter Scale.

The Hanford Site is located in an area of moderate seismic activity. The poor cohesive quality of the sand deposits in and around the site would make it unlikely that a fissure formed by seismic activity, however extreme, would remain open. The most serious potential seismic impact associated with the site would be the possibility that an earthquake could accelerate waste subsidence through mechanical agitation. This subsidence could lead to a rupture of containers or damage to the cover. However, earthquakes intense enough to cause subsidence have not been recorded at the US Ecology Site.

Conservative studies performed to support the use of nuclear reactors on the Hanford Site estimated the maximum credible earthquake for the next fifty years. The estimated largest earthquake associated with a known geologic structure would be a Richter magnitude 6.7 event located at the northwestern end of the Rattlesnake-Wallula alignment of deformation. The maximum earthquake not associated with a fault structure is estimated to be of Richter magnitude 5.75. Other seismic–related activity such as fault-rupture, reservoir induced seismicity, subsidence and liquefaction are either of low probability or not likely to adversely affect waste disposal. The high relative density of the Hanford Formation sands combined with the large depth to groundwater provides suitable soils for supporting heavy foundation loads and eliminates the possibility of liquefaction.

Igneous Activities. There are two volcanoes in proximity to the US Ecology Site. Mount Rainier is located about 125 miles (201 km) from the Richland site. At 14,410 feet (4380 m), it is the highest peak in the Cascade Range. This dormant volcano's size and mass of glaciers pose a variety of geologic hazards, both during dormant periods and inevitable future eruptions. Mount St. Helens is 130 miles (209 km) from the US Ecology Site. Although this volcano is much smaller than Mount Rainer, it is active and as recently as 1980 had a major eruption. Other than the devastation in the blast zone, the primary impact from the 1980 eruption was from ashfall. Lesser impacts were felt within 50 miles (80 km) of the US Ecology Site. If Mount Rainier were to erupt, the only hazard predicted to affect the US Ecology Site is volcanic ash. Ashfall on the US Ecology Site would have a temporary impact on site operations.

Flooding. Potential flooding in the vicinity of the US Ecology Site have been analyzed both on a local and regional basis. The Cold Creek is a small seasonal stream that flows through the Hanford Site. It is the only potential offsite source of local flooding in the vicinity of the US Ecology Site and the facility would not be impacted by a maximum peak discharge on Cold Creek. The Yakima River follows a small part of the southern boundary of the Hanford Site. The closest portion of the Yakima River is approximately 13 miles (21 km) southeast of the site. Based on historic flood flows, a flood on the Yakima River is not expected to impact the US Ecology Site. The only major potential source of local flooding in the vicinity of the facility from an offsite source is the Cold Creek watershed. Results of a hydraulic analysis utilizing PMP and Probable Maximum Flood peak discharge indicate the US Ecology Site would not be affected by this event.

Three potential scenarios for a catastrophic flood on the Columbia River were reviewed. They are a maximum precipitation event, a breach of a nearby dam, or a landslide blockage of the Columbia River. The probable maximum flood for the Columbia River below Priest Rapids Dam was calculated to be 1,400,000 cubic feet per second (XX m3/s). A flood of this magnitude would inundate much of the Hanford Site adjacent to the river, and large areas of the City of Richland. The central plateau, including the US Ecology Site, would remain unaffected by such a catastrophic flood. A U.S. Army Corps of Engineers study concluded that a hypothetical 50% breach of Grand Coulee Dam resulted in a calculated flow of 8,000,000 cubic feet per second (XX m3/s). The areas inundated by such a flood would be more extensive than the probable maximum flood event described above. The US Ecology Site would not be affected by this catastrophic flood event.

Water Table Fluctuation. In general, waste should remain isolated from water contact either due to infiltrating water from above or fluctuating groundwater levels from below. The water table at the US Ecology Site is currently about 320 feet (97 m) below ground surface and does not impact the trench or trench contents.

Severe Storms. No analysis was found on the effect of potential tornadoes and hurricanes on site stability. However, hurricanes do not normally occur in the regions and aspects of tornadoes that could cause destabilization were analyzed in the context of water and wind erosion potential. Analyses included the PMP event of a single design storm and the episodic movement by wind particles on the disposal unit cover. The later calculated the lift on critical particles using aerodynamic formulae and a design wind speed of 139 ft/s (xx m/s). These calculations were used to size the gravel mulch to be placed on the US Ecology cover to resist erosion during high winds.

Fires. Range fires are not uncommon in the arid shrub-steppe environment. A range fire burned approximately 200,000 acres (xx m2)on Hanford in August of 1984. In June 2000, the 24 Command Fire burned 163,884 acres (xx m2). One hundred percent of the fire area was classified as low burn severity or unburned. This result was regarded as typical of a range fire that spreads rapidly through light fuels. Range fires typically burn hot on the surface but move fast enough so that the subsoil is unaffected. A range fire of this magnitude could easily destroy a trench cover's vegetation, but it is unlikely to damage the buried waste or the root systems below. The vegetation on the cover is unlikely to deteriorate because of future drought or disease because of the hardiness and diversity of plants that will be established on the cover, so that healthy root systems or surviving seeds would revegetate a cover after a fire. Studies of

fires at the Hanford Prototype Barrier have demonstrated this to be the case while other studies have shown that vegetation in the Hanford Site is strong enough to have a mitigating effect upon erosion of the facility cover and other reclaimed land. Erosion and gullying would be a main concern if fire denuded a cover for a considerable length of time. Thus, vegetation will provide significant protection to the soil cover and was considered in the performance evaluation of the cover design.

Human Activity. Of the 31 airplane crashes in the Tri-Cities area, four crashes involved unsuccessful crop dusting encounters with "terrain conditions" and/or man-made objects, and three involved engine problems during flight. None of the three Tri-Cities accidents with engine problems were associated with the US Ecology Site. There are no airports within ten miles of the US Ecology Site, nor are there agricultural fields or "terrain conditions" in the vicinity. Based on this information, an airplane crash in the vicinity of the US Ecology Site would most likely be initiated by engine problems. Under such circumstances, the pilot would be seeking a flat, smooth area for a landing strip. Open disposal trenches would be avoided in favor of the smooth surface of one of the completed trenches. Landing gear would likely sink into the soft sand or other cover material, and the aircraft would likely "nose over" or flip as has been documented on other engine failure crashes. Damage to the US Ecology Site from a crash onto the site cover would likely be limited to surface damage of the cover. A resulting fire might impact cover vegetation on closed trenches.

Humans also can cause subsidence through their activities. Traffic over the trenches at US Ecology's Sheffield facility was identified as a probable cause of trench subsidence by primary consolidation (NRC, 1981). Traffic can compact soils beneath the vehicle tires leaving ruts to act as collection areas for precipitation and runoff.

Biointrusion. Biointrusion is the penetration of deep-rooted plants or burrowing animals into the waste zone. Plant roots in the waste could mobilize waste constituents and move the contaminants to the ground surface. At the surface, the waste constituents could be dispersed. Animals burrowing directly into the waste zone could contact the waste and transport waste constituents to the earth's surface as soil castings where the constituents could be dispersed by physical and biological agents. The animals' burrows might increase infiltration by creating preferential migration pathways through the soil cover.

The effectiveness of coarse-grained barriers confronted with plant root growth was demonstrated at the Field Lysimeter Test Facility, located east of the 200-West Area. The control of plant-root intrusion is accomplished by the capillary break layer. This layer discourages plant-root intrusion by limiting water available to plants.

The typical animal burrow in the Hanford Site area has been shown to be no deeper than five ft (1.5 m). Favorable biological conditions are found for the animals within the top most part of the ground surface. Because there is no need or incentive for these animals to burrow deeper and because the layers below the capillary barrier layer are not favorable (e.g., dry, sterile, composed of rocks) the animals will not expend the additional energy required to dig deeper into the cover.

Extensive studies were performed on the effects of smaller mammals and large mammals, e.g., badgers and coyotes, on the materials of the cover. The presence of small-mammal burrows did not appear to have a significant effect on the deep percolation of water through the barrier. Large mammals did appear to cause increased deep penetration of water in the fine-soil layer, but it was observed that much of this water was removed by increased vegetation growth and ET during the following growing season.

2.2.19 NRC Evaluation—Site Stability:

Subsidence and Differential Settlement. Following a review of the Closure Report and supporting documents, the assumptions, analyses, and calculations to estimate future subsidence and differential settlement at the US Ecology Site were considered to be adequate.

Attachment 1 from the Attachment L of the Closure Report contained Subsidence Reports from the US Ecology Site. Very few of these records pertained to trenches one through six. However, the field work done by Sowers (1973) was carried out at municipal landfills. Although the parameters were adjusted the characteristics of the site, the waste itself and the processes involving its degradation may differ from that of a LLW disposal site. Municipal waste will biodegrade differently than radioactive waste and its packaging in a semi-arid environment. The rate of subsidence may be slow and actual subsidence occur tens to hundreds of years later as waste packaging material such as metal drums degrade. However, since degradation will be slow, the subsidence rate should also be slow so that no abrupt settlement will damage the engineered barrier.

An additional area of study concerns the type of cover to be built. The Closure Report concluded that a total subsidence of three and one half feet will not be enough to breach the cover planned. However, the planned cover analyzed at the time the Closure Report was developed was the so-called US Ecology cover. Critical components were to be naturally-occurring materials. Furthermore, Section 1.4 stated that, “The proper functioning of these components should not depend upon man-made materials with uncertain service lifetimes.” The preferred cover alternative described in the Final Environmental Impact Statement from 2004 (i.e., the enhanced geosynthetic cover), does use man-made materials such as geosynthetic clay liners and geotextile filters. It would need to be shown that the calculated subsidence would not be enough to breach the enhanced geosynthetic cover.

Erosion and Mass Wasting. Following a review of the Closure Report and supporting documents, the assumptions, analyses, and calculations to estimate erosion and mass wasting at the US Ecology Site were considered to be adequate.

Current cover design will maintain the minimum thickness set in 10 CFR 61.52 of 5 meters between waste and future ground level after calculated subsidence and erosion thickness are subtracted. Similar analyses should also be performed for the final cover design chosen so as to maintain the cover thickness of 5 m into the long-term. Future analyses and conclusions should also comport with the NRC’s newer guideline on designing for erosion protection, i.e., NUREG-1623.

Seismic Activities. Following a review of the Closure Report and supporting documents, the assumptions, analyses, and calculations related to site stability and seismic activities at the US Ecology Site were considered to be adequate.

Igneous Activities. Following a review of the Closure Report and supporting documents, the assumptions, analyses, and calculations related to site stability and igneous activities at the US Ecology Site were considered to be adequate.

Flooding. Following a review of the Closure Report and supporting documents, the assumptions, analyses, and calculations related to site stability and flooding at the US Ecology Site were considered to be adequate. The elevation of the US Ecology Site is generally too high to be effected by the regional or local flooding.

Water Table Fluctuation. Following a review of the Closure Report and supporting documents, the assumptions, analyses, and calculations related to site stability and fluctuating groundwater levels at the US Ecology Site were considered to be adequate. No projected climate change could bring the current water table level close to the waste of the US Ecology Site.

Severe Storms. Following a review of the Closure Report and supporting documents, analyses related to site stability and severe storms at the US Ecology Site were considered to be adequate.

Fires. Following a review of the Closure Report and supporting documents, analyses related to site stability and fires at the US Ecology Site were considered to be adequate. However, if the design of the top of the cover changes, it will have to be demonstrated that future plants establishing themselves on the cover will have the necessary hardiness and diversity. For example, if a future cover design intended to use non-native flora on the cover surface, it would need to be shown that that plants used to vegetate the cover had the necessary hardiness and adaptability to ensure a relative quick recovery after a fire.

Human Activity. Following a review of the Closure Report and supporting documents, analyses related to site stability and human activity at the US Ecology Site were considered to be adequate.

Biointrusion. Following a review of the Closure Report and supporting documents, analyses related to site stability and biointrusion at the US Ecology Site were considered to be adequate.

However, since larger mammals did appear to cause increased deep penetration of water in the fine-soil layer, it should be determined if large mammal typically build their burrows or dens on small elevational high points similar to a surface cover. If so, then it should be determined what effect ponding in such burrows during and after intense rainfall events would have.

2.3 NRC Review and Conclusions:

Based on extensive review of US Ecology and Washington DOH disposal facility documentation and its own independent evaluation, NRC staff concludes that performance objectives in 10 CFR Part 61, Subpart C (and WAC-246-250) can be met for special nuclear material disposals authorized by the NRC between 1965 and 1980 provided certain key modeling assumptions are met. Key assumptions include the following:

1. The inventory of key radionuclides such as isotopes of U is similar to or less than assumed in the PA analyses.

2. Lack of explicit consideration of certain early (pre-1980) waste disposal practices (e.g., less stringent controls on waste segregation, waste form stability, and other controls based on waste classification system) does not lead to a significant underestimation of risk due to a greater potential for increased infiltration, leaching, and waste concentrations.

3. Mobility of key radionuclides such as U isotopes is not significantly under-estimated (e.g., Kds, solubility, and mobile release fractions are appropriate).

4. The as-emplaced engineered cover will perform as well as assumed in PA analyses with respect to infiltration and radon mitigation.

However, certain uncertainties in the performance of the disposal facility remain such that the 10 CFR 61.41 and 61.42 performance objectives related to protection of the general population from releases of radioactivity and protection of individuals from inadvertent intrusion, respectively, could be slightly exceeded under certain conditions. These conditions include (i) higher inventories and/or significantly more concentrated areas of SNM within the disposal facility, (ii) higher mobility waste, or (iii) higher infiltration and radon flux rates than assumed in the FEIS PA analysis (Washington DOH, 2004).

Table 2-2.6 below lists major sources of uncertainty in dose estimates for early disposals and attempts to qualitatively or semi-quantitatively evaluate the potential impact of these uncertainties on dose estimates to provide context for the potential issues raised in the preceding text. In order to provide a more complete picture regarding disposal facility risk, the table includes constituents outside the scope of the TAR request (e.g., U-238 derived primarily from depleted uranium which is expected to drive the dose from groundwater-related pathways and radon which is expected to drive the onsite or intruder pathway dose). Further, not all uncertainties are readily quantifiable (e.g., conceptual model uncertainty) or included in this evaluation (e.g., radiation dosimetry or exposure parameters such as consumption rates or occupancy factors). Thus, the table is not expected to represent a probabilistic risk assessment, nor is statistical information regarding dose estimates provided (e.g., peak of the mean, ninety-ninth percentile dose, etc.). Although less quantitative, this approach is similar to the approach used by Washington DOH in its FEIS (2004) in that a comprehensive probabilistic risk assessment is not attempted. Rather a semi-quantitative analysis of the potential magnitude increase (or decrease) in the deterministic dose predictions presented in Washington DOH's FEIS (2004) is presented. In some cases, mitigating information is considered if a sound

technical basis is provided. For example, it was not clear that uncertainty in cover properties was appropriately considered in estimating radon doses; however, more recent calculations on the 90 percent final cover design (Daniel B. Stephens & Associates, 2007) manage many of the uncertainties with conservative assumptions and show the depth of cover to be underestimated in FEIS analyses. Thus, many of NRC staff's initial concerns were addressed in the more recent analysis with the exception of the radon emanation factor evaluated below. Another example of a mitigating factor considered in developing the table below is recent modeling that shows that the H-3 concentrations in the FEIS were overestimated by around a factor of 8 (Thatcher, 2008). This information is included because H-3 is a short-lived constituent and will decay to negligible levels in a hundred years. Because it is reasonable to expect DOE control of the greater Hanford site for one hundred years and H-3 from the disposal facility is not expected to migrate offsite at significant levels, NRC staff thinks that the risk-significance of H-3 is low with or without consideration of uncertainty in key parameters affecting H-3 transport include inventory, release rates, and cover performance and therefore, H-3 is not included in the table below.

Considering uncertainty, NRC analysis generally shows upper range doses that could be greater than the mean but less than the ninety-fifth percentile doses presented in Washington DOH's quantitative uncertainty analysis (2004), but the results are comparable. On-site dose estimates are significantly higher than reported in the FEIS (Washington DOH, 2004) due to consideration of uncertainty in radon flux calculations (e.g., uncertainty in emanation factor related to radium sealed source performance) that bias the doses high. In general, the upper range of doses presented in Table 2-2.6 for off-site receptors would fall between the mean and ninety-fifth (95th) percentile dose presented in Appendix II of Washington DOH's EIS (2004).

The early dose in Table 2-2.6 is greater than the mean but less than the 95th percentile dose reported for the 60-year and 1000-year time periods in Washington DOH's FEIS (2004). Pu-238 and Pu-239 doses can be greater than the deterministic doses reported in Washington DOH's FEIS due to (i) consideration of a more concentrated distribution of Pu in the early trenches and (ii) consideration of the impact of higher cover infiltration rates on mobile Pu transport. The U doses at early times are also affected by several factors. The U doses reported in Table 2-2.6 below can be higher or lower than the deterministic doses reported in Washington DOH's FEIS due to inventory uncertainty; are expected to be lower than reported in the FEIS due to what appears to be an underestimate in the trench 5, U inventory used in model calibration (which biases the mobile fraction high); or could be significantly higher than reported in the FEIS due to underperformance of the cover. The cumulative impact of all of these sources of uncertainties on U peak dose is a higher overall dose than reported in the deterministic FEIS analysis. The upper bound of the 10,000 year dose reported in Table 2-2.6 below is close to the mean dose reported in Appendix II of the FEIS when solubility controls are considered and between the mean and 95th percentile dose when solubility control is not considered. Although the uncertainty in inventory, distribution coefficient, and infiltration rate are particularly significant for U, the peak U dose is limited when solubility limits are considered. Furthermore, the upper range of dose presented in the FEIS (the 95th percentile dose in the probabilistic uncertainty analysis) is expected to be significantly larger than the upper range of doses reported in NRC staff's analysis below, given the greater number of uncertain parameters considered in the FEIS analysis. While some areas of overlap exist, the focus of Washington DOH's uncertainty analysis is considered to weigh more heavily on radiation exposure and dosimetry compared to NRC staff's analysis presented in Table 2-2.6 below which attempts to provide upper estimates

of the potential dose based on waste release and transport parameter uncertainty assuming the dosimetry, scenarios and critical groups evaluated by Washington DOH are acceptable and appropriate. This approach (i.e., lack of consideration of scenario, receptor behavioral parameter, and dosimetric uncertainty) is common in NRC technical analyses. Important uncertainties not addressed in Washington DOH's analysis that are important for early waste disposals include uncertainty in the inventory of U, assumption regarding homogeneity of waste over the disposal facility (e.g., Pu inventory is expected to be concentrated in early trenches), intact cover infiltration rates, and uncertainty in the mobile release fraction calibration process. Uncertainty in radon flux calculations is also considered in Table 2-2.6 below.

Important constraints on overall peak dose include solubility limits for U-238 that mitigate the potential higher doses associated with the uncertainty in the U inventory and Kd; and thicker covers to reduce the potential radon flux from the disposal facility. However, solubility control of U is also considered uncertain and additional support for this key modeling assumption is needed to increase confidence in PA model predictions. It is also important to note that dose estimates are particularly sensitive to uranium Kds which have the potential to significantly increase the peak dose associated with U-238 and U-234, as well as the overall peak dose. At the lowest Kd values for U, the U and overall peak dose can occur within the 10,000 year compliance period at values ranging anywhere from 10 to 100 times the peak dose reported in the FEIS for the mobile U fraction. At higher (what Washington DOH labels "best-estimate") Kds the peak dose occurs beyond the 10,000 year compliance period and at much lower values. Reduction in the uncertainty in U mobility is expected to significantly reduce the uncertainty in the FEIS dose estimates and should be a focus of future studies. Design considerations important to radon flux considering uncertainty in radon transport parameters should also be considered a high priority in future analyses. Alongside each uncertainty category listed in Table 2-2.6 below is also an evaluation of potential methods for reducing or managing the listed uncertainty through collection of additional information, modeling, or through disposal facility design to allow resources to be focused on the most risk-significant aspects of facility performance.

Table 2-2.6 Semi-Quantitative Analysis of More Significant Uncertainties Identified In Review^

	Primary Radionuclides Affected					Methods to Reduce or Evaluate Uncertainty
Inventory	U-238 2X ↑↓	U-235 2X ↑↓	U-234 4X ↑↓			Inventory uncertainty is expected to affect all radionuclides to some degree; however, refinements to radionuclide inventories over time generally led to lower (and better) estimates indicating the conservative nature of original estimates and potential for positive bias especially for SNM. Uncertainty in U estimates is expected due to expected errors in record-keeping and due to assumptions regarding the class of waste and enrichment. Remaining U inventory uncertainty is not expected to be readily reducible. Pu inventory is expected to be biased slightly high as not all waste manifests were reviewed. Not listed, Tc and I inventories are expected to be biased high but further efforts to reduce the already relatively low risk estimates are not expected to be of significant benefit.
Homogeneity of Waste				Pu-238 3X ↑	Pu-239 3X ↑	The FEIS calculations assume homogeneous waste (i.e., inventories are averaged over the disposal facility). However, most of the Pu waste was disposed of in the pre-1980 trenches which constitute about 18 percent of the waste by volume compared to the modeled area/volume (could lead to a factor 5 higher source concentrations). NRC calculations show the groundwater concentrations could be a factor of 3 higher. Studies could be conducted to better discretize the waste within the disposal facility, evaluate the point of maximum exposure in groundwater, and calculate maximum expected dose to an intruder on a trench by trench basis to further reduce and evaluate this uncertainty.
Kds **(vadose and saturated zone Kd for U and waste zone Kd for Tc)**	U-238 10X+ ↑ (10,000 yr dose only)	U-235 10X+ ↑ (10,000 yr dose only)	U-234 10X+ ↑ (10,000 yr dose only)			The dose results are sensitive to the Kd for U, as the selection of the Kd for the immobile fraction dictates whether the peak dose for U occurs within the 10,000 year compliance period. The waste zone Kd for Tc-99 was based on calibration to monitoring data; however, there is a potential for the inventory of Tc-99 in trench 5 to have been over-estimated leading to calibration parameter uncertainty

						(i.e., waste zone Kd). If, in fact, Tc-99 is more mobile than assumed, the peak Tc dose could be slightly higher. However, the expected uncertainty in the Tc-99 inventory (overly conservative) makes the issue with the Tc-99 Kd moot and so this constituent is not listed. Updated modeling (Rood, 2008) indicates that H-3 concentrations/dose are over-estimated in FEIS analyses based on calibration of waste zone partitioning coefficients to monitoring data. FEIS dose estimates are assumed to be lowered based on Thatcher (2008). H-3 is therefore not included due to its expected low risk significance. While Pu mobility is highly uncertain given the complex geochemistry of this constituent which can exist in five different oxidation states, even the lowest Kds for Pu would result in Pu peak doses beyond the 10,000 year compliance period. Continued monitoring and modeling could provide insights on contaminant mobility for key radionuclides such as U and Pu and should continue to be studied.
Conceptual Model for Waste Release (assumption regarding inventory of trench 5 that affects mobile fraction and early doses)	U-238 2X ↓ (Affects early dose from mobile fraction only)	U-235 2X ↓ (Affects early dose from mobile fraction only)	U-234 2X ↓ (Affects early dose from mobile fraction only)			All radionuclides are affected by waste release conceptual model uncertainty that could lead to large uncertainties with respect to mobile fractions on a trench by trench basis. However, assuming (i) the entire inventory is subject to enhanced transport and (ii) no buffering along the flow path through the vadose zone in the case of chemical effects or threshold moisture content in the case of a colloidal mechanism is expected to introduce a conservative bias in the assessment. Coupled with the fact that the risk associated with a highly mobile fraction is expected to be significantly smaller when considering the scale of the entire disposal facility (due to additional controls that came into effect in the early 1980s), this uncertainty is not explicitly considered. However, the uncertainty in the trench 5 inventory, which influences the calibration of the mobile fraction, is evaluated as trench specific inventory information is available. While collection of additional data and information on potential enhanced

						transport mechanisms (e.g., colloidal transport) may help reduce conceptual model and parameter uncertainty, due to the complexity of the site, difficulties with obtaining representative sampling data, and due to variability across the disposal facility, this uncertainty is considered less tractable.
Radon Transport Calculations (Intruder Calculations)	Rn-222 3X ↑					Radon doses could be significantly higher than assumed in the FEIS due to assumptions regarding emanation rates, moisture content, degradation and clay layer performance. However, the FEIS analysis was overly conservative with respect to cover depth which can compensate for most of this uncertainty. Recent calculations for the Phase 2 cover design manage many of the potential uncertainties with conservative assumptions with the exception of the radon emanation rate and potential impacts of waste form/cover degradation. Nonetheless, important design features should be identified (e.g., cover thickness) and uncertainties continued to be managed with either (i) conservative assumptions or (ii) through additional modeling, data collection, and/or field experiments.
Infiltration rates	U-238 5X ↑ (Early dose only)	U-235 5X ↑ (Early dose only)	U-234 5X ↑ (Early dose only)	Pu-238 3X ↑ (Early dose only)	Pu-239 4X ↑ (Early dose only)	Certain assumptions were made in the FEIS analysis (Washington DOH, 2004) regarding cover performance that effectively reduce the potential peak doses from certain key radionuclides due to decreased infiltration rates. Uncertainty in the projected doses for key radionuclides is considered due to late construction of cap or under-performance of the interim or final cover. All radionuclides are expected to be affected by uncertainty in infiltration rates—some more than others due to the timing of overall peak dose in comparison to the assumed period of performance for the cover. For example, long-lived, immobile radionuclides are not expected to be significantly affected as the cover is assumed to be completely degraded after 1000 years. Additional support regarding cover performance could be generated through additional modeling, studies, comparison to analog sites, etc.

Cumulative Impacts	U-238	U-235	U-234	Pu-238	Pu-239	
Basecase (FEIS) Doses mrem/yr^						Basecase dose values are taken from Table 5.1.3 in Appendix II to Washington DOH's EIS (2004). Base case values are multiplied by the uncertainty factors provided above to estimate a potential upper end estimate on individual radionuclide doses for two time periods—for early (<1000 years) and late (around 10,000 years) times within the 10,000 year compliance period when the overall peak dose is expected to occur.
Native American Adult	8	0.2	1.6	4.5	4.2	
Rural Resident	1.2	<<1	0.2	0.2	0.2	
Groundwater Pathway—Early Dose (0-1000 years) mrem/yr						Considering uncertainty, the early public dose is expected to be lower than the dose limit of 25 mrem/yr (0.25 mSv/yr) for the rural resident but could be higher than the standard for the Native American adult with most of the risk attributable to U-238 and Pu isotopes. Higher Pu inventories in the early disposal trenches (likely) and underperformance of the cover early in the compliance period (less likely) could lead to higher doses.
Native American Adult	10 - 40	0.3 – 1	1.0 - 16	45	48	
Rural Resident	2 - 6	< 1	0.1 – 2	2	2	
Groundwater Pathway--Late Dose (near 10,000 year dose) mrem/yr						Considering uncertainty, the public dose at later times in the compliance period (near 10,000 years) could be greater than 25 mrem/yr (0.25 mSv/yr) for the Native American scenario. Much of the uncertainty is related to the mobility of U (e.g., solubility and Kds) and dose impacts from U-238 and U-234 due to use of a sweat lodge. Upper end estimates of public dose for the rural resident are similar to or less than the 25 mrem/yr (0.25 mSv/yr) standard.
Native American Adult ***(no solubility)***	40 - 60 (***160)***	1 - 4	4 - 64			
Rural Resident ***(no solubility)***	6 - 8 (***24)***	<1	0.5 – 8			
On-site Rn-222 Dose (0 to 10,000 years) mrem/yr%						

Native American Adult	190 (Rn-222)					The Washington DOH FEIS (2004) indicates that about 60 percent of the total intruder dose (107 mrem/yr total)^ is from radon for the preferred alternative. Sixty percent of 107 mrem is 65 mrem. Based on subtraction of the groundwater dose (11 mrem to 22 mrem depending on the time period) from the total peak intruder dose (107 to 105 mrem depending on time period), it is estimated that the groundwater pathway is about 10 to 20 percent of the dose and the contribution of the drill cuttings to the intruder dose is approximately 20 to 30 percent. A total (bounding) intruder dose can then be calculated by summing the potential radon dose of around 190 mrem/yr with the maximum groundwater concentration (around 35 for rural resident and 230 for Native American) with the largest dose from drill cuttings (30 percent dose estimate of 30 mrem/yr) multiplied by a factor of 2 for inventory conservatism (for a total of 60 mrem/yr) even though the maximum doses from these various pathways occur at different times. Considering uncertainty, the total onsite or intruder dose could be above the intruder standard used by Washington DOH of 100 mrem/yr but less than the dose standard of 500 mrem/yr used by the NRC for both the rural resident (285 mrem) and Native American (480 mrem).
Rural Resident	190 (Rn-222)					

^NRC staff's evaluation of the cumulative impacts of key uncertainties identified in the review. Upper end estimates of dose are provided for the preferred alternative in Washington DOH's FEIS (2004) and for both the (i) Native American scenario and (ii) Rural Resident Adult. Two different time periods are considered for the groundwater pathway (i) early (<1000 years) and (ii) late (around 10,000 years) doses. Cumulative impacts to the on-site or intruder due to uncertainties in the groundwater pathway, radon,and direct impacts from contaminated drill cuttings dose are also presented under the radon-222 section.
%The radon dose decreases from 500 to 10,000 years due to decay of its parent Ra-226 (1600 year half-life). Over time Ra-226 will grow in from its parent radionuclides but at a lower activity than initially present.
^100 mrem = 1 mSv

3 Technical Assistance Request--Question 2:

TAR Question 2 reads as follows:

What is the potential radiological risk to worker health and safety if waste is exhumed? Exhumation of waste would encompass seven trenches which contain approximately 1,267,000 cubic feet of waste. These trenches are pre-Part 61.

The second question the NRC was tasked to answer focuses on the risks to workers associated with the retrieval, processing, and dispositioning of pre-Part 61 waste that was disposed of in trenches 1-6 at the US Ecology site. This issue was brought forward as a result of inquires from the Confederated Tribes of the Yakama Nation and Confederated Bands and Tribes of the Umatilla, who feel that if transuranic waste was disposed in concentrations greater than 100 nCi/g, the Part 61 regulatory requirements, those wastes should be exhumed and disposed in a geological repository.

Upon receiving the TAR from Washington DOH NRC staff clarified the scope of Question 2 with regards to the extent that the issues need to be evaluated. Specific points of clarification included:

- The TER will focus on the workers involved in the exhumation, retrieval, processing, and dispositioning of waste. Worker risks associated with the transportation of waste (i.e., transportation risk) are not considered as part of this TER.
- Only trenches 1-6, which contain pre-Part 61 waste, will be considered in the TER.
- All of the waste in trenches 1-6 would need to be retrieved, characterized, and re-packaged.
- To assist with answering question 2 NRC staff will evaluate worker doses and other relevant information associated with similar remedial activities at DOE-Hanford and other facilities.

To answer question 2, NRC staff began by evaluating the characteristics of trenches 1-6 (Section 3.1) and the processes known to be used to dispose of the waste at US Ecology prior to the implementation of Part 61 (Section 3.2). NRC staff then evaluated current dose hazards to workers at US Ecology from the ongoing day-to-day activities and possible issues that would impact the doses received by workers involved in the excavation, retrieval, processing, and disposition of waste from trenches 1-6 (Section 3.3). A general overview of the excavation and retrieval process (Section 3.4) and a review of similar activities at other sites were also considered to provide some guidance on the methods required, potential worker exposures, and lessons learned that can be incorporated into the planning and implementation of excavation activities for trenches 1-6 (Sections 3.5, 3.6, and 3.7). NRC staff also conducted a conservative cost-benefit analysis using the data provided from other sites scaled to the characteristics of trenches 1-6. A discussion of the uncertainties associated with this type of evaluation was also included to help the NRC staff make conclusions regarding the risks to workers associated with the exhumation of pre-Part 61 waste disposed of in trenches 1-6 (Section 3.8).

NRC staff found that evaluating the risks to workers from the retrieval, processing, and dispositioning of pre-Part 61 waste disposed of in trenches 1-6 difficult due to:

1. Limited site-specific information available regarding the waste contents, type and condition of the waste packages used, and the location of the waste packages in trenches 1-6;

2. Uncertainties associated with doses received by workers during the retrieval of waste packages from the trenches;

3. Uncertainties associated with the costs and doses received by workers during the processing of the exhumed waste packages.

4. Uncertainties regarding risks to workers and disposal costs associated with the dispositioning of exhumed waste.

NRC staff used information gathered from similar excavation and retrieval projects conducted at other sites to conservatively estimate, based on the volume of material involved, worker doses and costs associated with the possible exhumation of pre-Part 61 waste from trenches 1-6. NRC staff concluded that although previous projects have shown that risks to workers involved in the excavation, retrieval, processing, and dispositioning of TRU waste from disposal sites can be maintained below regulatory limits, the costs associated with this type of project at US Ecology should be considered cost prohibitive, especially as the inadvertent intruder is adequately protected (see section 2). Using the results of recent characterization activities and the construction of an interim cover to limit infiltration rates and doses associated with more mobile constituents, in combination with continued monitoring, could significantly reduce further risks associated with radioactive releases from the disposal site and would prevent the need for a complete exhumation of waste materials from trenches 1-6.

3.1 Summary of Characteristics of Trenches 1-6:

The special nuclear material licensed for disposal by the NRC in this TER was disposed of in six trenches at US Ecology between 1965 and 1980. These disposal activities occurred prior to the development of 10 CFR Part 61, the NRC regulations related to land disposal of radioactive waste. Trenches 1-6 are conventional, shallow-land, unlined burial cells. Specific trench dimensions, which are needed to evaluate radon (and other gaseous elements) gas diffusion through the trench cover, short and long-term dose assessments to the general public and intruder(s), design of the interim and final cover over the trenches, and cost evaluation for the closure of the facility were not accurately recorded at the time of construction. Staff of the Waste Management Section of the Washington DOH met in March of 1998 to develop a consensus summary of dimensions for trenches 1-6 using data compiled from previously published reports and assorted memos prepared by US Ecology and Washington DOH staff (Ahmad, 1998). Table 3-1 summarizes these consensus trench characteristics.

During disposal operations accurate records of the types of waste being disposed of and their locations within each trench were not maintained. A variety of waste forms, including low-level radioactive, naturally occurring radioactive material (NORM) and accelerator-produced material (NARM), non-radioactive hazardous, and mixed waste (radioactive waste having a hazardous component) are suspected of having been disposed of in these trenches. Suspected waste products in the trenches include scintillation fluids, absorbed liquids, metal drums, fiber-board drums, cardboard, wood, and metal boxes. Sources of these materials included nuclear power plants, industrial users, government and military organizations, academic institutions, and the medical community. Specific radionuclides of concern are discussed in Section 2 of this report.

Table 3-1 Characteristics of Trenches 1-6[1]

	Trench #					
	1	**2**	**3**	**4**	**5**	**6**
	Dates of Operation					
Trench Opened	9/16/65	8/18/66	12/1/71	4/1/75	4/29/78	8/22/79
Trench Closed	9/12/66	11/30/71	3/31/75	8/10/78	9/5/79	6/10/80
	Trench Dimensions					
Length (ft)	315	311	315	400	425	496
Width (ft)	133	61	45	100	80	75
Depth (ft)	25	25	25	30	30	30
Volume (ft^3) [2]	1.05E+06	4.74E+05	3.54E+05	1.20E+06	1.02E+06	1.12E+06
Slope W (H::V)	1.5	1.5	1.5	1.5	1.5	1.5
Slope L (H::V)	0.5	0.5	0.5	0.5	0.5	0.5
Interim Cover (ft) [3]	3	3	3	3	3	3
	Waste Information					
Waste Thickness (ft)	22	22	22	22	22	22
Volume (ft3)	64571.30	64571.30	64571.30	64571.30	64571.30	64571.30
Byproduct (Ci) [4]	1106.36	1106.36	1106.36	1106.36	1106.36	1106.36
SNM (g)	916.03	916.03	916.03	916.03	916.03	916.03
Source (kg)	242.07	242.07	242.07	242.07	242.07	242.07

[1]Adapted from Ahmad, 1998.

[2] Calculated; total volume of trenches 1-6 calculated to be 5.21E+6 m^3

[3] Values for interim cover are estimated by subtracting waste height (depth) from the trench depth

[4] To convert Ci to Bq multiply by 3.7e+7,

3.2 Disposal Operations for Trenches 1-6:

Aside from the lack of accurate records of waste forms disposed in trenches 1-6 disposal processes during this time period were much less organized than current operations and in many cases consisted of nothing more than dumping the waste off the back of a truck or dropping containers from a crane.

Although considered random, methods used for disposing of waste in trenches 1-6 evolved over time. Waste disposed in trenches 1-4, which operated from September 1965 through August 1978, were generally contained in metal drums, fiberboard drums, and cardboard boxes. The waste was placed in the trench by hand. Liners from casks were either placed at the bottom of the trench and shielded with other waste or backfill, or placed in slit trenches in the sloping wall and covered with 3 to 5 feet (0.9 to 1.5 m) of site soil. Most of these slit trenches are at least 20 feet (6.1 m) below grade with the shallowest liner buried approximately 10 to 15 feet (3.05 to 4.57m) deep in the extreme west end of Trench 4. Cranes with hooks or slings were used to place boxes in the trenches. If the packages exceeded the weight capacity of the crane they were maneuvered down the operating face of the trench. Approximately 25 to 30 percent of the volume of trenches 1-4 consists of waste with the remaining 70 to 75 percent consisting of sandy backfill.

Disposal of waste in trench 5 lasted from April 1978 through September 1979. Cardboard boxes were no longer accepted for burial when waste was placed in trench 5. Drums were placed into the trench two at a time by crane. A new, larger crane made stacking of boxes possible, although they were generally only two high and two deep. Approximately 35 percent of trench 5 was used for waste storage.

Trench 6, which received waste from August 1979 through June 1980, used a crane and sling to place the boxes. Stacks were typically two to three high and two to three deep with an open space in the center. High radiation cask liners may have been placed in the center and covered with sand to reduce radiation levels.

Most of the backfill, which consisted primarily of native sandy soil, was excavated from other areas onsite. Other components, including gravel, were brought in from offsite. The backfill was applied using bulldozers and other construction equipment to a height of 3 feet (0.9m) below ground surface. Additional soil was placed to the ground surface and mounded over the closed trenches to a height of 2 feet (0.61m) above the ground surface and then covered with 6 inches (15.2 cm) of gravel (US Ecology, 1996).

Although no specific documentation regarding their use was found, additional disposal practices, based on the size and radiation level of the waste packages, were used during the disposal of waste packages at the time when trenches 1-6 were filled. Liners, boxes, and heavy containers received during overlapping periods when multiple trenches were being filled or when a new trench was being excavated may have been placed on the floor of the new trench or held in storage until the new trench was completed. This was because the weight, configuration, and potential to form unfillable void spaces prevented these materials from being safely placed upon randomly placed drums already disposed of in the trenches. At the same, time smaller packages and drums were held until the trench was almost filled because their size

allowed for more specific placement, including filling void spaces developed by the larger packages. The placement of waste packages with higher radiation levels toward the bottom of the trench allowed shielding provided by other waste packages and backfill on top to be used (Carpenter, 1990). Differences in the trenches, types of waste placed in them, and the methods used during waste disposal would require separate approaches when planning the excavation and retrieval of the waste from each of the six trenches.

3.3 Primary Dose Hazards to Workers from Trenches 1-6:

Excavation and retrieval activities are not part of the ongoing day-to-day activities at US Ecology. Exposures to workers at US Ecology are related to activities associated with the off-loading and disposal of waste shipped to the site as well as activities associated with non-offloading operations. Non-offloading operations include activities such as maintenance operations within the controlled area, backfilling and associated surveys, trench maintenance and cleanup, waste verification inspections, routine surveys, environmental monitoring surveillances, maintenance of the engineered barrier cell, and exhumation of waste from active trenches. Current procedures for shielding waste and incorporating remote-handling operations at US Ecology allow exposures associated with waste handling to be low with a significant portion of the dose coming from tasks not directly related to waste handling. Table 3.2, compiled from US Ecology's annual ALARA reports, provides a summary of the workers' exposures associated with offloading and non-offloading activities over the last twenty years for the US Ecology site.

Doses to workers associated with waste excavation activities will depend on several factors, including retrieval techniques used, the number of waste packages characterized and handled, types of sampling and measurements conducted during the cleanup process, number of workers involved in characterization and waste handling, worker experience and training, and the equipment used. Removing waste from trenches 1-6 would require significant ALARA engineering and planning in order to minimize doses to workers. Excavating materials from trenches 1-6 would require digging the material up, inspecting and repackaging of the material, and eventually disposing of the material again. Possible damage to the waste containers or exposure to already leaking containers would also need to be considered. Inspection, repackaging, and eventual disposal of the containers at some unknown location could result in additional volumes of waste being generated. It can also be assumed, based on the lack of existing information, that each waste package would need to be sorted and reclassified once it has been retrieved from the trench. Incorporating some of the new technologies and procedures (see Section 3.7) developed during similar excavation projects at other sites could help decrease the exposures to workers involved in the excavation of waste from trenches 1-6, but these procedures and technologies will not completely remove all risks associated with this type of work (US Ecology, 1996).

3.4 Overview of the Exhumation Process:

The proposed exhumation of trenches 1-6 would require extensive efforts to characterize each trench and associated waste, excavate and retrieve each waste package from the trenches, process each waste package and characterize the waste contents, and treat the exhumed waste, if necessary, prior to final waste disposition either onsite or at an appropriate off-site location. NRC staff reviewed the general excavation and retrieval process as well as similar

projects with similar objectives to those that would be required at US Ecology. Section 3.5 discusses key issues associated with planning and implementing the exhumation of trenches 1-6. Risks to workers associated with these activities are discussed in Section 3.6. Lessons learned that could be applied in the planning and implementation of similar activities at US Ecology are discussed in Section 3.7.

Table 3-2 Annual Site-wide and Non-Offloading Exposures

Year	Total Facility Exposure (Person-rem)[1]	Non-Offloading Exposure (Person-rem)	Offloading Exposure (Person-rem)
1988	3.515	0.395	3.12
1989	3.115	0.805	2.31
1990	2.19	0.71	1.48
1991	2.71	0.459	2.251
1992	3.309	0.927	2.382
1993	1.656	0.798	0.858
1994	0.431	0.134	0.297
1995	1.243	0.589	0.654
1996	1.158	0.684	0.474
1997	1.138	0.888	0.25
1998	1.237	0.952	0.285
1999	0.953	0.57	0.383
2000	2.319	1.04	1.279
2001	0.582	0.205	0.377
2002	0.599	0.285	0.314
2004	1.049	0.557	0.492
2005	0.843	0.34	0.503
2006	1.303	0.595	0.708
2007	0.78	0.18	0.6
2008	1.145	0.405	0.74

Data compiled from US Ecology's Annual ALARA reports for 2008, 2002, and 1997
[1] 1 Person-rem = 0.01 Person-Sv

In general, the first step in the exhumation process would be the review of any existing information available on trench construction, such as the dimensions of the trench and the materials used as fill and overburden, as well as expected waste contents. Available information on the types, quantity, location, weight, and characteristics of both the waste and waste packages as well as consideration of the age of the waste packages, their structural integrity, and the stability of the waste piles once the overburden and initial waste packages are removed would aid in the planning process. Differences in the trench characteristics, types of waste placed in them, and the methods used during waste disposal and retrieval may require the development of site-specific approaches for each of the six trenches.

The excavation process would require the removal of the overburden, most likely with the use of heavy equipment. Great care would be required to avoid damaging any of the waste packages. Hand digging or other methods may also be needed to remove the final remnants before the waste packages can be removed. Prior to removal the waste packages would need to be inspected: inspection activities may involve conducting dose and radioactive contamination surveys, inspecting the structural integrity of the waste packages, and evaluating possible industrial health hazards that may need to be dealt with during the actual removal process. Results from these inspections will determine whether additional precautions are needed during the retrieval and processing of the waste packages. These precautions might include the use of additional protective clothing for workers, workspace monitoring of radiation exposures, and patching and overpacking of leaking or damaged waste packages in place prior to removal.

Retrieval operations implemented at a specific site can vary based on the knowledge of site characteristics, the type of waste being excavated, and the possible condition of the waste packages being removed. More recently disposed waste packages (1980s and later) are currently being removed from other sites using “open air” processes, which do not involve the use of containment structures. Waste packages at these sites are typically well characterized and stacked in neat, engineered configurations. Older burial sites, such as trenches 1-6 at US Ecology, which have less adequately containerized waste, randomized burial methods, and uncertainties associated with the conditions of the radiological waste, may require the use of enclosures to prevent the spread of contaminants and minimize risks to workers and the public during excavation and retrieval activities (DOE, 2006). Once retrieved, waste packages are typically transported to a nearby area where additional processing, including addressing waste package structural issues and characterizing the waste package contents as TRU or non-TRU waste. In cases where containment enclosures are used, these processes may be conducted on site using gloveboxes and other safety precautions to minimize risks to workers. Once processing, repackaging, and other activities associated with waste stabilization are completed the packages can be sent to the appropriate facilities for dispositioning.

3.5 Exhumation Projects Similar to the Exhumation of Trenches 1-6:

3.5.1 Previous Excavation and Retrieval Activities at US Ecology:

Previous minor exhumations have been conducted at US Ecology, but not in trenches 1-6. In 1985 US Ecology attempted to dig up resins that had sluiced into tanks (not in a trench). Workers could not remove all of the material because some of it had solidified to the sides of the tank. In 1993 efforts were made to locate and remove some suspect waste from one of the trenches. In 1997 workers exhumed bolts from the Trojan reactor head that is stored in trench 16. In all three cases no formal reports explaining the planning and retrieval processes were developed. Efforts required for these excavations were minor compared to what would be required to exhume trenches 1-6 (Haight, 2010).

3.5.2 Excavation and Retrieval Activities at DOE-Hanford:

Numerous exhumation activities have been planned and executed throughout the DOE-Hanford Site. These include the removal of retrievable TRU waste packages from trenches in various sections of 200 Area for shipment to WIPP and the exhumation of the liquid disposal site associated with the N-Reactor in 100 Area.

A review of exhumation activities associated with trench 4C-T04 in 200 West Area focused on the most recently disposed waste containers, which are expected to be in better physical condition because they have been stored for shorter lengths of time. Retrieval efforts were expected to deal with the balance of the retrievably stored TRU waste. This project includes the construction of all support facilities and related infrastructure upgrades necessary to carry out the retrieval operations as well as storage facilities to house the exhumed waste as well as any newly generated waste while it awaits shipment to a final disposal site. Mobile enclosures would be used to protect workers from the weather and provide sites for conducting inspections and venting of the drums following retrieval. Additional mobile structures would be used as facilities for the workers during excavation and retrieval operations. The retrieval process would involve the removal of approximately 10,000 drums of suspect TRU waste. Following retrieval the waste containers would be inspected, overpacked, vented, x-rayed, and assayed at the Retrieval Complex and moved to the Storage Facility. Extensive details regarding the excavation, retrieval, and inspection processes related to this exhumation project can be found in DOE/EA-0981 (DOE, 1995) and other related documents.

NRC staff also reviewed an environmental assessment for the exhumation of suspect contact-handled TRU waste from trench 218-W-4B Low Level Waste Burial Ground (LLWBG) and trench 218-W-4C LLWBG as well as the drums stored in trench V7, an engineered trench constructed with concrete associated with 218-W-4B LLWBG. The same general process is used for this retrieval as was planned for trench 4C-T04, except for the waste stored in V7. One difference, however, is the use of plastic tarps and plywood, which would be placed on top of the drums prior to applying the overburden. Planning for the removal and disposal of this material would also need to be considered. Trench V7 is the first engineered storage location for drummed TRU waste. The trench was constructed as a 90-degree V-shaped concrete slab. The drums were placed on their sides in a different configuration then the other trenches. Excavation of drums from V7 would require the removal of the overburden and then the galvanized steel cover, which may be done in its entirety or cut up into smaller pieces. Extensive details regarding the retrieval and operations processes related to the exhumation can be found in DOE/EA-1405 (DOE, 2002).

The removal of the liquid discharge system associated with the N-Reactor involved the excavation and retrieval of concrete and soil used to construct the effluent trenches. The N-Reactor, which operated at DOE-Hanford between 1963 and 1987, contained an effluent disposal system consisting of two trenches that were used to filter contaminants from water as it percolated through the soil column. 116-N-1 was composed of a concrete crib and a zigzag-shaped trench. The crib is approximately 290 ft long by 125 ft wide by 5 ft deep (88.4 m long by 38.1 m by 1.5 m deep). The bottom was filled with a 3 ft (0.91 m) layer of large boulders and 2 ft (0.61 m)of cobble. The zigzag trench was 1600 ft long by 10 ft wide at the bottom and 12 ft deep (487.7 m long by 3.05 m wide and 3.66 m deep). Effluent water released from the reactor spilled over the crib into the trench. Concrete panels covered the trench to minimize wildlife intrusion and airborne contamination. 116-N-3 also consisted of a crib and trench. The crib consisted of a trough running down the middle that drained into several lateral distribution legs. The walls were made of concrete with an open bottom of soil. The trench, constructed after the crib, was straight, 3000 ft long by 55 ft wide by 10 ft deep (914.4 m long by 16.76 m wide by 3.05 m deep), and divided into four sections with dams. Only the first 740 ft (225.5 m) section of the trench received effluent. The trench was also covered with precast concrete panels to

minimize wildlife intrusion and airborne contamination. The principal radionuclides of concern during cleanup of this site were Co-60, Cs-137, Pu-239, and Sr-90. Cumulative radiological inventories for the two waste sites were estimated at 730 Ci (27 TBq) of Co-60, 2300 Ci (85 TBq) of Cs-137, 27 Ci (1 TBq) of Pu-239, and 1650 Ci (61 TBq) of Sr-90, which were contained in a 75-mm surface layer at the top of the waste site. Remediation required the demolition, size reduction, and removal of the concrete trench cover panels and contaminated soils from the trenches. Issues related to the high concentration of radioactive material contained in the sludge that still remained in the troughs also had to be dealt with. Once efforts to reduce the size of the material and the doses associated with some of the materials were completed, dump trucks transported the material to an onsite disposal facility for processing and eventual storage. This project used numerous innovative processes (Section 3.7) and demonstrates the need to be able to adapt to unplanned issues encountered during this type of remediation project (Sitsler and DeMers, 2003).

3.5.3 Demonstration Projects at INL:

The Glovebox Excavator Method (GEM) Project in Pit 9 and the Accelerated Retrieval Project (ARP) in Pit 4 and Pit 6 at Idaho National Laboratory (INL) are DOE demonstration projects conducted to evaluate specific processes associated with the retrieval, characterization, packaging, and interim storage of waste contaminated with TRU radionuclides. Aside from cleaning up small sections of the pits, the ultimate goal of these projects was to provide information to DOE, EPA, and the State of Idaho regarding methods for improving the efficiency of proposed larger-scale retrieval operations. Although both of these projects are on a much smaller scale than what would be required for the exhumation of trenches 1-6 at US Ecology, the projects are similar to a proposed exhumation. The processes used and the corresponding results would most likely be similar at both sites.

The GEM project was conducted in a portion of Pit 9 of the Subsurface Disposal Area. The area, approximately 490.3 ft^2 (45.5 m^2), was selected based on previous knowledge of the waste packages disposed of in that area (DOE, 2004a). An estimated 8580.2 ft^3 (241.4 m^3) of soil, waste, and related materials were removed from Pit 9 as part of the project. Approximately 21780 ft^2 (2023 m^2) of Pit 4 and Pit 6 were excavated as part of the ARP Phase II project (Idaho DEQ, 2006). Approximately 235,000 ft^3 (6665 m^3) of soil, waste, and other materials were excavated as part of the ARP Phase II project (DOE, 2010). ARP Phase II was one of multiple accelerated retrieval projects occurring concurrently at various sites throughout INL.

Pits 4, 6, and 9 received waste from Rocky Flats and other waste generators during the 1960s. Waste removed as part of the ARP Phase II project was disposed of in Pits 4 and 6 between August 1966 and April 1968 and Pit 9 received waste between November 1967 and June 1969 (DOE, 2007; DOE, 2004a). Although packages were initially stacked, the disposal practices, similar to those at US Ecology during that time, ultimately involved dumping drums and boxes into the pit while using a crane to place larger items in an effort to minimize costs and personnel exposure. DOE maintained information on the inventory of materials being disposed of in the pits. In most cases waste was disposed of as it was received at the site, which means that the waste is commingled within the pits. Depending on the procedures at the time, a soil cover was applied over the waste after weekly or daily operations. Once all of the waste was placed into the pit an additional layer of soil was applied.

The waste contents included both transuranic waste and low level waste. The material shipped from Rocky Flats for storage included plutonium and uranium isotopes. Specific radionuclides of concern include Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, and Am-241 as well as uranium isotopes (i.e., U-234, U-235, and U-238), most likely shipped in the form of depleted uranium oxides. Other radionuclides, such as Co-60, Cs-137, and Sr-90, originating from INEEL and other waste generators were also found. The majority of the waste received from Rocky Flats was disposed in 55 gallon (208.2 liters) drums; other waste packages used to dispose of waste included plastic bags, plastic bottles, boxes, and liners. As is the case with trenches 1-6 at US Ecology, the actual conditions of these storage containers were not known prior to retrieval. Corrosion and leaks were found in many of the packages retrieved from both Pit 4 and Pit 9 (DOE, 2004b; DOE, 2007).

The GEM project used a Retrieval Confinement Structure (RCS), which enclosed the entire excavation area and a Packaging Glovebox System (PGS) consisting of three gloveboxes for examining and repackaging the retrieved waste. A protective Weather Enclosure Structure with floor contained the RCS, PGS, and the cab of the excavator, which scooped waste into transfer carts for sorting by personnel. The initial overburden was removed by personnel wearing personal protective equipment and respirators. The remainder of the overburden was removed as part of the waste retrieval process. Once the waste was sorted into appropriate containers operators changed out the drums and transferred them for assay measurement and interim storage at a RCRA-permitted storage area. A total of 454 drums of waste material totaling 2270 ft^3 (63.56 m^3) were removed during the project (DOE, 2004a).

The accelerated retrieval projects at INL were conducted after the GEM project and focused on the retrieval of certain waste types likely to contain higher concentrations of transuranic waste, such as sludges, graphite waste, and filters. The processes incorporated into the ARP focus on faster retrieval of higher-concentration waste while leaving less hazardous, less radioactive wastes in the pit (Idaho DEQ, 2006). The ARP uses a single retrieval enclosure (RE) instead of the two enclosures used in the GEM project. The RE, waste storage facility, and other related facilities were constructed on the site following the excavation of the initial overburden from the area. Information on the types of waste and associated volumes that were disposed, including the general location within the area that the waste was placed, allowed operators to identify waste types and potential hazards associated with the waste. Following retrieval the waste was segregated into targeted waste and non-targeted waste. The targeted waste was repackaged, screened to ensure radiation exposures to personnel are appropriately controlled, and transferred to interim storage in WMF-698. The non-targeted waste will be returned to another portion of the retrieval area and covered (DOE, 2007).

3.6 Summary of Worker Doses for Similar Exhumation Activities:

The original letter sent by Washington DOH requested that NRC staff evaluate potential radiological risks to worker health and safety associated with the exhumation of all of the waste from trenches 1-6. Further discussion narrowed the focus to consider only the risks from processes associated with the excavation, retrieval, and processing of the waste packages. Any doses associated with transportation of material were considered beyond the scope of this evaluation.

Doses to workers associated with waste exhumation activities are site-specific and depend on several factors including the types of waste exhumed, the number of waste packages that need to be retrieved and processed, the types of sampling and measurements required during the inspection of waste packages, the number of workers involved in the project, worker experience and training, and the equipment and techniques used. Doses received by workers associated with exhumation projects such as the one being considered for trenches 1-6 would be expected to comply with federal and state radiological dose limits as well as 'As Low As Reasonably Achievable (ALARA) principles. The similar projects reviewed that DOE performed or planned were able to meet the radiological dose limits in 10 CFR Part 835, Occupation Radiation Protection, 5 rem (50 mSv) annual effective dose equivalent (EDE) and 100 mrem (1 mSv) EDE for a member of the public. These regulatory limits are identical to the values provided in the NRC regulatory limits listed in 10 CFR Part 20 (DOE, 2001; NRC, 2001b).

3.6.1 Previous Exhumation Activities at US Ecology:

A review of US Ecology's ALARA reports provide some guidance on worker exposures associated with the three previous excavations conducted on the site. Although these activities are not on the same scale as the proposed exhumation of trenches 1-6 and the trenches excavated contained different classifications of waste this information can provide a starting point for estimating the doses received by workers excavating portions of trenches at US Ecology. Ultimately the risks to workers exhuming trenches 1-6 and retrieving the waste packages would be much higher than the doses received during these previous activities. The 1993 ALARA report indicates that a total 385 person-mrem (3.85 person-mSv) were received during the period when workers were exhuming waste for the U.S. Navy (US Ecology, 1994). There is no indication of the number of workers involved in this activity. A review of the 1986 ALARA report, which contains the dose data for 1985 and 1986, estimates that the dose to workers involved with the attempted removal of resins was 16 person-rem (0.16 person-Sv) (US Ecology, 1987). The 1997 ALARA report indicates that the Trojan box retrieval project, which involved finding and retrieving waste already placed in trench 16, resulted in 330 person-mrem (3.30 person-mSv) of exposure over 406 man hours worked (US Ecology, 1998).

3.6.2 Exhumation Activities at DOE-Hanford:

A review of planned excavation and retrieval projects associated with waste stored in trenches and the dose estimates can provide additional guidance regarding what could be expected during the excavation and retrieval of trenches 1-6. In general the waste packages in trenches 1-6 were not classified prior to disposal and the location and arrangement of waste packages in the trench is unknown. Therefore the excavation and retrieval of the waste packages from trenches 1-6 is expected to be much more difficult and could require more time and effort compared to trenches containing more recently disposed waste. Once removed each waste package would also need to be sorted and reclassified. The possibility of encountering comingled radionuclides that were not found at the other sites further increases the risk to workers. NRC staff estimates that the larger volume of material that needs to be exhumed, uncertainties associated with the arrangement of waste packages, and the additional time and effort required to retrieve and reclassify all of the waste packages would lead to doses received by workers excavating and retrieving material from trenches 1-6 of at least an order of magnitude higher than values anticipated for the projects planned at DOE-Hanford.

Workers excavating, processing, and disposing of waste from trench 4C-T04 in the 200 West Area were expected to receive dose of approximately 300 mrem (3 mSv). Over an estimated 3 years of retrieval activity the projected group of 14 workers would receive a dose consequence of 12.6 person-rem (0.126 person-Sv) (DOE, 1995). Based on the estimates considered in the environmental assessment, workers excavating, retrieving, and processing TRU waste from 218-W-4B LLWBG and 218-W-4C LLWBG would be expected to receive an annual dose of 1.18 person-rem (0.0118 person-Sv) or 5.9 person-rem (0.059 person-Sv) for the entire 5 year period of the proposed action. No estimates of the number of workers involved in the project were provided in the environmental assessment (DOE, 2002).

Although it does not involve the excavation and retrieval of waste packages from trenches, excavation and remediation activities associated with the liquid waste disposal facilities associated with N-Reactor were also evaluated. This project involved the excavation and retrieval of soil, sludge, and concrete contaminated with TRU waste from two sets of cribs and trenches that were used to filter reactor effluent. The excavation and remediation of the 116-N-3 crib and trench resulted in an estimated 3 person-rem (0.03 person-Sv), which was below the project goal of 10 person-rem (0.1 person-Sv). The dose estimate for remediation of the 116-N-1 crib and trench, which contains significantly more radioactive material than 116-N-3, was 17 person-rem (0.17 person-Sv) (Sitsler and DeMers, 2003).

3.6.3 Demonstration Projects at INL:

Demonstration projects being conducted at INL such as the GEM project and the ARP are smaller scale versions of the excavation and retrieval of waste from trenches 1-6 at US Ecology. The types of waste packages and waste contents being retrieved during these projects are similar to what would be expected at US Ecology. Both of these projects use enclosure facilities and other methods to minimize exposure to workers involved in the excavation, retrieval, and processing of waste. GEM project workers used gloveboxes to sort process sludges, graphite, and debris into waste containers. Over the length of the project a dose of 230 person-rem (2.3 person-Sv) was recorded over 92,710 worker hours (DOE, 2004a).

The ARP project involved the excavation and retrieval of waste analogous to waste removed from Pit 9 in terms of form and time spent buried. This project, however, used only one enclosure facility. Instead of manually sorting the waste ARP characterized the waste using the WIPP-approved Central Characterization Project (CCP), which incorporates certified characterization equipment and trained qualified personnel to evaluate the waste. CCP waste characterization activities include visual examination, sampling of solids, radioassays, headspace gas sampling and analysis, and gas generation testing (ICP, 2005). Doses to workers associated with the ARP were maintained below the regulatory limits.

3.6.4 Dose Modeling:

The major exposure pathways associated with the exhumation of trenches 1-6 are expected to be external radiation, inhalation, and, to a lesser extent, incidental ingestion. Based on scoping level calculations with a limited number of isotopes, key radionuclides, such as Co-60 and Cs-137, are expected to be external dose drivers while Pu isotopes are expected to be the dose drivers for the inhalation pathway. Dose to workers could be maintained at levels below5 rem/yr

(50 mSv/yr); however, limited occupancy or working times and extensive controls (e.g., dust suppression and shielding) would be required to manage worker dose.

3.7 Lessons Learned from Similar Exhumation Activities:

As operational experience associated with the excavation, retrieval, and processing of suspect TRU waste continues, new and innovative approaches to dose reduction and contamination control continue to be developed. Many of these techniques are developed to deal with specific situations and, in many cases, without much advanced planning and testing. These include the development of specialized tools, procedures, and equipment to stabilize heavily corroded drums with questionable integrity or the use of soils with lower contamination levels as shields to minimize exposure to more contaminated materials. A review of similar projects can provide some lessons learned that may make the exhumation process more efficient and minimize the risks to workers. Although primarily focused on waste retrievals from tanks, DOE maintains a database of lessons learned, known as the Retrieval Knowledge Center, which can also be used to better plan and implement excavation and retrieval activities (PNNL, 2009). Some lessons learned associated with key areas that need to be considered for the excavation, retrieval, and processing of waste from trenches 1-6 are discussed below.

3.7.1 Planning and Implementation:

The first step in the exhumation process for all of the examples reviewed was an evaluation of existing information regarding the area being excavated and the waste being retrieved. These records may include information like container identification numbers, quantity and location of the containers, physical waste forms, container weights, and radionuclide and chemical content. This information would serve as a basis for planning and development of operational and health and safety procedures. As discussed earlier sections of the TER, current records regarding the types of waste disposed of in trenches 1-6 and their specific locations are limited. In some cases discrepancies in the records further complicate the matter. US Ecology is currently in the process of sorting through the waste manifests for the waste packages disposed of in trenches 1-6, which should ultimately provide some useful information. However, since there are only limited records regarding the types of waste disposed of in trenches 1-6 and their specific locations, it is safe to assume that the entire contents of each of the trenches would need to be removed, sorted through, and reclassified. The lack of knowledge regarding the waste contents, waste packages used, and their current conditions would require additional protective measures to minimize the risks to workers during excavation and retrieval activities.

3.7.2 Worker Involvement:

A review of excavation and retrieval activities at DOE-Hanford and the INL provides numerous examples of how worker involvement in the planning led to the success of the project. Workers may be able to provide background knowledge regarding the site and the disposed waste that was not documented in records or reports. Workers at previous excavation and retrieval operations at DOE-Hanford have been actively involved in the activities such as the selection of retrieval locations and the sequencing of the excavation and retrieval process. During excavation and retrieval operations workers would be required to adapt to changing conditions and unplanned events. This includes the development of specialized tools, procedures, and equipment to deal with specific issues, such as the stabilization of heavily corroded drums with

questionable structural integrity (DOE, 2006). As experience is gained operating procedures may be refined and streamlined, ultimately increasing the overall effectiveness of the project while continuing to maintain safe conditions. For example, experience during the GEM project led to the reduction of the amount of personal protective equipment worn by workers during drum change-out activities, which allowed workers to work more effectively and increased the number of drums removed on a daily basis while still maintaining safe working conditions (DOE, 2004a).

Worker preparation and training was also determined to be beneficial for successfully implementing this type of project. Workers involved with the GEM project participated in classroom and on-the-job training as well as proficiency exercises and drills. Operator aids were developed to help workers identify various types of waste based on known contents of waste. A mockup facility was also developed to support safe and efficient operation of the project equipment. The mockup facility also allowed workers to perform various operational procedures and make modifications, such as modifications to tools used to puncture and open drums, which ultimately resulted in safer operation of the actual project equipment (DOE, 2004a).

3.7.3 Enclosure Facilities:

Excavation and retrieval projects conducted at DOE-Hanford currently focus on retrievable waste packages that, in general, were disposed of during the 1980s and later. The disposal methods used, knowledge of the container contents, the age of the waste containers, and the favorable worksite conditions allow these operations to be conducted “open air” without the use of containment structures. It is expected that excavation and retrieval activities for trenches 1-6 would require containment structures due to the uncertainties associated with waste contents and package conditions (DOE, 2006). The GEM project and the ARP, both conducted at INL, incorporated enclosure facilities around the areas being excavated. These temporary structures are large enough to house the excavation area, staging areas, and personnel and equipment ingress and egress activities. Once excavation and retrieval processes are completed these facilities are capable of being relocated to other areas for use with other projects. In addition to protecting workers from the weather, these enclosures prevent the spread of contamination and minimize radiological exposures to workers. Airborne emissions are mitigated using HEPA ventilation systems and dust suppression systems (ICP, 2005). The GEM project used a second enclosure surrounding the area being excavated. The project also incorporated gloveboxes into the retrieval process to further minimize the exposures to workers as they sorted through the waste. Despite adequate ventilation systems in the enclosures operations had to be paused when high levels of radon from atmospheric inversions were measured. Once the necessary actions were taken to reduce the radon levels, work was allowed to continue (DOE, 2004a).

3.7.4 Adapting to Site-Specific Issues:

Due to the uncertainties associated with the types of waste, the location of the waste, and waste package conditions, workers must be prepared to adapt or modify procedures for current conditions. Previous excavation and retrieval projects have found that in many cases corrosion of the drums was significant. Depending on conditions of the container, required repairs could range from taping and patching degraded areas to overpacking the entire container into a larger

container. Issues, such as the need to vent the container, were typically addressed once the container had been removed from the trench (DOE, 2006). Waste packages retrieved during the GEM project showed that plastic bags and plastic containers storing waste maintained much of their integrity, although some of the bags were less pliable and more brittle than expected and the writing and markings on the plastic containers and labels that were covered with plastic were still clear and legible (DOE, 2004a).

The remediation of the N-Reactor liquid disposal sites at DOE-Hanford used a variety of different techniques to control the spread of contamination and minimize exposure to workers that may also be incorporated into other excavation and retrieval projects. Workers used soils with lower levels of contamination as shields on top of soils with higher levels of contamination. The soils were then mixed, decreasing the contaminant concentrations in the soil and lowering the dose rates and airborne levels workers would be exposed to. Remote operations, such as the use of a remote saw to size-reduce the concrete cover panels, were also used to minimize exposures to workers. A polyurea fixative, similar to a spray-on truck bed liner, was sprayed on the trough prior to size reduction to lock up the surface radioactivity. Grout, applied remotely to further minimize exposures to workers, was used to bind sludge material located in the trough and laterals (Sitsler and DeMers, 2003).

3.8 Relative Costs and Benefits of Excavation:

The second question in the TAR asked the NRC staff to evaluate the potential radiological risk to worker health and safety if the waste contained in trenches 1-6 was exhumed. Removal of radioactive materials from the trenches could allow for a reduction in long-term risks associated with the site. However, complete exhumation of trenches 1-6 would require the removal of large amounts of soil and waste material along with extensive waste characterization and disposal activities. NRC staff anticipates that the costs associated with these exhumation activities would be high relative to the benefits associated with the reduction of risk to workers and the public.

Currently, trenches 1-6 are no longer receiving waste and are covered with backfill consisting of native sandy soils and gravel (US Ecology, 1996). A review of annual ALARA reports associated with present day activities at the disposal site shows that current operations, which do not deal directly with trenches 1-6, are not affected by the contents of the trenches. The NRC staff's review of documents collected from US Ecology and Washington DOH determined that current conditions at the disposal facility can meet the performance objectives associated with 10 CFR Part 61, Subpart C. This includes §§ 61.41, 61.42, 61.43, and 61.44, which are the regulations that protect workers, intruders, and the general public during different stages of the design, operation, and closure of disposal facilities.

Evaluating the potential risks to the health and safety of workers involved in the possible exhumation of trenches 1-6 required NRC staff to examine other exhumation activities at other sites and scale them to trenches 1-6. Using information collected from the planned exhumation of trenches at DOE-Hanford as well as the GEM Project and Phase II of ARP, two demonstration projects conducted at INL, risks and costs associated with trenches 1-6 were estimated by comparing the volumes of the excavated areas. Using the doses estimated for the two sites at DOE-Hanford and the doses measured during the GEM and ARP projects, the NRC staff estimated that potential worker doses associated with the excavation, retrieval, and

processing of waste from trenches 1-6 would range between 0.303 and 3970 person-rem (0.003 and 39.7 person-Sv). To maintain worker doses in this range NRC staff estimated that the cost associated with excavation, retrieval, processing, and dispositioning of waste would be substantial and probably cost prohibitive, ranging between $16 million and $4.3 billion.

These risks (i.e., doses) and costs only consider the processes and protective measures associated with the excavation, retrieval, processing, and, in some cases, treatment of the soil and waste from the trenches. These estimations assume similar waste forms, package conditions, and operational processes. For these reasons doses to workers and project costs are more likely to resemble the estimated costs and doses associated with the two demonstration projects conducted at INL. For the most part, the DOE-Hanford projects reviewed by NRC staff contain better characterized waste and waste packages that are presumably in better condition and disposed of in an organized manner, which would simplify excavation and retrieval processes. Further, a review of the Washington DOH FEIS (Washington DOH, 2004) shows that the primary risks associated with the disposal site are associated with the mobility of certain radionuclides that are presumed to have already migrated to the vadose zone and into the groundwater pathway. Although exhumation of the trenches would limit further contamination in the trenches, it would not reduce the risks from the radionuclides that have already migrated out of trenches 1-6 and into the vadose zone and groundwater.

The scope of this analysis focused on processes related to the excavation, retrieval, processing, and disposition of the material from trenches 1-6. It is assumed that all of the material in the trenches would need to be retrieved, sorted, and characterized due to uncertainties associated with the contents of each trench. Additional uncertainties related to worker doses and excavation costs also need to be considered due to the lack of information regarding additional costs that may be encountered during the retrieval, treatment, and final disposition of waste removed from trenches 1-6.

It should be noted that current NRC regulations do not provide disposal options for any commercially-generated TRU waste that is found during the excavation of trenches 1-6. In addition, current regulations prevent US Ecology from placing the TRU waste back into the trenches. Therefore additional storage facilities would need to be constructed. As a result additional construction, storage, and monitoring costs as well as the corresponding risks to workers and the public would need to be considered along with the costs and risks associated with the eventual redisposition of the stored waste in the future. Uncertainties associated with increased risks and additional expenses associated with these additional storage and disposition issues along with the costs associated with the transportation and disposal of the non-transuranic waste exhumed from the trenches are not considered in the NRC staff's current cost estimates.

Table 3-3 Estimated Worker Dose (Person-rem) and Costs for Excavation and Retrieval Activities for Trenches 1-6, US Ecology, Inc.

PROJECT	4C-T04 [1]	218-W-4B & C [2]	GEM [3]	ARP, Phase I [4]
LOCATION	DOE-Hanford 200 West	DOE-Hanford 200 West	INL, Pit 9	INL, Pit 4
DESCRIPTION OF PROJECT	Excavation and retrieval of the most recently disposed (i.e., better physical condition) waste containers	Excavation and retrieval of up to 15,200 buried 208-liter (55-gallon) drums of post-1970 suspect CH-TRU waste over a 5 year period	A demonstration project conducted in a portion of Pit 9 which contains waste similar to what is expected in trenches 1-6 at US Ecology.	A demonstration project conducted in a portion of Pit 4, which contains waste similar to what is expected in trenches 1-6 at US Ecology
VOL. OF MATERIAL (m^3)	2.26E+03	2.88E+06	8.58E+03	3.36E+05
DOSE (PERSON-REM)[6]	12.6	5.9	230	113.8
COST	$66 MIL	$330 MIL	$67 MIL	$208.5 MIL
TRENCHES 1-6, US ECOLOGY, INC.				
VOL. OF MATERIAL (m^3) [5]	1.48E+05	1.48E+05	1.48E+05	1.48E+05
ESTIMATED DOSE (PERSON-REM)[6]	8.25E+02	3.03E-01	3.97E+03	5.01E+01
ESTIMATED COST	$4.3 BIL	$16 MIL	$1.1 billion	$91 million

[1] DOE, 1995
[2] Volume and costs based on estimates provided in DOE, 2010; Dose data from DOE, 2002
[3] Volume data from ICP, 2005; Dose and cost data from DOE, 2004
[4] Volume and cost data from DOE, 2004; Dose data from Dickson, 2010
[5] Converted from volume (5.21E+06 ft^3) listed in Section 3.1, Table 3-1.
[6] 1 Person-rem = 0.01 Person-Sv

3.9 Conclusions:

Question 2 evaluated the risks to workers from the exhumation of pre-Part 61 waste disposed of in trenches 1-6 at the US Ecology site. The limited information available regarding the waste contents, waste packages used, and the location of the packages in trenches 1-6 makes the planning and execution of this type of project more difficult. Additional uncertainties can be associated with doses received by workers during the retrieval of waste packages from the trenches and the costs and doses received by workers during the processing of the waste packages. These uncertainties further complicate the NRC staff's attempt to understand the site-specific information required to directly assess the risks to workers from exhuming waste from trenches 1-6. To overcome this issue NRC staff reviewed a variety of exhumation projects conducted at US Ecology, DOE-Hanford, and INL. These reviews provided a better understanding of equipment, procedures, and risks associated with the excavation, retrieval, and processing of TRU waste as well as the costs for implementing this type of project. NRC staff used this information to estimate, based on the volume of material involved, worker dose and costs associated with the excavation and retrieval of waste from trenches 1-6.

Although previous projects have shown that risks to workers involved in the excavation, retrieval, characterization, and processing of TRU waste from disposal sites can be maintained below regulatory limits, the costs associated with this type of project at US Ecology should be considered cost prohibitive. Consideration of the risks associated with radionuclides that mobilized in the vadose zone and groundwater and the issues associated with disposing of the reclassified waste once exhumed further call into question the benefits of removing the waste. Using the results of recent characterization activities and the construction of an interim cover to limit infiltration rates and doses associated with more mobile constituents, in combination with continued monitoring, could significantly reduce further risks associated with radioactive releases from the disposal site and would prevent the need for a complete exhumation of waste materials from trenches 1-6.

4 Overall Conclusions:

Washington DOH presented NRC with two questions in a technical assistance request to evaluate the risks of early waste disposals at the US Ecology disposal facility in Richland, Washington. The two questions are as follows:

1. Did waste licensed by the NRC for disposal at the US Ecology disposal facility during the period 1965 to 1980 meet the four performance objectives of 10 CFR 61 (and WAC 246-250), even though it may have contained transuranics in excess of 100 nCi/gm?

2. What is the potential radiological risk to worker heath and safety if waste is exhumed? Exhumation of waste would encompass seven trenches which contain approximately 1,267,000 cubic feet of waste. These trenches are pre-Part 61.

With respect to Question 1, NRC staff concludes that performance objectives for LLW disposal in 10 CFR Part 61, Subpart C can be met provided certain key assumptions are met. Key assumptions include the following:

1. The inventory of key radionuclides such as isotopes of U is similar to or less than assumed in the PA analyses.

2. Lack of explicit consideration of certain early (pre-1980) waste disposal practices (e.g., less stringent controls on waste segregation, waste form stability, and other controls based on waste classification system) does not lead to a significant underestimation of risk due to a greater potential for increased infiltration, leaching, and waste concentrations.

3. Mobility of key radionuclides such as U isotopes is not significantly under-estimated (e.g., Kds, solubility, and mobile release fractions are appropriate).

4. The as-emplaced engineered cover will perform as well as assumed in PA analyses with respect to infiltration and radon mitigation.

A semi-quantitative evaluation of uncertainty in the dose estimates for early disposals suggests that upper-end estimates of dose are limited (see Section 2.3 above). Therefore, NRC staff concludes that the remaining uncertainty in facility performance is sufficiently low to allow closure decision to be made. To mitigate the remaining risk associated with early waste disposals, several recommendations are noted in Section 4.1. It is expected that data will continue to be collected and the site PA continued to be revised and updated as additional information is collected regarding site risk to support final decisions on the enhanced cover design and site closure.

With respect to Question 2, NRC staff concludes that radiological risk to workers and the public from the exhumation, retrieval, characterization, and processing of waste from trenches 1 through 6 can be maintained below regulatory limits. However, uncertainties associated with the waste contents, waste package conditions, and disposal locations makes calculating specific doses, to workers and the public, difficult. Review of similar excavations and retrieval projects confirmed that low doses can be maintained; however, costs associated with implementing this type of project are expected to be prohibitive. Operational issues, such as the disposal of reclassified waste following exhumation, may be hindered by current regulatory requirements and possibly lead to additional health and safety issues for workers and the public. Risks associated with higher mobility radioactivity that may have already leached out of the early disposal trenches and into the underlying vadose zone would not be mitigated if waste is exhumed, limiting the overall benefit of waste exhumation.

4.1 Technical Recommendations:

Based on NRC staff's review of Washington DOH's PA and other supporting information, as well as NRC staff's own independent assessment the following recommendations are noted:

1. Transparency in PA documentation could be increased.

2. Model support for key modeling assumptions is needed to increase confidence in PA results. Areas where model support could be increased are documented in the main body of this TER and include: (i) cover performance, (ii) conceptual models for waste release and contaminant transport, (iii) partitioning coefficients and solubility limits for key radionuclides, and (iv) radon transport through the waste zone and cover.

3. With regard to coordination of activities at the larger Hanford site:

   - US Ecology and the State should remain cognizant of larger DOE Hanford site activities and a process should be put in place to evaluate potentially risk-significant deviations in PA modeling approaches, assumptions and parameters as new and significant information is found.
   - US Ecology and the State should take every opportunity to collect additional data that could elucidate disposal facility performance including leveraging data from DOE Hanford activities to reduce key uncertainties in PA modeling.
   - The State should work with the DOE to ensure a comprehensive and consistent approach to assessing and managing risk from Central Plateau facilities is taken. Increased communication and collaboration between all involved parties will help ensure that resources are spent in the most cost effective manner practical to ensure protection of human health and safety to future generations, to achieve the greatest overall risk reduction and to maintain doses as low as is reasonably achievable.

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REFERENCES:

"A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities, Recommendations of NRC's Performance Assessment Working Group." NUREG-1573. Washington, DC: NRC. October 2000.

Ahmad, S. J. "Audit Results of US Ecology's Source Manifest." Internal memo to Mike Elsen and Nancy Darling. Washington DOH: Olympia Washington. July, 2002.

Ahmad, S. J. "Trench Information." Internal memo to Gary Robertson. Washington DOH: Olympia, Washington. April 1998.

Ahmad, S. J. "Review by WDOH of US Ecology's Radioactive Waste Shipment Records (June 1965 – December 1981)." Washington Department of Health: Olympia, Washington. July, 2003.

Bergeron, M. P., G. V. Last and A. E. Reisenauer. 1987. Geohydrology of a Commercial Low-Level Radioactive Water Disposal Facility Near Richland, Washington. Prepared for US Ecology, Inc., Louisville, Kentucky, by Battelle Pacific Northwest Laboratories, Richland, Washington.

"Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers." Regulatory Guide 3.64. Washington D.C.: NRC. 1989.

Carpenter, S.A. Letter to Gary Robertson, Washington DOH, providing follow-up information to Condition 58 report regarding trench contents including chemical trench. June 29, 1990a.

Carpenter, S.A. Letter to Mike Elsen, Washington DOH, providing follow-up information regarding trench contents from database. October 25, 1990b.

CH2M HILL, Inc., 1986. Monitoring Well Installation Report and Laboratory Testing Program Results for US Ecology, Inc., Richland, Washington. Report to US Ecology, Inc., Louisville, Kentucky.

Clark, D.L. "The Chemical Complexities of Plutonium." Los Alamos New Mexico: Los Alamos Science. Number 26. 2000.

Daniel B. Stevens & Associates, Inc. & Dwyer Engineering, LLC. "90-Percent Design for Evapotranspirative Final Cover Low-Level Radioactive Waste Facility US Ecology Washington. Volume III: Design Basis Report, Part 1." Albuquerque, New Mexico. February 26, 2007.

"Design of Erosion Protection for Long-Term Stabilization." NUREG-1623. Washington, DC: NRC. September 2002b.

Dickson, Richard L. Letter to Adam Schwartzman, Nuclear Regulatory Commission, regarding "Request for Accelerated Retrieval Project Radiation and Cost Information (OS-QSD-10-060)." DOE: Idaho Falls, ID. ML102640346, September 20, 2010.

DOE. 10 CFR Part 835, "Occupational Radiation Protection." Code of Federal Regulations, Office of Federal Register. Washington, D.C.: DOE. January 1, 2001.

DOE. "Environmental Management Richland Operations Office FY 2011 Congressional Budget Request." Richland, Washington: DOE Richland, http://www.hanford.gov/files.cfm/FY_2011_RL_Budget_Roll_Out_Feb_1_2010_Final.pdf, February 1, 2010.

DOE. "Final Environmental Impact Statement on Tank Waste Remediation Systems, Hanford Site." DOE/DEIS-0189, United States Department of Energy, Richland, Washington. 1996.

DOE. "Hanford Site Risk Assessment Methodology." DOE/RL-91-45, Revision 3, Richland, Washington, 1995.

DOE. "Screening Assessment and Requirements for a Comprehensive Assessment: Columbia River Comprehensive Impact Assessment." DOE/RL-96-16 Rev. 1, Richland, Washington, 1998.

"Draft Environmental Impact Statement on 10 CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste." NUREG-0782. Washington, D.C.: Nuclear Regulatory Commission. September 1981b.

Dwyer, S. "Water Balance Measurements and Computer Simulations of Landfill Covers." University of New Mexico, Civil Engineering Department. May, 2003.

Eckerman, K.F., and J.C. Ryman. "External Exposure to Radionuclides in Air, Water, and Soil." Federal Guidance Report No. 12. Washington D.C.: U.S. EPA. 1993.

"Engineered Covers for Waste Containment: Changes in Engineering Properties & Implications for Long-Term Performance Assessments." NUREG/CR-7028. Washington, D.C.: Nuclear Regulatory Commission.

"Engineering Evaluation/Cost Analysis for the Accelerated Retrieval of a Designated Portion of Pit 4." DOE/NE-ID-11146. Idaho National Engineering and Environmental Laboratory. DOE Idaho. April, 2004b.

Email from Sheila Pachernegg, Washington DOH, to Cynthia Barr, NRC. Dated May 11, 2010. Select drawings of the Phase 1 cover system "USE-Phase 1 Cover system" Power Point presentation slides [ML103020361].

"Environmental Assessment: Solid Waste Retrieval Complex, Enhanced Radioactive and Mixed Waste Storage Facility, Infrastructure Upgrades, and Central Waste Support Complex." DOE/EA-0981. Richland, Washington: DOE Richland. September, 1995.

"Environmental Assessment: Transuranic Waste Retrieval from the 218-W-4B and 218-W-4C Low-Level Burial Grounds, Hanford Site, Richland, Washington." DOE/EA-1405. Washington, D.C.: DOE. March, 2002.

Fayer, M.J. and T.J. Jones. "UNSAT-H Version 2.0: Unsaturated Soil Water and Heat Flow Model." PNL6779, Pacific Northwest Laboratory: Richland, Washington. 1990.

"Final EIS for 10 CFR Part 61 – Licensing Requirements for Land Disposal of Radioactive Waste." NUREG-0945, Volume 1. Washington D.C.: Nuclear Regulatory Commission. 1982.

"Final Policy Statement for the Decommissioning Criteria for the West Valley Demonstration Project at the West Valley Site." Washington, DC: NRC. February, 2002a.

Fjeld, R.A., S.M. Serkiz, P.L. McGinnis, A. Elci, and D.I. Kaplan. "Evaluation of a Conceptual Model for the Subsurface Transport of Plutonium Involving Surface Mediated Reduction of Pu(V) to Pu(IV)." *Journal of Contaminant Hydrology*. Vol. 67. pp. 79–94. 2003.

Fjeld, R.A., T.A. DeVol, R.W. Goff, M.D. Blevins, D.D. Brown, S.M. Ince, A.W. Elzerman, and M.E. Newman. "Characterization of the Mobilities of Selected Actinides and Fission/activation Products in Laboratory Columns Containing Subsurface Material from the Snake River Plain." *Nuclear Technology*. Vol. 135. pp. 92–108. 2001.

Gee, G.W., M.J. Fayer, M.L. Rockhold, and M.D. Campbell. "Variations in Recharge at the Hanford Site." *Northwest Science*, vol 61, pp237–250. 1992.

Grove Engineering. "Microshield." Version 5.03. Rockville, Maryland: Grove Engineering. 1998.

Guensch, G.R. and Richmond, M.C. "Groundwater/Vadose Zone Integration Project System Assessment Capability: Appendix E River Data for Initial Assessment Performed (Rev 0)." 2001.

Haight, R.F. "Annual Environmental Monitoring Report for Calendar Year 2008: US Ecology Washington Low Level Radioactive Waste Disposal Facility." US Ecology, Inc., Richland, Washington. May, 2009.

Haight, R. "Excavations at US Ecology." Email to Adam Schwartzman. May, 27, 2010.

Harris, S.G. and B.L. Harper. "A Native American Exposure Scenario." Risk Analysis 17:6, 1997.

Harris, S.G., and B.L. Harper. "Exposure Scenario for CTUIR Traditional Subsistence Lifeways." Pendleton, Oregon: Department of Science & Engineering, Confederated Tribes of the Umatilla Indian Reservation. September 2004.

Ho, C.K. "Analytical Risk-Based Model of Gaseous and Liquid-Phase Radon Transport in Landfills with Radium Sources." Albuquerque, NM: Sandia National Laboratories. January 2008.

Hunn, E.S., "Nch'i-Wana, 'The Big River;' Mid-Columbian Indians and Their Land", University of Washington Press, Seattle, Washington, 1990.

ICP. ICP/CON-04-00598, "Idaho Completion Project's Accelerated Retrieval Project Overview of The Pit 4 Non-Time Critical Removal Action." Idaho Completion Project. Bechtel BWXT Idaho, LLC. Idaho Falls, Idaho. March, 2005.

ICRP, "Human Respiratory Tract Model for Radiological Protection", ICRP Publication 66, Oxford, Pergamon Press, 1994.

ICRP. "Recommendations of the International Committee on Radiological Protection." ICRP Publication 60. Oxford: Pergamon Press. 1990.

ICRP. "Data for Use in Radiological Protection Against External Radiation." ICRP Publication 51. Oxford: Pergamon Press. 1987.

Idaho DEQ. "Progress on Cleanup of Buried Waste." State of Idaho Oversight Monitor. Idaho Department of Environmental Quality, Boise, Idaho. 12 pp. November, 2006.

Kennedy, W.E., Jr. and D.L. Strenge. "Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent." NUREG/CR-5512, PNL-7994, Washington, D.C., 1992.

Kincaid, T., et al. "Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site," PNNL-11800, Pacific Northwest National Laboratory, Richland, Washington. 1998.

Last et al. "Vadose Zone Hydrogeology Data Package for Hanford Assessment." PNNL-14702, Revision 1. Richland, Washington: Pacific Northwest National Laboratory. June, 2006.

Minor, D.A., "Data Evaluation: Facility Investigation Data: US Ecology Inc Data: Washington State Department of Health Data." Prepared for the Washington State Department of Health, Nuclear and Environmental Consultant, August 1999.

NCRP. "Limitation of Exposure to Ionizing Radiation." NCRP Report No. 116. National Council on Radiation Protection and Measurements: Bethesda, Maryland. 1993.

NCRP. "Measurement of Radon and Radon Daughters in Air." NCRP Report No. 97. National Council on Radiation Protection and Measurements: Bethesda, Maryland. 1998.

Newmark, N.M. and E. Rosenblueth, Fundamentals of Earthquake Engineering, Prentice-hall, Inc., Englewood Cliffs, New Jersey, 1971.

NRC. "Evaluation of Trench Subsidence and Stabilization at Sheffield Low-Level Radioactive Waste Disposal Facility." NUREG/CR-2101. Los Angeles: Ralph Stone and Company, Inc. May 1981a.

Note to File. From Mike Elsen. Subject: "Radium Disposal at US Ecology." September 17, 2003. Washington DOH (internal document).

Office of River Protection (ORP), "Single-Shell Tank System Performance Assessment for the Hanford Site." DOE/ORP-2005-01, Revision 0. Richland, Washington: Department of Energy. April 2006.

Palmer, A.J. Letter to Gary Robertson, Washington DOH, regarding "Review of Radioactive Shipment Records for the US Ecology Low-level Radioactive Waste Disposal Site at Richland, Washington." American Ecology Corporation: Oak Ridge, TN. December 1994.

PNNL. PNNL-18356, "EM-21 Retrieval Knowledge Center: Waste Retrieval Challenges." Pacific Northwest National Laboratory, Richland, Washington. April, 2009.

Porstendorfer, J. and A. Reineking. "Radon: Characteristics in Air and Dose Conversion Factors." Health Physics 76(3): 300-305. 1999.

Prikryl and Pickett. "Recommended Site-Specific Sorption Coefficient for Reviewing Non-High-Level Waste Determinations at the Savannah River Site and Idaho National Laboratory." Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas, October 2007

"Remedial Action Report for the OU 7-10 Glovebox Excavator Method Project." DOE/NE-ID-11155. Idaho National Engineering and Environmental Laboratory. DOE Idaho, November, 2004a.

"Removal Action Plan for the Accelerated Retrieval Project I and II." DOE/NE-ID-11178, Rev. 3. Idaho Cleanup Project. DOE Idaho. October, 2007.
"Retrieving Suspect Transuranic Waste from the Hanford Burial Grounds – Progress, Plans, and Challenges." DOE-0313-FP. Richland, Washington: DOE. March, 2006.

Ridolfi, Inc. "Yakama Nation Exposure Scenario for Hanford Site Risk Assessment, Richland, Washington." September 2007.

Rood. A.S. "Calibration of Tritium Release Rates to Vadose Zone and Ambient Air Measurements for the US Ecology Radioactive Low-Level Waste Disposal Facilty, Richland, Washington." K-Spar Inc. Scientific Consulting. Idaho Falls, Idaho. June 13, 2008.

Rood, A.S. "FOLAT: A Model for Assessment of Leaching and Transport of Radionuclides in Unsaturated Porous Media." Rigby Idaho, K-Spar, Inc. December, 2002.

Rood, A.S. "Further Evaluation of Groundwater Concentrations for Different Covers at the US Ecology Low-Level Waste Disposal Site Hanford Washington using GWSCREEN 2.5 and Minimizing the Cover's Effect at Depth." K-Spar Inc, Rigby, Idaho, May 10, 2000b.

Rood, A.S. "Groundwater Pathway Uncertainty Analysis in Support of the Performance Assessment for the US Ecology Low-Level Radioactive Waste Facility." K-Spar Inc., Rigby, Idaho, Originally published September 16, 1999, Revised May 24, 2000a.

Rood, A. S. "GWSCREEN: A Semi-Analytical Model for Assessment of the Groundwater Pathway from Surface or Buried Contamination, Theory and User's Manual Version 2.5." INEEL/EXT-98-00750, Rev. 1. Idaho Falls, Idaho: Idaho National Engineering and Environmental Laboratory. February, 1999.

Sitsler, R.B. and S.K. DeMers. "Remediation of Hanford's N-Reactor Liquid Waste Disposal Sites." Health Physics. Vol. 84, Suppl. 1, pp. S41-S46. 2003.

Sower, G.G., "Settlement of Waste Disposal Fills," Proceedings, 8th International Conference on Soil Mechanics and Foundation Engineering, Vol. 2, pp. 207-210, 1973.

Sullivan, T.M. "DUST Disposal Unit Source Term, Data Input Guide." NUREG/CR-6041. BNL-NUREG-52375. Upton, New York: Brookhaven National Laboratory. 1996.

Thatcher, A.H. "Addendum to the Final Environmental Impact Statement Radiological Risk Assessment." Olympia, WA : Washington Department of Health. June 2008.

Thatcher, A.H. Memo from D. Thatcher to M. Elsen. "FEIS Source Term Documentation for Uranium." Olympia, WA: Washington Department of Health. May 20, 2010a.

Thatcher, A.H. Memo from D. Thatcher to N. Darling. "EIS Source Term Documentation." Olympia, WA: Washington Department of Health. April 28, 2010b.

US Ecology. "ALARA Analysis 2008." US Ecology, Inc., Richland, Washington. 2008.

US Ecology. "ALARA Analysis 2002." US Ecology, Inc., Richland, Washington. 2002.

US Ecology. "ALARA Analysis 1993." US Ecology, Inc., Richland, Washington. 1994.

US Ecology. "ALARA Analysis 1986." US Ecology, Inc., Richland, Washington, 1987.

US Ecology. "ALARA Report for Calendar Year 1997." US Ecology, Inc., Richland, Washington. 1997.

US Ecology. "Comprehensive Facility Investigation Richland LLRW Disposal Facility Richland, Washington Phase 1 and 2 Report." US Ecology, Richland Washington. 1999.

US Ecology. "Facility Standards Manual." US Ecology, Inc. Richland, Washington, July 2009.

US Ecology. "Site Stabilization and Closure Plan for the Low-Level Radioactive Waste Disposal Facility." US Ecology, Inc., Richland, Washington. 1996.

Washington DOH. "Department of Health Preliminary Summary 2008 US Ecology Borehole Radiological Sample Investigation Results." Revision 1. Washington DOH: Olympia, Washington. January 2010.

Washington DOH. "Final Environmental Statement Commercial Low-Level Radioactive Waste Disposal Site, Richland, WA," DOH Publication 320-031, May 28, 2004.

Washington DOH. "Hanford Guidance for Radiological Clean-up." Revision1. Washington DOH. 1997.

Wood, M.I., et. al. "Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds Prepared for the U.S. Department of Energy Office of Environmental Management." Richland, Washington: Westinghouse Hanford Company, Washington Hanford Operations and Engineering Contractor. June 1995.

10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Code of Federal Regulations, Office of the Federal Register. Washington, DC: NRC. January 1, 2001a.

10 CFR Part 20, "Standards for Protection against Radiation," Code of Federal Regulations, Office of the Federal Register. Washington, DC: NRC. January 1, 2001b.