ORP-63747
Revision 2

Comment Responses for the Nuclear Regulatory Commission Request for Additional Information on the Draft Waste Incidental to Reprocessing Evaluation for Waste Management Area C

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Office of River Protection

P.O. Box 450
Richland, Washington 99352

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APPROVED
By Janis D. Aardal at 10:16 am, Oct 23, 2019

Release Approval   Date

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October, 2019

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Acronyms and Abbreviations

ADAMS	NRC's Agency-wide Documents Access and Management System
BBI	Best Basis Inventory
bgs	below ground surface
C-301	241-C-301 Catch Tank
CCU	Cold Creek unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CPGW	Central Plateau Groundwater
CPGWM	Central Plateau Groundwater Model
CR-Vault	244-CR process tank vault
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
CWP1/CWP2	PUREX coating waste
DOE	U.S. Department of Energy
DQO	Data Quality Objectives
DST	double-shell tank
Ecology	Washington State Department of Ecology
EDTA	ethylene diamine tetraacetic acid
EHM	equivalent homogeneous medium
EMCF	Environmental Model Calculation File
EPA	U.S. Environmental Protection Agency
ERSS	Extended Reach Sluicer System
FEP	Features, Events, and Processes
GRT4	H2 sand hydraulic properties
HEDTA	hydroxyethyl ethylene diamine triacetic acid
HDW	Hanford Defined Waste
HLW	high-level radioactive waste
HPW	high pressure water
HSU	hydrostratigraphic unit
HT	hydrogen gas
HTO	tritiated water
Kd	Plutonium distribution coefficient
LFRG	Low-Level Disposal Facility Review Group
LLW	low-level radioactive waste
MARS	Mobile Arm Retrieval System
MARS-V	Mobile Arm Retrieval System – Vacuum
MCL	Maximum Contaminant Level
MRT	Mobile Retrieval Tool (FoldTrack)

MTCA	Model Toxics Control Act
NRC	U.S. Nuclear Regulatory Commission
NTA	nitrilotriacetic acid
P2 waste	PUREX high level waste
PA	performance assessment
PM	particulate matter
PSN	PUREX supernate waste
PUREX	Plutonium Uranium Extraction (Plant)
QA	quality assurance
RAI	request for addition information
RCRA	Resource Conservation and Recovery Act of 1976
RDR	Retrieval Data Report
RI/FS	Remedial Investigation/Feasibility Study
RFI/CMS	RCRA Facility Investigation/Corrective Measures Study
RM	Responsible Manager
SACS	Surveillance Analysis Computer System
SAP	Sampling and Analysis Plan
SOF	sum-of-fractions
SOP	Standard Operating Procedure
SST	single-shell tank
T2	tritium gas
TBP	Tri-Butyl Phosphate
TER	Technical Evaluation Report
TOC	total organic carbon
TWINS	Tank Waste Information Network Systems
UWMQ	Unresolved Waste Management Question
WIR	waste incidental to reprocessing
WMA C	Waste Management Area C
WMA C PA	Performance Assessment of Waste Management Area C, Hanford Site, Washington (RPP-ENV-58782)

Units

μg	microgram
Ci	curie
cm	centimeter
ft	foot
ft^2	square foot
ft^3	cubic foot
g	gram
gal	gallon
in	inch

kg	kilogram
km	kilometer
L	liter
m	meter
m^3	cubic meter
mrem	millirem
nCi	nanocurie
pCi	picocurie
psi	pounds per square inch
psig	pounds per square inch gauge pressure
yr	year

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1.0 INTRODUCTION

In accordance with DOE Order 435.1 and its accompanying manual, DOE Manual 435.1-1, the U.S. Department of Energy (DOE) manages radioactive waste in a manner that protects the public, workers and the environment, and that complies with applicable federal, state and local laws. Certain waste resulting from reprocessing of spent nuclear fuel that is incidental to reprocessing is not high-level radioactive waste (HLW) and is managed in accordance with the requirements for low-level radioactive waste (LLW). In June, 2018, DOE issued the *Draft Waste Incidental to Reprocessing Evaluation for Closure of Waste Management Area C at the Hanford Site* (herein referred to as the Draft WIR Evaluation) (DOE/ORP-2018-01).

By means of an interagency agreement between DOE and the U.S. Nuclear Regulatory Commission (NRC), NRC is conducting a consultative technical review of DOE's Draft WIR Evaluation. Prior to preparation of the Draft WIR Evaluation, DOE interacted with NRC staff in development of DOE's *Performance Assessment of Waste Management Area C, Hanford Site, Washington* (herein referred to as the WMA C PA) (RPP-ENV-58782), which is a technical reference document for the Draft WIR Evaluation. The interactions included extensive discussions and scoping meetings between DOE, NRC, and other parties regarding the fundamental technical bases, approaches, and key parameter values to be used in developing the WMA C PA. The WMA C PA was issued in 2016, and the Draft WIR Evaluation was subsequently issued for NRC consultation and comments by states, Tribal Nations and the public in June, 2018.

Beginning in June 2018, DOE and NRC staff have engaged in a series of technical exchanges and public meetings to clarify the approaches and rationales documented in the Draft WIR Evaluation and WMA C PA. On April 30, 2019, NRC staff submitted comments on the Draft WIR Evaluation and WMA C PA in the form of requests for additional information (RAIs) (External letter, "Request for Additional Information on the Draft Waste Incidental to Reprocessing Evaluation for Closure of Waste Management Area C at the Hanford Site" [McKenney, 2019]). On May 30, 2019, DOE and NRC held a joint public meeting in Richland, Washington to discuss and clarify the intent of the NRC RAIs.

This document provides DOE's responses to the NRC staff RAIs, to facilitate NRC's completion of a Technical Evaluation Report (TER) on the Draft WIR Evaluation. For each of the 21 RAIs, the NRC comment, basis information, and proposed path forward is quoted directly as received from NRC (with minor typographical corrections). These are followed by DOE's response. The topics discussed herein are technical in nature. Although DOE has attempted to present this information in an accessible manner, it cannot be considered a stand-alone document. The RAIs and responses are part of the on-going interaction between DOE and NRC staff regarding the review of the Draft WIR Evaluation and the associated WMA C PA, and can only be understood in that context; a working knowledge of those documents is assumed.

The RAIs were organized by NRC according to the three criteria contained in DOE Manual 435.1-1, Section II.B(2)(a). Those criteria provide, in relevant part, that the wastes:

1. *Have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical; and*
2. *Will be managed to meet safety requirements comparable to the performance objectives set out in 10 CFR 61 Subpart C; and*

3. *Are to be managed, pursuant to DOE authority under the Atomic Energy Act of 1954, as amended, and in accordance with the provisions of Chapter IV of DOE M 435.1-1, provided the waste will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration limits for Class C LLW as set out in 10 CFR 61.55[.]*

The RAIs are organized according to applicable categories based upon these criteria, as presented in Sections 2.0, 3.0, and 4.0 below.

2.0 REMOVAL OF KEY RADIONUCLIDES TO THE MAXIMUM EXTENT PRACTICAL

RAI 1-1

Comment

An insufficient basis was provided that removal of waste from plugged pipelines is not necessary in order to satisfy removal of key radionuclides to the maximum extent that is technically and economically practical.

Basis

DOE indicated it would not be technically practical to remove additional waste and key radionuclides from ancillary structures. The basis for this statement was not provided for plugged pipelines. Plugged pipelines represent one of the highest risks from all of the potential structures proposed to be left in place. Removal would seem to be a viable option for plugged pipelines unless it is not technically and economically viable to do so. DOE has spent approximately $750 million dollars to remove waste from the tank farm at WMA C (NRC's Agency-wide Documents Access and Management System [ADAMS] Accession No. ML18337A404). According to DOE's "Draft Waste Incidental to Reprocessing Evaluation for Closure of Waste Management Area C at the Hanford Site" (DOE/ORP-2018-01), [Draft WIR Evaluation], they will have removed approximately 96% of the waste from the tank farm at closure. The "Performance Assessment of Waste Management Area C, Hanford Site" (RPP-ENV-58782) [WMA C PA] shows that the waste residuals result in a dose to a member of the public of approximately 0.166 mrem/year within the sensitivity analysis period (Figure 8-22, WMA C PA) and a dose to a hypothetical acute inadvertent intruder of approximately 4 mrem (averaged over sixteen 100- and 200- series tanks). The average amount spent on removing waste from an average tank (life-cycle) would be approximately $47 million.

By comparison, DOE indicated that the dose to a chronic intruder (rural pasture exposure scenario) from a plugged pipeline is 160 mrem/year at 100 years.

The actual inventory in plugged pipelines is unknown and assumed (see following request for additional information).

In addition, it is not clear why the rural pasture exposure scenario would be the most limiting intruder dose result for a plugged pipeline when for every other source type the suburban gardener exposure scenario is the most limiting result of the chronic intruder exposure scenarios. The acute driller dose impacts are larger than the chronic dose impacts by a factor of 2.5 to 3.8 for other sources with similar waste composition.

DOE has performed various activities to access contaminated structures (including buried pipelines) at Hanford. The experience from those activities may be used to provide cost and other information.

Path Forward

Please provide a basis that it is not technically and economically practical to remove and dispose of plugged pipelines.

DOE Response

As discussed in Section 4.3 of the Draft WIR Evaluation, removal of key radionuclides to the maximum extent that is technically and economically practical includes consideration of actual conditions and the sensibleness and usefulness of a potential approach under those conditions. Among other things, this criterion contemplates: comparison of the expected costs (including human health and safety costs, environmental costs, and monetary costs) and potential benefits; timing, delays, and other exigencies; and technical accessibility, limitations and risk in actual conditions. The following paragraphs demonstrate that the costs and risks far outweigh the potential benefits of removing pipelines that are assumed to be plugged. The removal of buried pipelines would be a hazardous effort that would come at a high monetary cost, engender delays, and pose an unnecessary risk to workers and the public during operations.

As the Basis section of this RAI points out, a plugged pipeline could represent a source of higher potential dose to an inadvertent intruder than other components within WMA C, suggesting that resources might be well spent in removing this source. However, this is not born out in an analysis of costs and benefits. RPP-PLAN-47559, *Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation*, was prepared as a scoping study to support WMA C closure planning, and is a primary reference document on this topic for the WMA C PA and Draft WIR Evaluation. As suggested in the Basis section of this RAI, RPP-PLAN 47559 relies upon previous Hanford site experience in accessing and characterizing contaminated structures as benchmarks for the analyses for WMA C. RPP-PLAN-47559, Section 7.3.1, provides a detailed examination of the costs, risks, and benefits of characterizing or removing waste transfer pipelines, and concludes that "further pipeline characterization or supplemental closure actions for protection of human health and the environment are not necessary when risks are balanced against the high cost and schedule impacts associated with these actions." Several key points in the report which support this conclusion are summarized below.

Monetary Costs:
Waste transfer pipelines in WMA C are of two general categories: cascade lines, which run directly between single-shell tanks (SSTs) and operate by gravity flow only[1]; and pressurized transfer pipelines through which waste was pumped between various pits and diversion boxes to route the waste to the desired location. The WMA C PA assumes that all eight cascade lines in WMA C and one pressurized transfer line (V-122) are plugged. RPP-PLAN-47559, Section 6.3, provides two detailed cost estimate examples for removal of waste transfer pipelines in WMA C. Example B, summarized in Table 6.2 of RPP-PLAN-47559, applies to cascade lines. The cost of removal of each 25-foot (7.6-m) cascade line segment is estimated to be approximately $28 million. Therefore, removal of all eight cascade lines in WMA C could cost in excess of $200 million. The pressurized transfer line assumed to be plugged (V-122) is a direct-buried pipeline that is 494 feet (151 m) long and buried 5 to 9 feet (1.5 to 2.7 m) below ground surface. No specific cost estimate has been prepared for removal of a transfer line of this configuration. The other example cost estimate provided in RPP-PLAN-47559 (Example A) assumes an encased transfer line and therefore is not directly applicable to V-122. However, it may be useful for illustration of the magnitude of the task. Table 6.1 of RPP-PLAN-47559 summarizes the cost estimate for Example A as approximately $18 million for a 25-foot segment of pipeline. At 494 feet in length,

[1] Cascade lines in WMA C include no valves, nozzles, or cleanouts. They are simply an open conduit between tanks, allowing overflow of waste from one tank to the next. There is therefore no way to access them for flushing, pressure testing, cleaning, or characterization. Because they operated by gravity flow only, they were more prone to "plugging" than pressurized transfer lines. However, removal of cascade lines is technically impractical due to their unique configuration – because they are attached directly to tank walls below the dome, they are buried deeper than other transfer pipelines, and cannot be safely excavated until the adjacent tanks are fully stabilized (e.g., grouted).

transfer line V-122 would comprise over 19 such segments[2]. Therefore a gross order-of-magnitude estimate for its removal could be as much as $342 million. In total, the monetary costs alone of removing the assumed plugged pipelines in WMA C could exceed $500 million[3].

Other Cost Elements:
Although monetary costs are the most readily quantifiable, other factors cannot be ignored. These include radiological and industrial risk to workers, schedule delays, potential for contamination spread to public areas and further environmental insult during removal and waste transport. As a scoping study, RPP-PLAN-47559 provides only general discussion of these elements. Excavation in radioactive contamination areas can pose significant worker exposure and contamination control issues. Remotely-operated excavation equipment would be recommended, and the work would likely have to be completed within a containment structure for control of fugitive dust and radiological contamination (RPP-PLAN-47559, Section 6.3.1).

Regarding schedule, Example A discussed above was estimated to require approximately 39 months to complete for a single pipe segment; Example B was estimated to require approximately 42 months to complete, or up to 48 months for multiple segments. This would extend the overall closure schedule for WMA C, and these activities would also preclude most other concurrent work within WMA C (RPP-PLAN-47559, Section 7.1).

Potential Benefits:
As pointed out in the Basis section of this RAI, the intruder dose was analyzed in the WMA C PA to be as high as 160 mrem/year. This dose is derived from a sensitivity case in Section 9.5 of the WMA C PA, which assumes the following:

- Closure occurs in the year 2020.
- Institutional controls last for 100 years after closure, and societal memory is lost at that time.
- After the 100 years, a well is drilled through the engineered surface barrier, striking a 3-inch (7.6 cm) cascade line which is 100 percent filled with waste.

The first two of these assumptions are critical to the dose calculation. However, the 2020 closure date assumed in the WMA C PA was based upon the then-current milestone for closure of WMA C. This milestone date is currently under negotiation by the parties to the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989), also known as the Tri-Party Agreement. Furthermore, there is no planned date at which DOE expects to relinquish control of the Hanford site. There are many projects and activities that will continue at the Hanford site, including in the vicinity of the tank farms, well beyond the closure of WMA C; for example, retrieval and closure of the 200 East Area double-shell tanks (DSTs) are currently expected to continue until approximately 2068 [4].

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[2] Another reason that removal of assumed plugged pipelines is technically impractical is the difficulty of identifying the actual number and location of "plugged" pipeline segments which would be useful to remove. As discussed in the DOE response to RAI 2-5 regarding residual waste inventory within plugged pipelines, the assumed number of plugged lines is overestimated to be conservative.

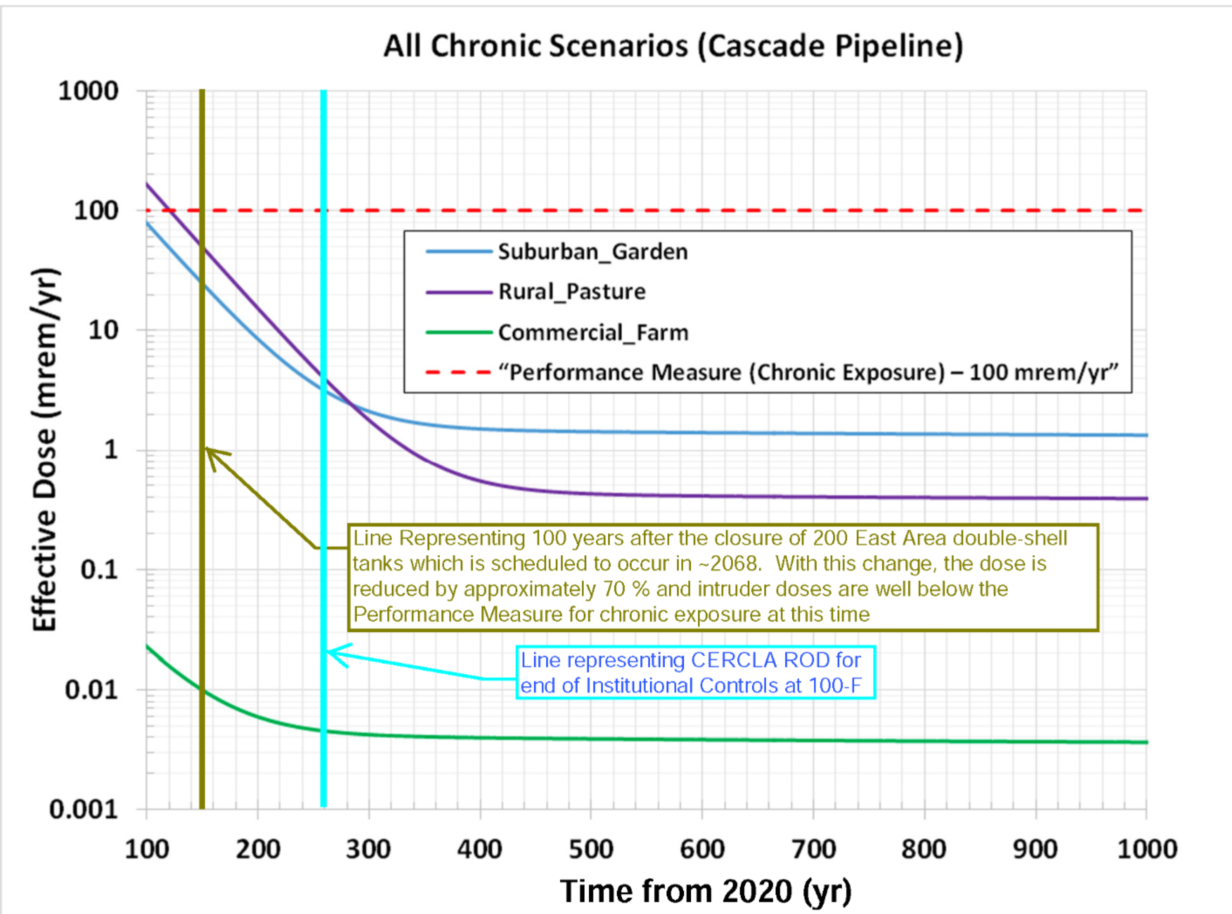
[3] All dollar values provided in the RPP-PLAN-47559 estimates are in 2010 dollars; no escalation has been provided for current or future time periods.

[4] According to RPP-RPT-60192, *System Plan*, Rev. 8, Lifecycle Cost Analysis, the baseline scenario for completion of retrieval and closure of the 200 East Area double-shell tanks (DSTs) occurs in 2068 (RPP-RPT-60192, Table 5, Item WBS# 5.03.04). Ten other scenarios are also examined with the closure of the 200 East Area DSTs ranging from 2063 to 2121.

Within 100 years of the time such activities in the 200 East Area are expected to be complete, the potential dose to the hypothetical chronic intruder (from the pipelines assumed to be plugged) will be significantly reduced, due primarily to decay of Sr-90 and Cs-137 whose half-lives are 28.8 and 30.2 years, respectively. To illustrate, assuming completion of activities in the 200 East Area in 2068 and assuming the hypothetical human intrusion occurs 100 years later (i.e., in 2168), the dose from inadvertent intrusion into a full cascade line would be reduced by approximately 70 percent due to radioactive decay of Sr-90 and Cs-137. Thus, the previously-calculated 160 mrem/year dose would be reduced to below 50 mrem/year, which is well below the DOE performance measure (100 mrem/year) for the chronic exposure scenario. To illustrate these results graphically, Figure 9.15 from the WMA C PA is reproduced below as Figure 1, with vertical lines added to illustrate the hypothetical dose result at various assumed intrusion dates. Given these considerations, the hypothetical net benefit of removing "plugged" pipelines is significantly reduced.

Figure 1. Effective Dose for Three Chronic Exposure Scenarios for a Fully Plugged Cascade Pipeline.

(from Figure 9.15, WMA C PA, Modified for Different Assumed Closure Timelines)[a]



[a] The line representing the CERCLA ROD for the end of Institutional Controls at 100-F is based on Table A1-16 in DOE/RL-2001-41.

Also, the hypothetical "plugged pipeline" described in the WMA C PA is assumed to be completely filled with waste solids along its entire length (Section 9.5 of the WMA C PA). This provides a bounding estimate of waste inventory. While this is useful for estimating dose and exposure risk to the public and inadvertent intruders, it can be misleading in terms of closure planning. No actual pipeline is thought to be "fully filled" with residual waste solids as this hypothetical "plug" would suggest. Therefore, the benefit from removal of "plugged" pipeline segments, even if they could be identified, would be less than the assumed inventory values would suggest.

Finally, the Basis section refers to the reasoning for the Rural Pasture Scenario being the most limiting. The apparent discrepancy may be due to comparing the pipeline intruder scenarios – which are calculated at 100 years post-closure – with the tank intrusion scenarios, which are calculated at 500 years post-closure. As shown in the graph above, the Rural Pasture Scenario is bounding early on, but its relationship to the Suburban Garden Scenario is inverted in the later timeframe. This is due to the assumption that people living on the farm would be drinking and using the milk produced by a dairy cow consuming the pasture grass contaminated with Sr-90, which decays away over a shorter timeframe than other dose drivers.

RAI 1-2

Comment
An insufficient basis was provided for terminating waste removal activities for some tanks.

Basis
Section 4 of the Draft WIR Evaluation steps through the waste removal processes used for each tank and component in WMA C. For the 100-series tanks, two thirds of the retrieval campaigns did not achieve their goal. For the 200-series tanks, all the retrieval campaigns achieved their goal. A variety of different processes and technologies were deployed to remove waste from the tanks. The DOE approach to removing waste focused on bulk waste removal. For most of the 100-series tanks charts were provided showing the asymptotic approach of the amount of waste removed to a threshold value, demonstrating that the limits of that particular technology were being approached. However, charts were not provided for C-105, C-106, C-109, C-111, and C 112.

DOE stated on page 4-68 of the Draft WIR Evaluation that removal of 96% of the waste volume has also resulted in removal of 96% of the radioactivity in the tanks from pre- to post-retrieval. The solids (sludge) generally have higher concentrations of radioactivity and are more difficult to remove, therefore it would be anticipated that a higher percentage of radioactivity would remain. The removal efficiencies for key radionuclides were not provided.

Additional observations associated with waste removal include:

- For Tank C-104 an obstruction was encountered which limited pump placement and waste removal. It is not clear why the obstruction couldn't be cleared or additional access provided. For some tanks, risers have been modified or new risers installed.
- For Tank C-108 the waste was stated as being insoluble in DST AN-106 supernate. Information was not provided as to why other supernate couldn't be used and how it was determined that other supernate would not be effective.
- For Tank C-108, Figure 4-17 of the Draft WIR Evaluation shows waste removal is primarily limited by access locations. It is not clear why additional access could not be provided or if providing additional access locations was evaluated.
- For Tank C-109, Figure 4-22 does not appear to shown decreasing effectiveness of the technology with time. The fluoride concentration increases with circulation time. Longer circulation time should correspond to more waste removal.
- For Tank C-110, Figure 4-27 shows very effective performance of the FoldTrack Mobile Retrieval Tool (MRT) system.

The system was stopped due to a component failure. It is not clear why the component could not be repaired or replaced to continue removal. In addition, owing to its effective and efficient performance it is not clear why it could not be deployed on other tanks for which retrieval goals were not met.

Path Forward
Please provide removal efficiency charts for tanks C-105, C-106, C-109, C-111, and C-112. Provide the removal efficiencies of key radionuclides Cs-137, Sr-90, I-129, Tc-99, U-isotopes, Pu-isotopes, Am-241, Np-237, and C-14, non-decay corrected. Address the additional observations noted above associated with particular tank cleaning campaigns.

DOE Response

Section 4.3 of the Draft WIR Evaluation discusses the removal of key radionuclides to the maximum extent technically and economically practical as an iterative process, including the following steps: identification of the best available technologies applicable to an individual tank; deployment of the chosen technologies to their practical limits; evaluating whether additional technologies are needed, available, and/or useful; and evaluating the costs and benefits of additional actions or technology development. Moreover, Section 4.3.2 of the Draft WIR Evaluation includes a statement from the 2010 Consent Decree recognizing the definition of "limits of technology" as meaning "that the recovery rate of that tank retrieval technology for that tank is, or has become, limited to such an extent that it extends the retrieval duration to the point at which continued operation of the retrieval technology is not practicable, with the consideration of practicability to include matters such as risk reduction, facilitating tank closures, costs, the potential for exacerbating leaks, worker safety, and the overall impact on the tank waste retrieval and treatment mission."

For each WMA C tank, a Retrieval Data Report (RDR) has been prepared, which describes the retrieval technologies selected, the operational campaigns to remove waste from the tanks, and the detailed decision process to determine when the practical limits have been reached. These RDRs illustrate important points on relevant data in various forms, including charts and tables, depending on the technologies applied and the specific considerations unique to each tank and its contents. Sections 4.3.3 and 4.3.4 of the Draft WIR Evaluation summarize these narratives, and refer to the RDRs for additional details. The specific removal efficiency charts requested in the RAI Path Forward section were not necessarily created for every tank. However, the following paragraphs offer additional information to strengthen the basis for terminating removal activities within the tanks in question, presented in the order listed in the RAI Basis section. As requested, removal efficiencies of key radionuclides are also provided below.

Removal Efficiency for Tanks C-105, C-106, C-109, C-111, and C-112:

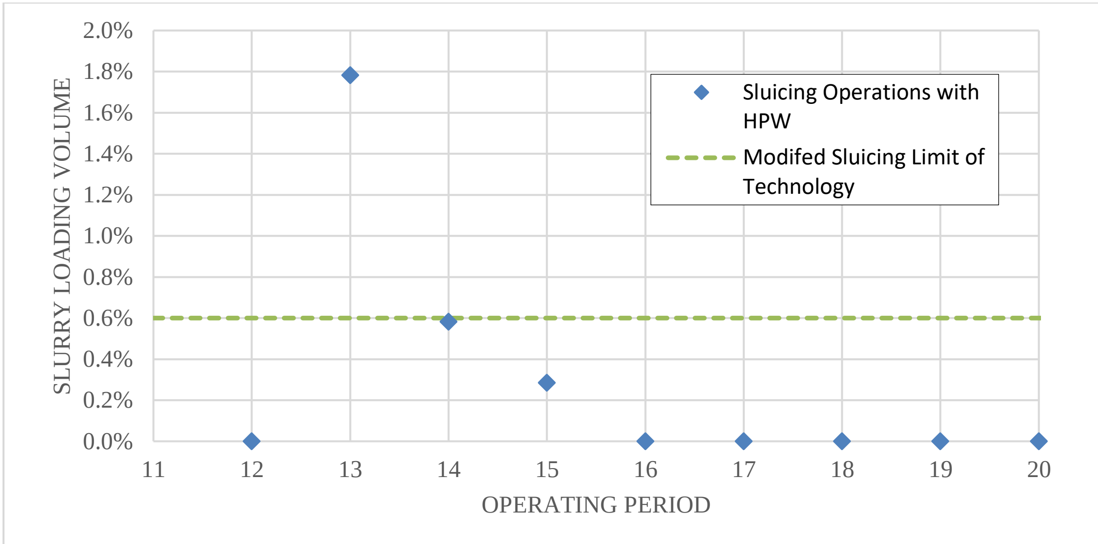
Tank C-105:

Waste retrieval had only recently been completed in Tank C-105 when the Draft WIR Evaluation was issued for review, and the formal RDR was not yet available. RPP-RPT-61449, *Retrieval Data Report for Single-Shell Tank 241-C-105*, has since been issued and will be made available to NRC staff.

The first retrieval technologies deployed in Tank C-105 were the Mobile Arm Retrieval System – Vacuum (MARS-V) , including high-pressure water (HPW) sluicing, which operated from September 2014 to September 2015. MARS-V was effective in removing approximately 75 percent of the starting waste volume. No efficiency charts were developed for this stage of retrieval. The campaign ended due to equipment failure.

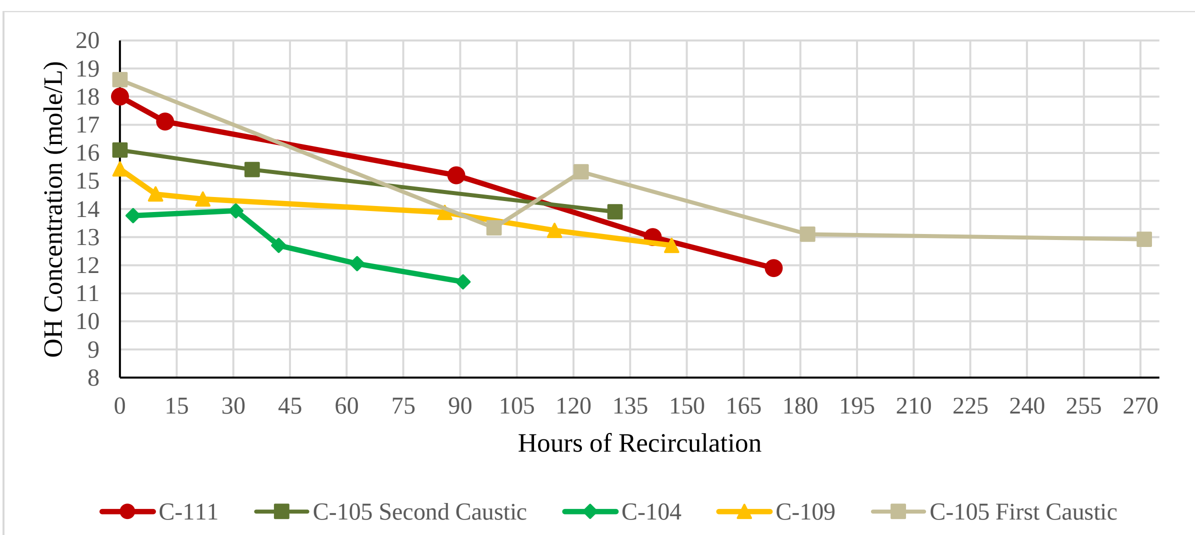
In 2017, MARS-V was replaced with an Extended Reach Sluicer System (ERSS), to be used with caustic dissolution. Supernate and HPW sluicing was conducted intermittently with caustic dissolution cycles starting in August 2017. ERSS sluicing operations with high pressure water were terminated in Tank C-105 on October 20, 2017. At that time, operations had continued for five consecutive periods without being able to retrieve any additional solids. Figure 2-4 from RPP-RPT-60717, *Retrieval Completion Certification Report for Tank 241-C-105*, reproduced below as Figure 2, depicts the slurry loading per operating period from October 14, 2017 to October 20, 2017 (operating periods 15 to 20). The dashed line represents the 0.6 volume percent limit specified in RPP-50910, *Single-Shell Tank Waste Retrieval Limit of Technology Definition for Modified Sluicing*.

Figure 2. Tank 241-C-105 Retrieval Slurry Loading (RPP-RPT-60717, Figure 2-4).



A second caustic dissolution cycle was then performed and reached the limits of the technology in November 2017. Hydroxide concentration and percent solids were plotted as shown in Figure 1 of RPP-RPT-60552, *Single-Shell Tank 241-C-105 Hard Heel Retrieval Completion Report*, reproduced below as Figure 3.

Figure 3. Hydroxide Concentration During Second Caustic Dissolution Compared to Previous C Farm Examples (from RPP-RPT-60552, Figure 1).

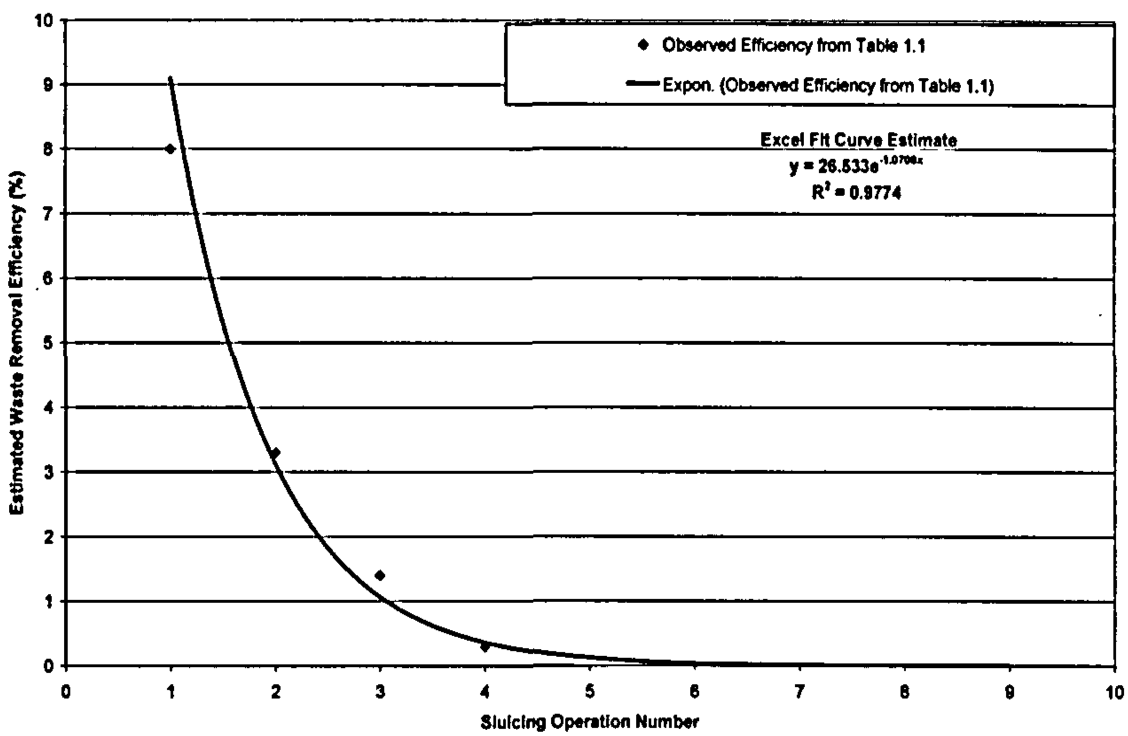


In summary, three technologies – MARS-V, ERSS, and caustic dissolution – were deployed to their practical limits in Tank C-105, resulting in retrieval of approximately 99 percent of the starting waste volume.

Tank C-106:
As discussed in Section 4.3.3.6.2 of the Draft WIR Evaluation, the sluicing campaign from November 1998 to October 1999 was effective in removing approximately 84 percent of the starting waste volume (i.e., waste volume was reduced from approximately 230,000 gallons to approximately 36,000 gallons) from Tank C-106. RPP-20577, *Stage II Retrieval Data Report for Single-Shell Tank 241-C-106*, discusses the criteria used to determine the limits of this technology, but no plots were generated for this phase of retrieval.

In 2003, a second retrieval campaign was conducted using oxalic acid dissolution and a modified sluicing process. Table 4-6 in the Draft WIR Evaluation presents tabular data showing the declining removal efficiency over subsequent batches of oxalic acid. These data are also represented in graphic form in Figure 5.4 in Appendix B of RPP-20577. The best-fit plot is duplicated below as Figure 4.

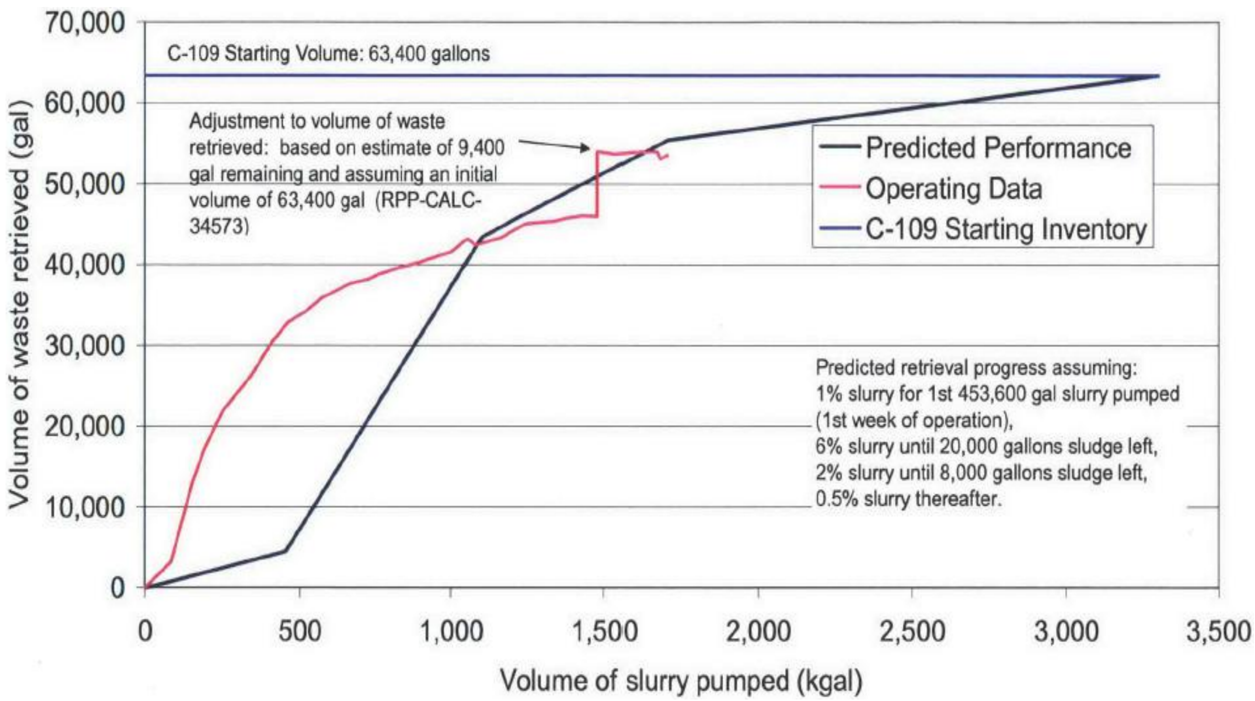
Figure 4. C-106 Modified Sluicing Efficiency - Exponential Evaluation.
(from RPP-20577, Appendix B, Figure 5.4)



In summary, two technologies – modified sluicing and caustic dissolution – were deployed to their practical limits in Tank C-106, resulting in retrieval of approximately 99 percent of the starting waste volume.

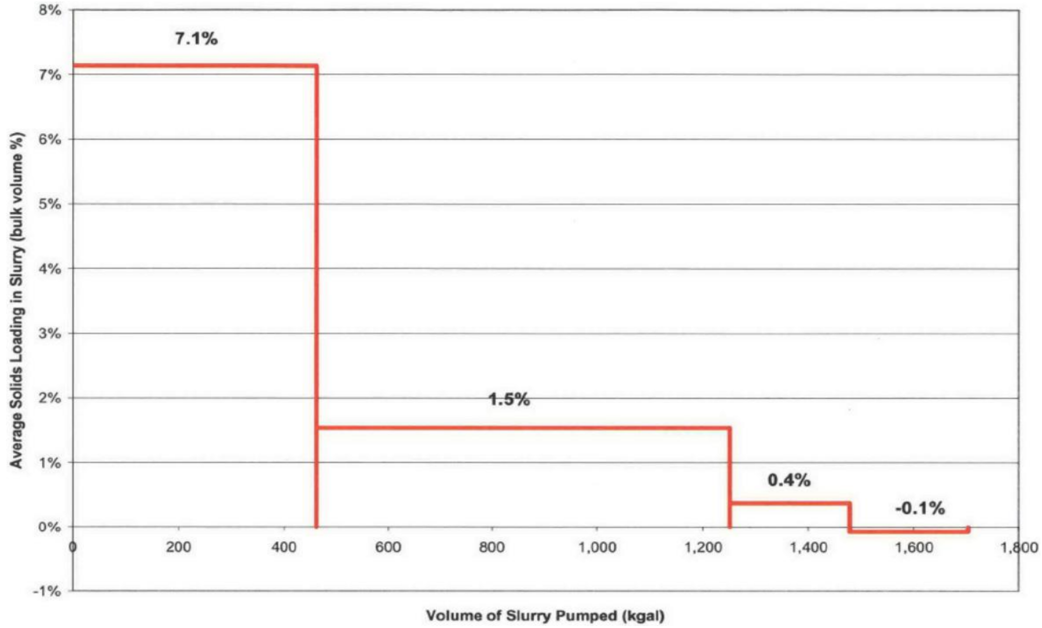
Tank C-109:
Waste retrieval in Tank C-109 consisted of three campaigns: modified sluicing, a FoldTrack MRT demonstration, and caustic dissolution. Sluicing began in June 2007 and reached the limits of technology in August 2007. Figure 4-21 from the Draft WIR Evaluation, reproduced below as
Figure 5, depicts removal efficiency for sluicing, which removed approximately 85 percent of the starting waste volume.

Figure 5. Tank C-109 Modified Sluicing Waste Retrieval System Performance.
(from DOE/ORP-2018-01, Figure 4-21)



Another representation of retrieval efficiency is provided in RPP-53824, *Retrieval Completion Certification Report for Tank 241-C-109*, Figure 2, reproduced below as
Figure 6. This depicts the depletion of readily mobilized sludge, based on solids loading in the slurry. The final days of operations show no net waste removal.

Figure 6. Solids Loading in Tank 241-C-109 Slurry (RPP-53824, Figure 2).



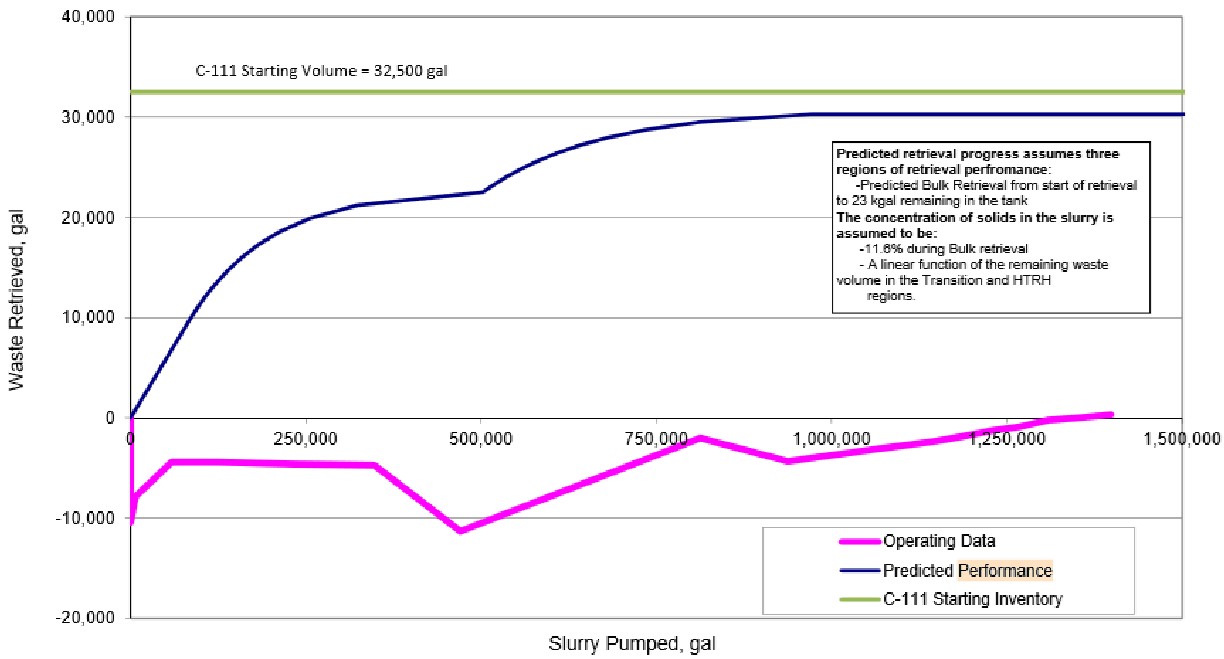
In June 2008, a demonstration of the FoldTrack MRT was conducted in Tank C 109 to evaluate its performance in association with sluicing. This activity removed approximately1600 additional gallons of waste from the tank. No credit was taken for the FoldTrack MRT as a separate retrieval technology in Tank C-109.

The caustic dissolution campaign was conducted in March 2012 through September 2012. This campaign had two distinct phases, each with multiple soak/pump cycles. Declining effectiveness after three cycles of the second phase led to the conclusion that the technology had reached its practical limits. For a detailed discussion of this determination, see Section 2.4 of RPP-53824.

In summary, two technologies – modified sluicing (with FoldTrack MRT demonstration) and caustic dissolution – were deployed to their practical limits in Tank C-109, resulting in retrieval of approximately 97 percent of the starting waste volume.

Tank C-111:
Waste retrieval in Tank C-111 consisted of two campaigns: modified sluicing, and ERSS combined with caustic dissolution. The modified sluicing system was operated from September 2010 to November 2010. This technology removed little or no waste (less than 1 percent), as shown in RPP-RPT-59363, *Retrieval Completion Certification Report for Tank 241-C-111*, Figure 2-2, reproduced below as Figure 7.

Figure 7. Tank 241-C-111 Bulk Retrieval Waste System Performance (RPP-RPT-59363, Fig. 2-2).



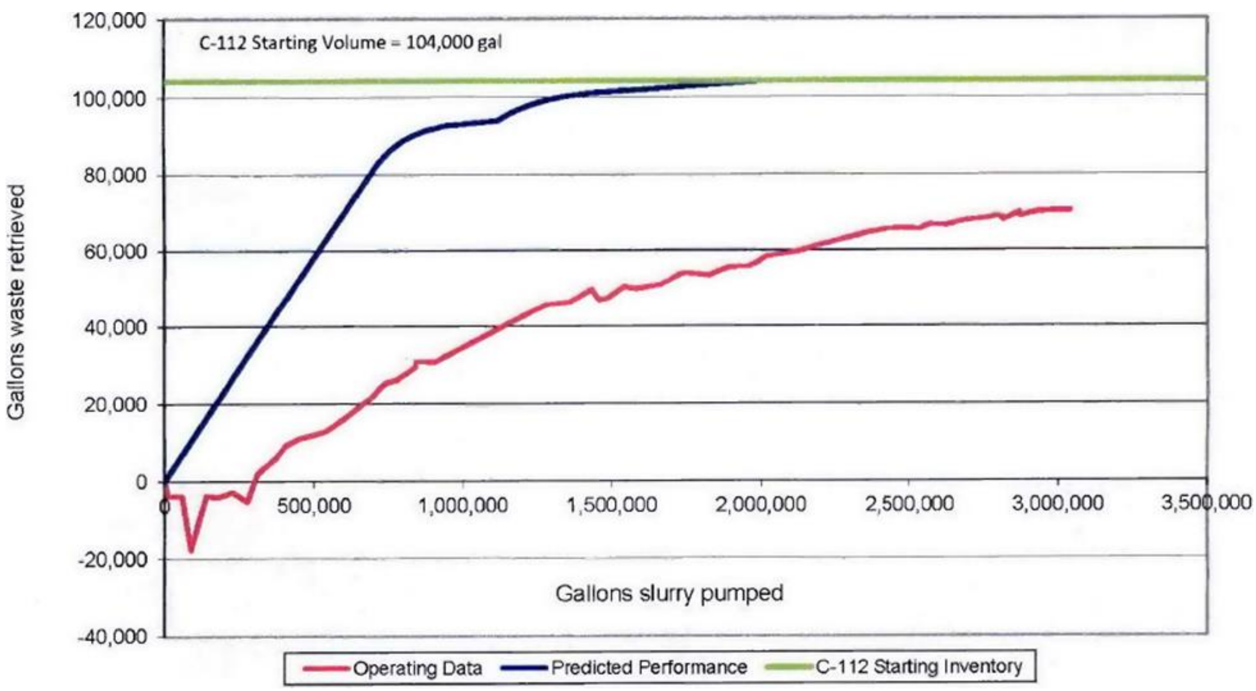
The second campaign consisted of HPW sluicing with an ERSS, combined with caustic dissolution, from October 2015 to March 2016. The hydroxide concentration and percent solids were plotted for Tank C-111 caustic retrievals as shown in RPP-RPT-60552, Figure 1 presented in the Tank C-105 response above. Declining effectiveness led to the conclusion that the process had reached its practical limits. For a detailed discussion of this determination, see Section 2.4 of RPP-RPT-59363.

In summary, three technologies – modified sluicing, ERSS with HPW, and caustic dissolution – were deployed to their practical limits in Tank C-111, resulting in retrieval of approximately 85 percent of the starting waste volume.

Tank C-112:
Retrieval in Tank C-112 was similar to Tank C-111, with a combination of sluicing and caustic dissolution. The sluicing was more effective, however, resulting in removal of approximately 67 percent of the starting waste volume before reaching the limits of that technology. The removal efficiency chart for Tank C-112 sluicing was provided as Figure 4-29 in the Draft WIR Evaluation, reproduced below as

Figure 8.

Figure 8. Tank C-112 Waste Retrieval Progress (DOE/ORP-2018-01, Figure 4-29).



Subsequent caustic dissolution cycles were able to remove additional waste, resulting in total retrieval of approximately 90 percent of the starting waste volume. For the discussion of the limits of technology determination, see Section 2.4 of RPP-RPT-58140, *Retrieval Completion Certification Report for Tank 241-C-112*. Application of a third technology was determined to be not practicable, as documented in RPP-56935, *Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-112*.

Removal Efficiency of Key Radionuclides:
Footnote #50 on page 4-68 of the Draft WIR Evaluation explains the calculation showing that the waste retrieval efforts in WMA C had removed an estimated 96 percent of overall total radionuclide activity, as well as 96 percent of waste volume. This was not meant to suggest that the radionuclide removal was assumed based upon volume removal. Radionuclide removal was calculated independently, based on the post-retrieval sampling results. This will be clarified in the Final WIR Evaluation. Overall pre- and post-retrieval inventories of key radionuclides for WMA C SSTs are shown in
Table 1 below.

Table 1. Key Radionuclide Retrieval Efficiencies for All 100-series and 200-series SSTs.

2002 vs 2019 Best Basis Inventory (BBI) Estimates, Rads decayed to 1/1/2020				
	Unit	**2002 [a]**	**2019 [b]**	**% Removed [c]**
Volume	kL	6.65E+03	2.38E+02	96.4
I-129	Ci	9.93E-01	1.39E-02	98.6
Cs-137	Ci	6.41E+05	9.20E+03	98.6
C-14	Ci	1.57E+01	9.12E-02	99.4
U-232	Ci	1.63E+01	3.59E-02	99.8
U-233	Ci	4.15E+02	2.58E+00	99.4
U-234	Ci	4.39E+01	2.97E+00	93.2
U-235	Ci	1.72E+00	1.54E-01	91.0
U-236	Ci	1.10E+00	4.30E-02	96.1
Np-237	Ci	5.72E+00	1.97E-01	96.6
Pu-238	Ci	4.42E+02	6.82E+00	98.5
U-238	Ci	3.76E+01	3.46E+00	90.8
Pu-239	Ci	1.83E+04	1.76E+02	99.0
Pu-240	Ci	3.22E+03	2.46E+01	99.2
Am-241	Ci	1.90E+04	1.49E+02	99.2
Pu-241	Ci	1.21E+04	9.61E+01	99.2
Pu-242	Ci	1.87E-01	3.07E-02	83.6
Sr-90	Ci	5.81E+06	1.90E+05	96.7
Tc-99	Ci	3.51E+02	2.31E+00	99.3
Total	Ci	6.50E+06	2.00E+05	**96.9**

Notes:
[a]2002 BBI estimates are based on data published in Appendix D.2 of DOE/ORP-2003-02, Rev. 0, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland, WA – Inventory and Source Term Data Package*.
[b]2019 BBI post-retrieval estimates are based on data retrieved from the Tank Waste Information Network Systems (TWINS) (TWINSa).
[c] Because the 2002 data include model-based estimates, this direct comparison with the 2019 sample-based data is only approximate, but represents the best available information.

Responses to Additional Observations in the RAI Basis section:

Tank C-104 (obstruction):
Section 4.3.3.4.2 of the Draft WIR Evaluation, page 4-31, lines 15-18 notes the obstruction was encountered during bulk sluicing and was removed, allowing approximately another 42,000 gallons of waste to be retrieved by sluicing. The remaining heel was then removed using caustic dissolution. Tank C-104 is one of the cleanest tanks in WMA C.

Tank C-108 (supernate solubility):
The statement regarding solubility of waste in AN-106 supernate, found in Section 4.3.3.8.2 of the Draft WIR Evaluation, was taken from RPP-53869, *Retrieval Completion Certification Report for Tank 241-*

C-108. The context is that after sluicing operations had successfully removed approximately 90 percent of the waste in the tank, then "the bulk of the remaining waste was mostly solids (hard heel) not moveable by sluicing action and insoluble in AN-106 supernate." This is not meant to imply that the primary purpose of AN-106 supernate in the sluicing process was to "dissolve" the SST waste. The DST supernate is primarily used as a motive force and carrier solution in sluicing, and in this case its usefulness had been exhausted. Hot water, acid, and/or caustic are used when additional solubility is required for hard heel waste residuals. As discussed previously, caustic dissolution was used for hard heel retrieval in Tank C-108.

Switching to use of supernate from another DST would not have been practical. Retrieval of waste from Tank C-108 using DST AN-106 supernate as a sluicing medium was selected and approved by DOE and Washington State Department of Ecology (Ecology) (see RPP-22393, *241-C-102, 241-C 104*, *241-C-107*, *241-C 108, and 241-C-112 Tanks Waste Retrieval Work Plan*). After determining the best available DST to pair with a given SST, and gaining regulatory approval, establishing an SST-DST supernate sluicing system is a multi-year, multi-million dollar effort involving installation of pumps, over-ground transfer pipelines, control trailers, and other equipment at each of the paired tanks. Use of supernate from another DST would require this entire process to be repeated, whereas use of caustic dissolution was the logical next step.

Tank C-108 (riser access):
Riser location is a limiting factor in retrieval planning, among many other factors. Where the constraint is significant, clearing legacy equipment from additional risers, and/or addition of new risers, have been considered. For Tank C-108, after the tank was retrieved to the limits of the technologies used (RPP-RPT 55896, *Retrieval Data Report for Single-Shell Tank 241-C-108*, and RPP-53869, *Retrieval Completion Certification Report for Tank 241-C-108*), further retrievals using additional technologies or construction of additional access locations were determined to be impracticable for this tank (RPP-52290, *Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108*).

Tank C-109 (fluoride concentration):
Although the fluoride concentration appears to be increasing as indicated in Figure 4-22 in the Draft WIR Evaluation, this is an artifact of the limited number of points on the graph. The reaction had gone to completion prior to the final sample. Section 2.4.2 of RPP-53824, *Retrieval Completion Certification Report for Tank 241-C-109*, provides the following explanation:

> *"All steps in the chemical cleaning process using caustic solutions for tank C-109 were performed as described in the process control plan (RPP-PLAN-51371). Analytical results from samples obtained during the metathesis step confirm that the reactions had consumed the hydroxide and had gone to completion. Results from the caustic solution sampling indicated that more than enough of the reactant was present (i.e., caustic solutions in the metathesis step and water in aluminate dissolution step) to support the objectives of this deployed chemical retrieval process. Systematic efforts were made to contact all areas of the waste with the caustic solutions and/or water. Observation of the operations, discussion with operators, and observance of the waste itself (e.g., reduction of waste piles) confirm that the efforts to contact the caustic solution and the residual wastes were successful. Continued deployment of this chemical retrieval process would not result in appreciably reducing the amount of waste remaining in tank C-109 and therefore the risk from the residual wastes in tank C-109."*

Based on the performance metrics examined with the implementation of the caustic technology and consideration of the factors specified in the Consent Decree, DOE concluded that the caustic cleaning retrieval technology was deployed to the limit of the technology at Tank C-109 (RPP-53824).

Tank C-110 (MRT effectiveness):
Even when it was fully operational, the FoldTrack MRT deployed in Tank C-110 did not prove to be significantly helpful in retrieving the solids in this application. The FoldTrack MRT was designed to push waste toward the pump with the intent to grind or size-reduce the solids using a blade and high pressure supernate; this did not appear to be effective, as the FoldTrack MRT tended to ride over the solids. Later the FoldTrack MRT was stationed in a fixed position near the pump and used as a backstop during sluicing, with the sluicer being responsible for the work being accomplished. The hard heel retrieval results shown in Figure 4-27 of the Draft WIR Evaluation may be misleading in this regard, because sluicer and FoldTrack MRT operations were conducted simultaneously. As the graph shows, after the first 21 days of operation, the amount of waste retrieved remained relatively flat as FoldTrack MRT operating hours continued to accumulate. After the FoldTrack MRT failed, the final hot water soak and rinse removed most of the remaining waste and the Consent Decree goal ($\leq$ 360 ft^3 [10 m^3] of residual waste volume) was achieved. At that point, based on the performance metrics examined and consideration of the factors specified in the Consent Decree, DOE concluded that the process retrieval technologies of the FoldTrack MRT and high pressure water dissolution were deployed to the limits of the technologies at Tank C-110 (See Section 2.4.2 of RPP-56214, *Retrieval Completion Certification Report for Tank 241-C-110*).

Based on the experience gained with the FoldTrack MRT in Tank C-110, DOE and Ecology determined that MARS, MARS-V, ERSS and caustic dissolution were the best technologies for the remaining WMA C tanks, as documented in subsequent Tank Waste Retrieval Work Plans.

RAI 1-3

Comment
An insufficient basis was provided in the Draft WIR Evaluation that pits, diversion boxes and pipelines were well-flushed, thereby removing waste containing key radionuclides to the maximum extent technically and economically practical.

Basis
DOE indicated that operational practices were to flush components after use. DOE stated that additional removal of waste from ancillary equipment was not necessary because the equipment was well-flushed.

However, some components were, based on available records, clearly not flushed.

- For instance, cascade lines were gravity drained and in some cases the source of leaks from long-term overfilling conditions.
- Diversion boxes (e.g., 152-CR, 151-C) experienced significant leaks. It is not clear how the material that may reside in the leak pathway from the interior to the exterior of the box would have been flushed.
- There are numerous records of piping that "failed" and was taken out of service. The report RPP-RPT-38152 identified 11 pipes that failed. It is not clear how the piping was flushed if it failed.

Path Forward

- Please provide the records available that indicate which components were flushed at the time they were taken out of service.
- Provide present radiation level measurements inside the diversion boxes and pits, including which radionuclides are the source of the radiation (if known).
- For ancillary equipment that was not well-flushed, provide information that key radionuclides have been removed to the maximum extent technically and economically practical.

DOE Response
The following information addresses the basis for determining that the waste, including key radionuclides, has been removed or will be removed to the maximum extent that is technically and economically practical from pits, diversion boxes, and pipelines.

Cascade Lines:
As the Basis section points out, the cascade lines operated only under gravity flow and cannot be flushed. Partly for this reason, <u>all</u> of the cascade lines in WMA C were assumed to be "plugged" with waste for inventory purposes in the WMA C PA. See the DOE response for RAI 1-1 for the basis that it is not technically and economically practical to remove these pipelines.

Pits and Diversion Boxes:
Pits and diversion boxes served as secondary containment for the waste transfer system and were not intended to store tank waste. These structures were designed with floor drains to carry any leaked waste, along with flush water or atmospheric water, to nearby storage tanks. Pits and diversion boxes were required to be equipped with working leak detection devices interlocked to stop the transfer pump, or alarm. Constant surveillance was required if the leak detection device was not operating (T0-025-001, *Tank Farm Transfer Procedure – General*).

These structures were routinely flushed or otherwise decontaminated whenever entries were required. For example, a leak occurred in diversion box 241-C-151 in 1985 (SD-RE-EV-0001, *Investigation Report of January 1985 241-C-151 Diversion Box Contamination Incident*). Prior to opening the diversion box after the event, operators flushed the interior with water through access ports in the lid. When the diversion box was opened after flushing, there was no standing water, indicating that the drain was functioning as designed. Some dirt, sand and debris were visible in the bottom of the box. The report notes "most diversion boxes are found to be damp when opened for routine work" (i.e., no standing water). This example supports the assumption in the WMA C PA that based on operational practices, pits and diversion boxes contain no measurable volume of waste beyond surface contamination,[5] and thus waste, including key radionuclides, has been removed to the extent technically and economically practical.

Current interior radiation readings are not available, as all pits and diversion boxes at WMA C are currently sealed and covered with weather-resistant foam. For reference, the most recent applicable area survey (COR-1800255, *Radiological Survey Report for 200E/241C/C101-C112, C201-204, and CR Vaults*) is included as Attachment A of this document. Although there is no evidence of more than superficial amounts of residual waste within pits and diversion boxes, DOE expects to perform video inspections, including radiation readings, as part of the detailed closure planning process for these components.

Failed Pipelines:
Historical and current operational practices and engineering standards for pipelines required waste transfers to be performed under pressure with routine flushing following transfers (with the exception of cascade lines). For example, ARH-CD-237, *Standard for Hydrostatic Testing of Existing Direct-Buried Waste Lines*, specifies that in-service transfer lines shall be pressure tested a minimum of once per calendar year using raw water at 200 psig. If a transfer line failed the test as indicated by a minimum designated pressure drop, the line was not used. Engineering standard TFC-ENG-STD-26, *Waste Transfer, Dilution, and Flushing Requirements*, provides the current requirements used in developing detailed procedures for each waste transfer. TFC-ENG-STD-26, Attachment A, states that "A flush of transfer lines (and jumpers and pumps) is required following waste transfers to remove residual waste." The standard provides detailed pre-transfer and post-transfer flushing requirements for waste transfer equipment, including standard practices and variations depending on waste type, temperature, specific gravity, piping slope, and other factors.

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[5] The latest dates for transfers into the WMA C tanks range from 1969 to 1979; the tanks were taken out of service in 1980 (WHC-MR-0132, *A History of the 200 Area Tank Farms*). Transfers out of the tanks after 1980 were largely for interim stabilization or retrieval, and new above-ground transfer lines were eventually installed. Routine flushing of pits became less common in the later years of operations as some of the SSTs were designated as known or suspected leaking tanks, and water additions were restricted. If flushing was not an option, any required decontamination would be done by application of absorbents and fixatives which would then be wiped or scraped off the surfaces for disposal. However, no known contamination events occurred in WMA C in this time period. The most recent pit entry in WMA C was in 2009, as documented in TFC-WO-09-3624, *Remove Burst Disc and Indicator in C-104 B-Pit*. In this example, the pit drain had been sealed with grout, so no flush water was added to the pit. Instead, fixative was applied to the walls and floor prior to the manned entry, as a precaution for contamination control. Surveys did not indicate the need for decontamination.

As indicated in the RAI Basis section, those pipelines known or suspected to have developed leaks during a waste transfer may not have been flushed prior to removal from service.[6] Such lines would still have been drained to the extent practical (WHC-SD-WM-ES-259, *Single-Shell Tank Saltwell Transfer Piping Evaluation*). However, it is not technically and economically practical to remove additional waste from these pipelines. RPP-PLAN-47559 provides a detailed examination of the costs, risks, and benefits of characterizing or removing waste transfer pipelines, and Section 7.3.1 concludes that "further pipeline characterization or supplemental closure actions for protection of human health and the environment are not necessary when risks are balanced against the high cost and schedule impacts associated with these actions."

[6] The report cited in the Basis Section, RPP-RPT-38152, *Data Quality Objectives Report Phase 2 Characterization for Waste Management Area C RCRA Field Investigation/Corrective Measures Study*, contains an apparent typographical error in the statement that 11 pipelines were known or suspected to have failed in WMA C. The subsequent paragraphs in Section 2.3.3 and Table 2-2 of RPP-RPT-38152 identify only four known and one suspected pipeline failures. Unfortunately, this error was repeated in RPP-PLAN-47559. However, the exact number of such failed pipelines does not change the conclusion that further waste removal from failed pipelines is not technically and economically practical.

3.0 RADIONUCLIDE INVENTORY AND RELEASE RATES

RAI 2-1

Comment
An insufficient basis was provided that demonstrates that procedures were effectively implemented to ensure proper quality assurance (QA) of the Draft WIR Evaluation and supporting analyses.

Basis
During the review process, staff identified discrepancies or inconsistencies in documentation, inputs, or other aspects of the calculations. These observations include:

- The inventory assigned for the C-301 tank and 244-CR vault in Table 3-15a of the WMA C PA do not match the values provided in Table 4-3 of the same document or Table 2-5 of the Draft WIR Evaluation.
- There is a portion of the WMA C source term that was inadvertently modeled as not being covered by the final closure cap, resulting in faster transport to the water table for a portion of the residual waste.
- The modeling of water fluxes uses a point below the center of the tank that is subject to a significant “tank shadow” effect, but is applied to all releases from the tank. Water flow and saturation at the periphery of an intact tank would be expected to be much higher.
- The intruder dose results for the pipelines 5% full of waste could not be verified. DOE estimated the dose to the acute intruder from drilling through a 0.137 meter (m) thick layer in tank C-301 as 21.1 mrem. DOE estimated the dose to the acute intruder from drilling through a 0.0253 m thick layer in the 244-CR vault as 3.91 mrem. The doses are directly proportional to the thickness of the waste layer. DOE estimated the dose from drilling through a 5% full pipeline as 36.0 mrem. The 5% full pipeline has a diameter of 7.62 centimeter (cm) and so an equivalent waste layer thickness of <0.5 cm. Since the composition of the waste is the same in each of these components it is not clear why the dose would be 36.0 mrem.
- The minimum value for the Pu distribution coefficient (Kd) provided in Table 6-5 of the WMA C PA does not agree with the value used in the model (7.1E5 vs. 7.14E5). GoldSim is the software package used to develop the WMA C PA model.
- Table 6-16 on page 6-111 of the WMA C PA indicated that the H2 sand layer has a middle portion consisting of 20 cells but the GoldSim model has 80 cells.
- The WMA C PA model lists the isotope Pb-210 but no inventory assigned to it. Parent radionuclides are present that would have expected to produce Pb-210 during the ~70 years of operations. During pre-RAI interactions DOE explained (ADAMS Accession No. ML18275A207) why Pb-210 was not included but that explanation was not provided in the WMA C PA documentation.
- The porosity of the soil backfill is not assigned a value of 1. DOE indicated that the porosity of other materials are assigned a value of 1 because porosity is included in the tortuosity parameter and the approach is conservative.

- The value for longitudinal dispersivity provided for 100 series tanks is 4 m multiplied by the SZ_dispersivity_multiplier parameter whereas the value use for the 200 series tanks is 10 m multiplied by the SZ_dispersivity_multiplier parameter.
- Relative aqueous permeability parameters are contained in the STOMP input file that were not provided in the WMA C PA documentation.
- The Henry's Law constant for tritium appears to be very large and inconsistent with values commonly used. If all the tritium ends up in the air pathway and the air pathway has large dilution factors, this approach would be non-conservative.

The NRC staff has performed a risk-informed review of the Draft WIR Evaluation and Performance Assessment. In order for the risk-informed process to be effective, there should be high confidence in the results of the calculations. Staff acknowledges that development of the analyses and documentation is a large effort involving many different people and groups. This amplifies the importance of applying strict quality assurance procedures and verifying that the procedures have been implemented effectively. Most of the discrepancies listed above are not believed to have a significant impact on the decisions. However they were pervasive enough to warrant a request for additional information to ensure the results of the calculations have been properly verified. These discrepancies were not limited to the highest-level documents reviewed (e.g., the Draft WIR Evaluation and WMA C PA), but were also found in the supporting documents (e.g., inventory reports) where errors were identified and values were updated in new versions of reports.

Path Forward

Please provide the QA procedures that were applied to development of the Draft WIR Evaluation, the WMA C PA, and supporting documents and models. Provide a qualitative description of how analyses are reviewed and checked, including how much time is afforded to the reviewers. Provide examples of records (e.g., environmental model calculation files) demonstrating how the performance assessment analyses were reviewed and checked. Describe the process for evaluating and resolving errors identified in analyses that were previously approved.

DOE Response

Quality Assurance Process and Examples:

The QA aspects of development, application, and preservation of environmental models used to support regulatory decision-making and analysis are described in the WMA C PA (RPP-ENV-58782), Section 11, *Quality Assurance*. These aspects of the PA are conducted under a general project plan that implements the requirements of DOE O 414.1D, *Quality Assurance*, and the direction related to modeling in EM QA-001, *EM Quality Assurance Program*, as well as U.S. Environmental Protection Agency (EPA) guidance provided in EPA/240/R-02/007, *Guidance for Quality Assurance Project Plans for Modeling*. This plan provides for modeling to be performed in a framework for quality assurance of the full project lifecycle, with integrated control of models, implementing software, applications, and supporting information as depicted in Figure 11-1 in Section 11 of the WMA C PA.

The controlling project plans for these general guidelines are found in:

- TFC-PLN-155, *General Project Plan for Environment Modeling*
- TFC-PLN-02, *Quality Assurance Program Description* - Section 2.7.29 in Part II (Model Development, Use, and Validation)

WMA C PA Section 11, *Quality Assurance*, describes the process for model documentation, control, and preservation. Features of this process include documentation of model development in model package reports (a quality configuration item); documentation of model applications in an Environmental Model Calculation File (EMCF), also a quality configuration item; and preservation of models, model applications, and model basis information (non-direct measurements) in an integrated archive. At the time the WMA C PA documentation was prepared, full checking and senior review of EMCFs were required as part of this process.

EMCFs are prepared, documented, reviewed and approved per TFC-ESHQ-ENV_FS-C-05, "Preparation and Issuance of Model Package Reports and Environmental Model Calculation Files." This procedure implements requirements of TFC-PLN-155 for quality assurance with specific application to environmental models and associated modeling calculations. The version of the procedure used in the preparation and issuance of EMCF's at the time the WMA C PA documentation was prepared in FY 2016 was:

- TFC-ESHQ-ENV_FS-C-05, Rev. A-1, "WRPS Environmental Model Calculation Preparation and Issuance"

The procedure does not specify time limits for the reviewing process. Depending on the complexity of each calculation, the Responsible Manager (RM) proposes a time frame for each review; however, it is up to the reviewer(s) to accept the period or negotiate additional time. Each EMCF is verified by a checker (see Section 4.2.2, *Calculation Checking*), and reviewed and approved by a Senior Reviewer and the RM or a designee (see Section 4.2.3).

Examples of EMCFs provided in this response include:

- RPP-CALC-60448, Rev. 0, *WMA C Performance Assessment Contaminant Fate and Transport Model To Evaluate Impacts To Groundwater*
- RPP-CALC-60451, Rev. 0, *WMA C System Model for Performance Assessment of Base Case, Uncertainty Analysis and Sensitivity Analysis*

The process for evaluating and resolving errors identified in analyses associated with model package reports and EMCFs that were previously approved would follow the procedural steps identified in TFC-ESHQ-ENV_FS-C-05, Rev. B-0, "WRPS Preparation and Issuance of Model Package Reports and Environmental Model Calculation Files."

Objective evidence of the review and approval of each EMCF are shown in Form A-6006-716, "EMC Cover Page." Note that errors identified in the reviewing process are resolved on a Review Comment Record (Form A-6400-090) or other accepted method, such as redline/strikeout of electronic or hard copy files and documents, email, or equivalent comment form as directed by the preparer. Comments that are resolved in this process do not become records.

Since February 2018, full checking and senior review of model package reports is now required as part of this process. As part of the review of the WMA C PA effort, the technical review team representing the Low-Level Disposal Facility Review Group (LFRG) considered the system of software configuration and model documentation used to support the PA to be very structured and controlled, and recognized it to be one of six best management practices identified in the review.

Responses to Examples Identified by NRC in the RAI Basis Section:

In the RAI Basis section, NRC identified discrepancies or inconsistencies in documentation, inputs, or other aspects of the calculations to be addressed. The following paragraphs provide responses to these observations with the observation from the Basis section identified in italics followed by the DOE response:

- *"The inventory assigned for the C-301 tank and 244-CR vault in Table 3-15a of the WMA C PA do not match the values provided in Table 4-3 of the same document or Table 2-5 of the Draft WIR Evaluation."*

The inventory entries for the C-301 Catch Tank and the CR-Vault in Table 4-3 of the WMA C PA are in error. The inventory entries for the same two facilities in Table 2-5 of the Draft WIR Evaluation is also in error because it used information provided in Table 4-3 of the WMA C PA.

The correct entries for these two facilities are provided in Table 3-15a in Section 3 of the WMA C PA. Table 3-15a of the WMA C PA is based on data from the files *C_2014* and *C_3 Ancillary Equipment* found in the Appendix C in RPP-RPT-42323, Rev. 3, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*.[7]

The inventories values used in the GoldSim-based System Model are the same as those provided in Table 3-15a in Section 3 of the WMA C PA and in files *C_2014* and *C_3 Ancillary Equipment* in Appendix C in RPP-RPT-42323, Rev. 3. The error associated with Table 4-3 of the WMA C PA and in Table 2-5 of the Draft WIR Evaluation did not affect any of the calculations documented in the WMA C PA. These entries will be corrected in updates to the WMA C PA and in the Final WIR evaluation.

- *"There is a portion of the WMA C source term that was inadvertently modeled as not being covered by the final closure cap, resulting in faster transport to the water table for a portion of the residual waste".*

The engineered surface barrier system that will be used at WMA C at closure has not yet been designed. As an approximation in the WMA C PA, the lateral extent of the barrier was assumed to be the same as the backfill area within the tank farm, which represents generally the area within which most of the tank infrastructure lies. DOE considers the areal extent of the barrier system modeled to be a conservative modeling assumption and not a quality assurance issue. The temporal and spatial distribution of recharge rates considered in the WMA C PA evaluation are also conservatively assumed.

As corrective measures are implemented before closure, DOE expects the final barrier system will cover more of the waste transfer line system and some of the unplanned releases near and just outside of the tank farm area. A more detailed analysis of this barrier system will be performed to support the final design and implementation of this engineered barrier system at closure. The area of the final closure cap will likely be considerably larger. One option would be the placement of a surface barrier not only cover the area of the tanks but other areas outside of the tank farm fence line in areas where waste leaks and releases have occurred in the past. Another option would involve a much larger surface barrier that would not only cover WMA C but also a nearby broader area associated the tank farms within A-Complex Area of 200 East area. Once the extent of the surface barrier is decided, the impact of this change in the WMA C PA will be evaluated through the Unresolved Waste Management Question (UWMQ) process. This

[7] RPP-RPT-42323 was revised from Rev. 3 to Rev. 4 concurrent with the development of this document. The WMA C PA and the Draft WIR Evaluation relied upon data from RPP-RPT-42323 Rev. 3. Some of the new analyses provided herein reference updated data in Rev. 4. Every effort has been made to distinguish between the revisions wherever cited.

evaluation process may result in the preparation of a special analysis related to this issue (DOE-STD-5002-2017, *Disposal Authorization Statement and Tank Closure Documentation*).

- *"The modeling of water fluxes uses a point below the center of the tank that is subject to a significant "tank shadow" effect, but is applied to all releases from the tank. Water flow and saturation at the periphery of an intact tank would be expected to be much higher."*

DOE considers the modeling of water fluxes to be a modeling assumption, not a quality assurance issue. The appropriateness of the modeling assumption has been thoroughly evaluated, as discussed in the following paragraphs.

Due to configuration of the tanks, some flow diversion around the tank will occur leading to a "tank shadow" effect underneath the tank and a focusing of water flow between the tank structures. These effects are illustrated in Figure 6-34 of the WMA C PA. In developing the source-term release to the vadose zone, the WMA C PA used a flow-field abstraction approach where the flow-field from the 3-D STOMP model is abstracted and implemented in the GoldSim-based system model. For this source-term release modeling, the diffusive length is selected to be the minimum thickness of the concrete and grout layer located at the tank bottom. This approach is deemed conservative based on the evaluation of tank geometry and the assumption that residual waste is located on the tank bottom as a thin layer[8]. If residual waste were assumed elsewhere, such as along the sidewalls, then appropriate diffusive pathways would also need to be chosen to reflect the increased diffusive length through the thicker part of the base mat concrete and side-wall concrete.

As shown in Figure 6-7 of the WMA C PA, the base mat and side-wall concrete thicknesses are greater away from the tank bottom and could lead to doubling of the diffusive thickness. Given the small effective diffusion coefficient and the retardation assumed for the concrete, an increase in diffusive length will lead to a lower contaminant mass flux than has been modeled in the WMA C PA. This is shown through a sensitivity case presented below where diffusive length for the concrete (and grout layer) is adjusted along with the concentration boundary condition outside the tank wall.

In the first sensitivity analysis, a zero-concentration boundary condition is applied at the edge of the C-105 tank bottom to approximate conditions that could occur due to flow focusing, as it occurs between the tanks. This is a bounding calculation that maximizes the assumed concentration gradient and the diffusive flux from the tank. Other than the placement of zero-concentration boundary condition, no other change is made to the Tank C-105 transport model. As a result, the diffusive thickness remains unchanged to 8 inches (20 cm) as in the base case.

A second sensitivity analysis was conducted by holding the zero-concentration boundary as in the first sensitivity case but increasing the diffusive thickness to be twice that of first sensitivity case (or the base-case) to represent the increase in concrete thickness at the sidewalls.

The results for the two sensitivity cases along with the base-case are presented in Figure 9 below in terms of diffusive flux of Tc-99 from Tank C-105. As can be seen, the diffusive flux increases in the first sensitivity case (orange line) compared to the base-case (dashed blue line) due to increased concentration gradient. However, the diffusive flux is appreciably reduced in the second sensitivity case (black line) indicating that the transport across increased thicker concrete (and grout) layer at the sidewall impacts the

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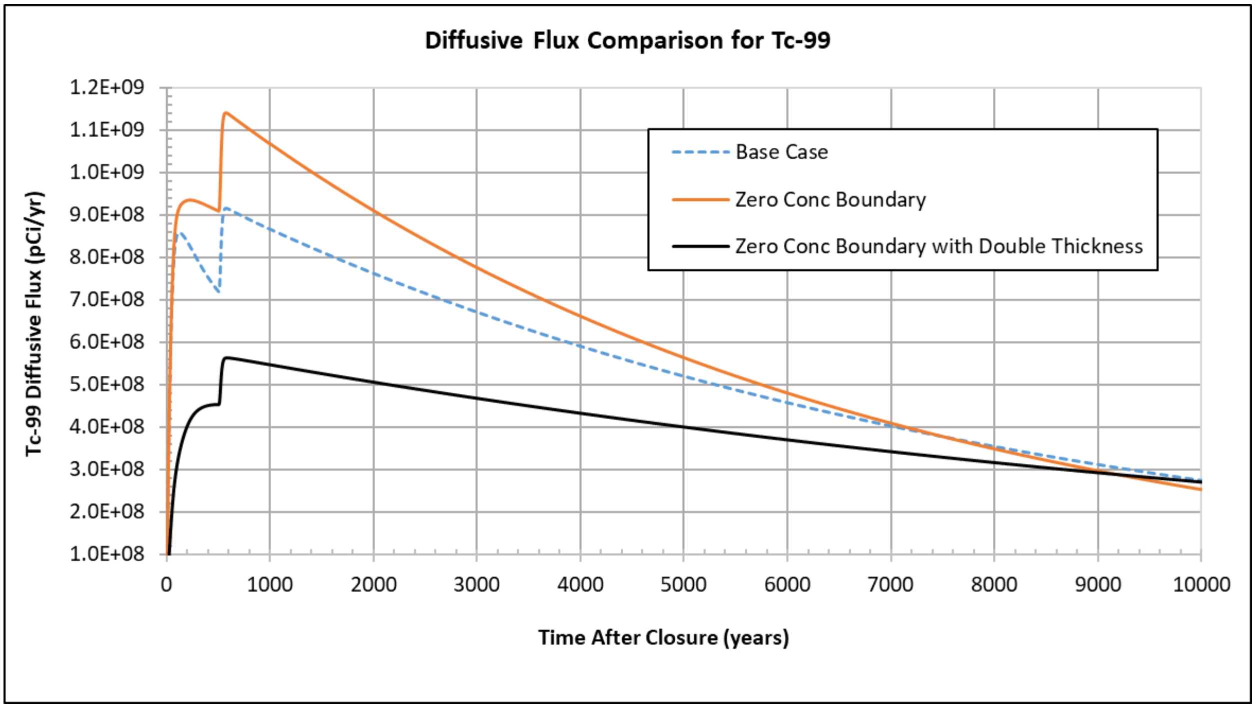
[8] As shown in Tables 3-19 and 3-20 of the WMA C PA, the majority of the residual waste volume is located at the tank dish bottom. However, some residual waste is on the stiffener rings and walls and in-tank equipment. The diffusive pathway lengths can be quite variable due to thicker concrete at the side wall and side of the base slab.

flux of Tc-99 notwithstanding the increased concentration gradient due to combination of the increased diffusive length and retardation. These results help illustrate that the base-case source-term release model conceptualization is reasonably conservative. Given that the minimum diffusive length occurs near the bottom of the tank and base-case source-term release modeling is performed conservatively, the flow-field is chosen appropriately to be consistent with the conceptualization of diffusive lengths and areas.

Figure 9. Diffusive Flux Model of Tc-99 from Tank C-105.



Additionally, a variety of sensitivity cases have been performed where the tank structure is assumed to be degraded at various times (WMA C PA Section 8.2.5; Figure 8-48) and effective diffusion coefficient is varied (WMA C PA Section 8.2.7; Figure 8-51). These results provide information on relative impacts if the safety functions associated with the concrete barrier are modified. In all cases, the peak concentrations for Tc-99 remains well below the drinking water standards.

In summary, DOE considers modeling of water fluxes as an assumption, which needs to be consistent with the conservative conceptualization of the source-term release modeling. This is not a QA issue.

- *"The intruder dose results for the pipelines 5% full of waste could not be verified. DOE estimated the dose to the acute intruder from drilling through a 0.137 meter (m) thick layer in tank C-301 as 21.1 mrem. DOE estimated the dose to the acute intruder from drilling through a 0.0253 m thick layer in the 244-CR vault as 3.91 mrem. The doses are directly proportional to the thickness of the waste layer. DOE estimated the dose from drilling through a 5% full pipeline as 36.0 mrem. The 5% full pipeline has a diameter of 7.62 centimeter (cm) and so an equivalent waste layer thickness of <0.5 cm. Since the composition of the waste is the same in each of these components it is not clear why the dose would be 36.0 mrem."*

NRC's comment on these inadvertent intruder results is a misinterpretation of results and not a QA issue. The results noted by NRC are taken from Table 9-7 in Section 9 of the WMA C PA. The footnote in Table 9-7 indicates that the peak doses are calculated at 500 years after closure for all sources except for the pipeline source, which is calculated at 100 years after closure.

- *"The minimum value for the Pu distribution coefficient (Kd) provided in Table 6-5 of the WMA C PA does not agree with the value used in the model (7.1E5 vs. 7.14E5). GoldSim is the software package used to develop the WMA C PA model."*

The Pu Kd values (mL/g) for grout/concrete used for Pu (7.14E+01 ml/g) provided in Table 6-5 of the WMA C PA reflect values for Pu as recommended in the cited reference (NAGRA NTB 02-20, *Cementitious Near-Field Sorption Data Base for Performance Assessment of an ILW Repository in Opalinus Clay*). The minimum value of the Kd (mL/g) for grout/concrete was slightly rounded to 71 ml/g in the GoldSim-based system model implementation to better reflect the number of significant figures in the value. DOE does not believe this rounding of the Kd to be a significant error or misrepresentation of adsorption of Pu in grout and concrete in the overall WMA C PA analysis.

- *"Table 6-16 on page 6-111 of the WMA C PA indicated that the H2 sand layer has a middle portion consisting of 20 cells but the GoldSim model has 80 cells."*

DOE acknowledges the discrepancy related to the grid discretization used to represent the H2 unit in GoldSim-based system model in Table 6-16 in the WMA C PA. The text on p. 6-107 (line 22) of the WMA C PA correctly describes the implemented grid discretization, and Table 6-16 needs to be updated to be consistent with that description when the WMA C PA is updated to respond to NRC comments.

- *"The WMA C PA model lists the isotope Pb-210 but no inventory assigned to it. Parent radionuclides are present that would have expected to produce Pb-210 during the ~70 years of operations. During pre-RAI interactions DOE explained (ADAMS Accession No. ML18275A207) why Pb-210 was not included but that explanation was not provided in the WMA C PA documentation."*

As mentioned in the pre-RAI teleconference on August 20, 2018, the Pb-210 initial inventory has not been estimated as mentioned in Section 4.1 of the WMA C PA, but will in-grow in the GoldSim-based system model over time from decay of U-238 and U-234. Given the time scales of the analysis, taking account of ingrowth of Pb-210 during the operations to produce an estimate of the Pb-210 inventory at closure would produce negligible differences in the available inventory at future times. Furthermore, the analysis shows that Pb-210 is relatively immobile and is not a risk-significant radionuclide. If requested, an initial inventory of Pb-210 could be estimated and considered in future analyses. DOE considers the initial inventory of Pb-210 to be an assumption of the analysis, not a quality assurance issue.

- *"The porosity of the soil backfill is not assigned a value of 1. DOE indicated that the porosity of other materials are assigned a value of 1 because porosity is included in the tortuosity parameter and the approach is conservative."*

The soil backfill material is used primarily for modeling transport from the pipelines. The soil backfill material is chosen to represent the contaminated zone within the pipeline diameter (3 in. [0.076 m]). A material property is needed to model diffusive releases from the pipeline zone to the vadose zone. The primary transport for the pipeline source term occurs via advection; the effect of diffusion is secondary.

To model diffusive transport through the 3 inch thickness of the pipeline, a simplification was made due to lack of knowledge on how the tortuosity would vary as a function of saturation. The implementation set the tortuosity parameter to a value of 1, but included the porosity explicitly to maximize the diffusive conductance. This can be better understood by evaluating Equation 6-3 of the WMA C PA. Both tortuosity and moisture content (porosity multiplied by saturation) multiply with the free water diffusivity. Holding the tortuosity equal to 1 and assuming saturation as 1, results in only porosity being multiplied to the free water diffusivity.

This implementation was chosen conservatively due to lack of knowledge of tortuosity for the material within the pipeline. Regardless, as mentioned earlier, the advective release far exceeds the diffusive release for the pipelines. Thus, the parameters related to diffusive transport are not important in source term releases from pipelines. DOE considers this item a modeling assumption of the analysis, not a quality assurance issue.

- *"The value for longitudinal dispersivity provided for 100 series tanks is 4 m multiplied by the SZ_dispersivity_multiplier parameter whereas the value use for the 200 series tanks is 10 m multiplied by the SZ_dispersivity_multiplier parameter."*

This comment is related to the saturated zone dispersivity implemented in the GoldSim-based system model. Note that the base case calculations for the groundwater pathway are performed using the 3-D STOMP model. The primary purpose of the system model is to conduct sensitivity and uncertainty analysis in a computationally efficient manner. Because a 1 D saturated zone transport model is implemented in the system model, the purpose is to match the breakthrough time and peak concentrations at the 100 meter compliance boundary with the 3-D STOMP model. However, because of inherent simplifications in representing the saturated zone in one dimension, the saturated zone dispersivities were adjusted to match the 3-D STOMP model results. The transport models for 100-series and 200-series tanks were compared to the 3-D STOMP model results and the saturated zone dispersivity of 4 meters (13 ft) and 10 meters (33 ft) was chosen, respectively, for representing transport over 100 meter (328 ft) distance. The SZ_dispersivity_multiplier parameter is set to 1, but is implemented to allow for additional sensitivity analyses.

DOE considers the dispersivity parameter used as a modeling choice to match the 3-D STOMP model (the process model used for compliance calculation) for the purpose of abstraction, not a QA issue.

- *"Relative aqueous permeability parameters are contained in the STOMP input file that were not provided in the WMA C PA documentation."*

Table 6-7 of the WMA C PA provides the van Genuchten-Mualem parameters for the various hydrostratigraphic units (HSUs) included in the Saturation Function Card of the input files.   The parameter Mualem "m" is not provided explicitly in Table 6-7 or in the Saturation Function Card, indicating that the value defaults according to the relationship of m = 1-1/n (see description for Equation 6-12 of RPP-ENV-58782 and the STOMP User Guide [http://stomp.pnnl.gov/user_guide/STOMP_guide.stm]). The soil matric potential-moisture retention relationship is given by Equation 6-12 of RPP-ENV-58782, while the relationship between unsaturated hydraulic conductivity and soil matric potential is given by Equation 6-13 of RPP-ENV-58782. All the parameters used in the equations, other than the soil matric potential, which is computed spatially at each time step, are provided in RPP-ENV-58782, Table 6-7, reproduced below as Table 2. The Mualem "m" values are calculated internally within the STOMP code computations for each HSU, and the output file includes those values (see the Aqueous Relative Permeability Function Cards). The Mualem "m" values calculated internally within STOMP are presented below (truncated and rounded to three significant digits) in Table 2.

Table 2. Van Genuchten-Mualem Parameters for Various Hanford Site Hydrostratigraphic Units as used in the Base Case (Table 6-7, RPP-ENV-58782).

HSU[a]	van Genuchten "n" Parameter	Mualem "m" Parameter
Backfill (Gravelly)	1.374	0.272
Hanford H1/H3 (Gravel-dominated)	1.491	0.329
Hanford H2 (Sand-dominated)	2.047	0.511
Hanford H2 – Gravel/coarse sand subunit	1.724	0.420
Hanford H2 – Silty-sand subunit	1.633	0.388

Notes: [a]HSU – hydrostratigraphic unit

The only permeability parameters in the input files without a basis included in the documentation involve the basalt, for which the parameters are arbitrary and inconsequential because basalt is inactive in the model domain. DOE does not consider this item to be a QA issue.

- *"The Henry's Law constant for tritium appears to be very large and inconsistent with values commonly used. If all the tritium ends up in the air pathway and the air pathway has large dilution factors, this approach would be non-conservative".*

The Henry's law constant is used for representing air-to-water partitioning of radionuclides that can potentially originate as gas. Tritium is one of the radionuclides considered in the air pathway. The partitioning of tritium can vary based on whether tritium originates in the water phase (as tritiated water [HTO]) or in the gas phase (either isotopic hydrogen gas [HT] or tritium gas [T2]). If tritium is considered present as tritiated water, then the air-to-water partitioning would be considerably smaller. Smiles et al. (1995) reports the Henry's law constant of 1.7E-5 [dimensionless] at 20 ˚C (68 ˚F) for HTO. In contrast, for HT and T2, the reported values are around 74,100 atm (BNWL-1659, *Scavenging of Gaseous Tritium Compounds by Rain*), which is approximately equal to 54.7 [dimensionless], and similar to the value of 53.36 (Sander, 1999) used in the WMA C PA calculation. This indicates a six order of magnitude difference in air-to-water partitioning based on whether tritium originates as a tritium gas or tritiated water.

While tritium in the residual waste inventory is likely present as tritiated water in the interstitial liquid in sludge, it will not be a dose contributor in the groundwater pathway due to combination of short half-life (12.3 years) and greater than 1000 years of travel time for the contaminant to reach the water table. The only potential pathway of dose significance for tritium is the air pathway. Given that the gaseous diffusive release mechanisms from grouted tanks under closure configuration are not well understood, for the purpose of the PA, the atmospheric pathway calculations were performed in a conservative manner in order to estimate the bounding dose. Besides assuming tritium to originate as a gas, parameters were chosen to maximize the diffusive flux to the ground surface. Additionally, a 2-meter (6.6-ft) air-mixing layer height was assumed for the gaseous plume with the receptor located at the centerline downwind to calculate the maximum concentrations (WMA C PA Section 6.3.2.5). Because of these conservative modeling choices for gaseous transport of tritium, the concentrations at the receptor location are considered bounding. Consequently, the total dose contribution of tritium to the receptor is maximized. DOE considers this item as a modeling assumption for maximizing the dose from tritium, not a QA issue.

RAI 2-2

Comment
The description of how viable alternative conceptual models or alternative future scenarios are identified is insufficient. DOE's current safety function methodology would not appear to be able to identify interdependencies and interrelationships between Features, Events, and Processes (FEPs) that could result in plausible alternative conceptual models or alternative future scenarios.

Basis
Conceptual models (different ways a disposal system might behave) and future scenarios (usually associated with a major event such as an igneous or climate event) can be a source of great uncertainty. DOE's WMA C PA has evaluated alternative conceptual models such as the alternative geological model II and the heterogeneous media model. While DOE has stated, and NRC staff agrees, that the two alternative conceptual models are plausible, the methodology by which these alternative conceptual models were derived is not clear although the alternative geological model II appears to have been evaluated at the request of stakeholders. DOE has stated that viable alternative conceptual models or alternative future scenarios are considered based on an evaluation of safety functions and their relationship to FEPs; however, results in the WMA C PA uncertainty and sensitivity analysis appear to indicate that many of the identified specific functions are not especially relevant to the performance.

DOE identified and documented an extensive list of relevant FEPs as would be done in a bottom-up approach to identifying alternative models and scenarios. In addition, safety functions were included as part of a top-down approach to identifying conditions that need to be evaluated in the WMA C PA. After the safety functions are identified, FEPs are identified that may degrade or modify the performance of a safety function in some way. However, in this hybrid approach, there appears to be no analysis of how the safety functions influence one another or if there are interdependencies and interrelationships between the identified features and processes. The one-at-a-time sensitivity analysis used in the WMA C PA does not lend itself to identifying risk-significant interdependencies and interrelationships between FEPs.

The uncertainty analysis appears to be focused on the evaluating the range of variability of the input parameter values for the base case and is not able to identify plausible alternative conceptual models. An assumption that there is only one plausible future scenario (i.e., no alternative future scenarios) with a non-dynamic environment for 10,000 year requires a rigorous technical basis. Results of analyses should evaluate the interdependencies and interrelationships between components of the system and provide supporting evidence of plausible alternative scenarios or conceptual models.

While plausible models and scenarios would be evaluated in the WMA C PA, these analyses would also provide the basis for determining which "what-if" models and scenarios are not plausible and require no further examination. This would remove any confusion about which conceptual model should be included the WMA C PA.

For example, in a previous technical review related to a Hanford tank closure, NRC staff provided eight examples of features, events, and processes that may be sufficiently plausible and significant as to require an alternative conceptual model or alternative future scenario to be considered (ADAMS Accession No. ML090090030).

Path Forward

Please provide a description of the approach to identifying plausible alternative conceptual models or alternative future scenarios used in development of the WMA C PA, or clarify how DOE's current safety function methodology would identify interdependencies and interrelationships that may lead to plausible alternative models or scenarios.

In addition, describe the process by which the safety functions were identified. If some safety functions are redundant barriers, DOE should demonstrate, as stated in Appendix H, how a safety function is a feature of the system that provides a specific function that is relevant to the performance (or safety) of the facility. The safety concept is considered to be a set of safety functions acting together in concert to provide the required safety. Provide a description of the how the safety functions act together.

DOE Response

The Path Forward section for this RAI requests additional detail on the safety function approach: how safety functions are identified, how it captures interdependencies, and how it identifies credible alternative models. The following discussion is intended to supplement the presentation of the hybrid safety function approach discussed in Chapter 8 and Appendix H of the WMA C PA, by providing specific details how these questions are answered in the methodology.

As a demonstration of how the hybrid safety function approach works, consider a specific feature of the closed tank system. For this discussion, consider the infill grout in the tank. The safety functions associated with the grout are simply logical expressions of why grout was chosen as the preferred approach for closure in the first place. It is a strong, stable, low permeability material with desirable chemical characteristics. This statement leads naturally and in a straightforward way to the safety functions identified in the WMA C PA, shown in Table 3. Safety functions associated with other features of the system are similarly straightforward to identify.

Table 3. Grout Related Safety Functions for the WMA C Performance Assessment.

Designation	Safety Function	Description
EB9	Grout in tank (permeability)	The grout acts to limit water flow through the facility, making releases dominated by diffusion from the waste.
EB10	Grout in Tank (chemical)	The grout acts to condition the chemistry of the waste residuals, with sorption characteristic of high pH environments.
EB11	Grout in tank (structural)	The grout provides structural support preventing subsidence of the closed facility.
EB12	Grout (intrusion)	The structural strength of the grout provides a barrier to intrusion.

As discussed in Sections 6.1, Section 8.2, and Appendix H of the WMA C PA, the structure of the WMA C PA is to evaluate the safety of the facility when these safety functions behave as expected, and also to evaluate conditions in which the safety function is lost or degraded, whether from anticipated conditions or from unlikely but credible conditions. The expected evolution of the facility is represented by the Base Case, in which it is assumed that the safety functions evolve in an expected manner. Uncertainty in input parameters in the base case is evaluated using the probabilistic uncertainty analysis. Therefore, the next step in the methodology is to identify the potential for one or more safety functions to be degraded in the future compared to their anticipated evolution, to include these conditions in the overall evaluation of system safety.

The approach to this is described in the WMA C PA, Chapter 8 and Appendix H, and as in "Approach to the Use of Safety Functions with Features, Events, and Processes (FEPs) in Performance Assessment" (Kozak and Bergeron, 2017). The approach begins with the top-down identification of safety functions, as discussed above, followed by a cross reference (WMA C PA, Appendix H, Section H-5, Tables H-1 and H-2) of the safety functions with a list of FEPs to identify potentially deleterious FEPs that may act to degrade a safety function. The FEPs were evaluated by a multi-disciplinary team of subject matter experts to identify what effects each FEP might have on the various safety functions. If no FEP is identified that could degrade a safety function, then there is no need to evaluate the system with that safety function degraded. For instance, in the above example there was no FEP identified that would substantively degrade safety function EB11, structural stability, and as a result there are no analyses in the WMA C PA in which this safety function is degraded.

By contrast, the intent of the process is to identify FEPs that can degrade one or more safety functions, and to develop sensitivity analyses to address them. In the above example, two FEPs were identified as potentially deleterious to the hydraulic safety function (EB9) of the grout: FEP 1.1.08 Quality Control (defects during construction causes grout to crack), and FEP 1.2.03 Seismicity (i.e. earthquakes cause cracks/openings in the grout). These FEPs have the potential to affect the quality of the safety function in different ways. However, the overall effect on the system would be similar: an increased permeability of the grout compared to the expected behavior. Therefore, both can be addressed by a sensitivity analysis evaluating the effect of increased permeability of the grout.

It is noteworthy that this approach intrinsically allows the identification of interdependencies between different FEPs on safety functions. Multiple FEPs acting on a single safety function represent an interdependency, in which the multiple FEPs may result in qualitatively similar type of degradation, but may increase the rate at which degradation occurs. A FEP that is relevant to more than one safety function indicates a second type of interdependency identified in the approach. A potentially deleterious FEP that applies to more than one safety function indicates the potential for a common failure mechanism. For instance, in the example discussed above, seismicity has the potential to affect both the grout hydraulic safety function, and also the tank structure safety function. Therefore, a sensitivity case developed to address this situation should take account of this potential for common failure.

The next step in the methodology was to develop specific sensitivity analysis cases to reflect the alternative conditions, in which the potentially deleterious FEPs are assumed to have acted on the safety functions to degrade their behavior from the base case. There are different approaches that can be taken for this step. One could specifically identify the magnitude of a FEP acting in the future and its likely action on the safety function, to establish a credible estimate of the likely degradation of the safety function. In this approach, considerable effort may be needed to investigate the FEP and its effect on the safety function, and to express it in a credible model that will withstand regulatory scrutiny. Alternatively, one can make unambiguously conservative assumptions about the amount of degradation that may occur in the future. The result will be an analysis case that clearly bounds the potential effect of any deleterious FEPs on the safety function. When this latter approach is taken, the sensitivity analysis case can support the decision about post-closure safety, without accurately representing potential future behavior of the system.

For some disposal facilities and site conditions, it may be worth the time and effort to fully develop a good understanding of potentially deleterious FEPs to develop a credible, plausible representation of the timing, manner, and degree of degradation of the safety function. This would lead to an alternative scenario or conceptual model that is a credible representation of the behavior of the system under different conditions than the base case. For other disposal facilities and site conditions, a conservative approach can be taken without expending the time and effort to justify the more reasonable representation. This may lead to an unrealistic representation of the disposal system, but one which demonstrates the robustness of the system performance in the absence of the safety function.

In the above example, to develop a credible model, one would need to do the following:

1. Develop a seismic hazard analysis relevant to the long performance period;
2. Evaluate the damage that a seismic event would cause to the infill grout and tank structure;
3. Develop a flow model to represent the damaged system; and
4. Incorporate the model into the performance assessment.

Each of these activities can in principle be done, but each is difficult, time consuming, and requires another set of assumptions which are potentially difficult to defend. By contrast, the approach taken in the WMA C PA was to assume that at some time in the future, the grout instantly transforms into a material consistent with the flow properties of sand. There is no credible FEP or combination of FEPs that could produce such a drastic change in the flow behavior of grout during the performance time period. Consequently, this sensitivity analysis case cannot be considered to represent a credible future condition of the facility. However, analysis of this case, in contrast with the Base Case, shows the importance and impact of a particular safety function in helping meet performance objectives and in supporting the safety case for the closed WMA C facility. (Note: As a cross-reference to RAI 2-9, the properties of the H2 sand used for the analysis are entirely arbitrary, and represent an extremely conservative representation of the post-degradation tanks. In addressing the RAI 2-9, the analyses will be updated to provide a different arbitrary and conservative end state, but one without the numerical artifacts noted in the RAI.)

For WMA C, sensitivity cases identified by the safety function methodology have been evaluated by this latter, conservative approach. Prior understanding developed from scoping analyses showed that WMA C would be extremely robust in performance relative to performance objectives and performance measures. For WMA C, it was found possible to treat safety functions very conservatively and still meet all performance objectives under all evaluated future conditions, alternative models, and combinations of parameters.

Not all of the sensitivity analysis cases selected for WMA C were developed by this methodology. At the outset of the development of the WMA C PA, an extensive set of scoping meetings was held with stakeholders (see WMA C PA, Section 1.1.1). These scoping meetings predated the development of the safety-function methodology. At the meetings, a number of commitments were made by DOE to run specific sensitivity analysis cases, which did not always correspond to the sensitivity cases identified from the safety-function methodology. These stakeholder-identified sensitivity cases were retained in the WMA C PA to enable DOE to honor its commitment to evaluate them. As a result of this project history, several of the WMA C sensitivity analysis cases do not fit the pattern of identification described in the above description.

2009 RAIs for Tank 241-C-106:
In a technical clarification meeting between NRC and DOE staff on May 30, 2019, it was suggested that discussion of the conceptual alternative scenarios (a, b, c, …) outlined the Path Forward section in Comment 1 of the previous RAI for Tank C-106 (External letter "Request for Additional Information on Update to the Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Retrieval Criteria for Single-Shell Tank 241-C-106, Request for U.S. Nuclear Regulatory Commission Review*" [Bubar, 2009]*) be included as part of the response for this RAI. The conceptual alternative scenarios as stated in Bubar (2009) are italicized below followed by DOE response for each scenario.

a. The loss of vegetation. In section 3.4.2.4 of DOE/ORP (2006) recharge rates are assumed to not exceed 1 mm/yr. This value is dependent on wind and water erosion calculations from Appendix D of "Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas" [DOE (1996)] that do not account for periods without vegetative cover caused by range fire or drought. In addition, the factors within these equations are invariant and may not be appropriate for isolated events.

The WMA C PA includes a variety of uncertainty and sensitivity analysis conditions with elevated recharge that address this comment. The upper end of the recharge sensitivity cases includes an extreme case representative of a gravel surface for the duration of the analysis. Infiltration rates associated with a loss of vegetation would be less than this extreme sensitivity case.

b. A cyclic drought / moderate humid climate. Current simulations are performed with steady-state; however, natural processes rarely are in a steady-state condition for such long time frames. Varying climatic conditions may influence significant parameters. Changes in one parameter may affect another parameter, e.g., increased erosion will more than likely increase infiltration/recharge, however is not accounted for in DOE/ORP (2006).

The WMA C PA includes a variety of uncertainty and sensitivity analysis conditions that address this comment by examining the ability of the safety function of the engineered surface barrier to limit the amount of recharge through the facility. The safety function approach in this PA is not focused on changes on one parameter or process that may affect another parameter or process but rather on the overall net positive or negative effect on the performance of the safety function. The range of uncertainty has been developed taking account of estimates of the variability in climate provided by the paleo record (WMA C PA, Section 3.1.2.6). Furthermore, the sensitivity cases included an extreme case outside of the credible range for long-term recharge on natural soils. This sensitivity case is representative of a gravel surface for the duration of the analysis.

c. A more humid, warmer climate. Important assumptions made, e.g., steady-state vadose flow and exclusion of fast pathways, are based on the arid / semi-arid climate of the present. The potential humid, warmer climate would require a reevaluation of these assumptions.

The range of uncertainty for recharge in the WMA C PA includes the potential for climate change, as discussed in Section 3.1.2.6 in the WMA C PA. The effect of a credible increase in precipitation over the assessment time scale is included in the range of uncertainty evaluated in the WMA C PA (see Section 8.1.3.1 "Uncertainty in Recharge Rates" and Section 8.1.4 "Development of Vadose Zone Flow Fields and Propagation of Uncertainty" in the WMA C PA).

d. A less humid, drier climate allowing potential upward movement of moisture and contaminants in the vadose zone. Contaminants being deposited at the surface would have the potential for further transport by wind erosion and surface water runoff. The latter may lead to a concentration of radionuclides at depositional areas.

The range of credible future climate states is discussed in Section 3.1.2.6 of the WMA C PA. It does not include sufficiently arid conditions for this mechanism to become a concern. The base case analysis already evaluates fairly dry conditions. Under such conditions, the effects of the upward movement of moisture and contaminants is negligible. Assuming less humid, drier climatic conditions would be expected to only enhance the performance of the facility with regard to both air and groundwater pathways.

e. Higher water table (contaminant transport within the Hanford unit) versus lower water table (contaminant transport within a lower subunit of the Cold Creek unit) with subsequent potential change in hydraulic conductivity and average linear groundwater velocity. The simulated dose would be affected by changes to the dispersion and the linear average velocity of the groundwater in which the contaminants are traveling.

The WMA C PA evaluates a wide range of uncertainty in the flow properties of the aquifer in its evaluation of the groundwater dilution safety function. The best geologic data and information available for wells in the vicinity of WMA C support the general geological conceptualization of the existence of a paleochannel in the vicinity of the WMA C. As indicated in Section C-2 *Hydrogeologic Conditions and Structure* of the WMA C PA, the principal textural class found within the unconfined aquifer are gravels. The best available geologic logging information suggests the presence of very permeable sequences of undifferentiated Hanford, Cold Creek unit, and Ringold gravels. While a higher or lower water table could have some effect on the average groundwater flow rate used to approximate the effect of the aquifer dilution safety function, it would still be within the wide range of groundwater flow rates considered in the uncertainty (See Section 8.1.3.6, *Uncertainty in Darcy Flux in Saturated Zone* of the WMA C PA) and sensitivity analyses (Section 8.2.2 *Aquifer Dilution Sensitivity Analyses* of the WMA C PA).

f. Episodic flow. Table 3-15 (p. 3-82) of the Initial Single-Shell Performance Assessment (SST PA) states that the impacts of episodic infiltration are considered sufficiently analyzed in Simulations of Infiltration of Meteoric Water and Contaminant Plume Movement in the Vadose Zone at Single-Shell Tank 241-T-106 at the Hanford Site [Smoot et al. (1989)], however, these are analyzes based on additional simulation results only. Generally, model support should not rely exclusively on the results of further numerical modeling. If the uncertainty and scenario analyses show that episodic flow has the potential to be a significant process, a stronger technical basis will be needed to support this assumption.

Understanding of vadose zone flow at the Hanford Site demonstrates that episodic infiltration rapidly redistributes in time and space, and a temporally constant infiltration is an appropriate assumption below a few meters below ground surface (Oostrom, 2016). As discussed in Section 6.4 of the WMA C PA, this observation is supported by observations of moisture content distributions in the vadose zone, and by a controlled field experiment that supports the vadose zone modeling approaches used in the performance assessment (Zhang, 2010).

g. Lateral movement of contaminants in the vadose zone in combination with clastic dikes as conducts for fast vertical transportation. Section 2.3.4.1.7; p. 2-27 in DOE/ORP (2006) stated that, "Thin, fine-grained layers in the Hanford formation also cause lateral migration." In *addition, Interpreted Extent of Subsurface Contamination Resulting from the 241-BX-102 Tank Leak 200 East Area, Hanford Site, Washington [Sobczyk (2004)] documented lateral movement of contaminants under the B-BX-BY waste management area (WMA). Clastic dikes are currently not considered fast pathways; however, perched water bodies or semi-saturated lateral movement of contaminants would have the potential to use clastic dikes as a conduit and move relatively quickly to deeper units thereby bypassing the retarding effects of the vadose zone.*

The WMA C PA has conducted extensive analyses evaluating the potential for lateral movement of contamination beneath WMA C in post-closure conditions, and has concluded that this process is not significant. This conclusion is based on a combination of factors and observations, leading to two responsive comments:

- The potential for lateral movement of contaminants is greater for contaminants in leak conditions than for the post-closure conditions evaluated in the WMA C PA. Therefore, the effects of lateral movement were primarily evaluated in RPP-RPT-59197, Analysis of Past Tank Waste Leaks and Losses in the Vicinity of Waste Management Area C at the Hanford Site, Southeast Washington. In that report, a wide variety of alternative conditions were evaluated, including highly heterogeneous representations of spatial variability beneath WMA C and the potential for the existence of a clastic dike as a possible fast vertical pathway. The results documented in that report demonstrate that the heterogeneous representation of vadose zone sediments or the potential occurrence of clastic dikes at WMA C do not result in significant lateral redistribution of contaminant plumes.
- Additional follow-on evaluations of the potential influence of spatial heterogeneities have shown that such behavior does not substantively change the results of flow and transport modeling at WMA C (a new report which presents these new evaluations and summarizes previous work on this topic is being finalized and will be made available upon release [RPP-RPT-61239, Multiple Lines of Evidence and Modeling Results for Heterogeneous Alternative Conceptual Models of the Subsurface at Waste Management Area C]). The new report represents a systematic review and analysis of numerous field data sets collected at WMA C to develop alternative geologic conceptual models to incorporate small-scale heterogeneities that may impact contaminant transport.

The cited study of lateral movement associated with the 241-BX-241 tank is not relevant to WMA C, as the geological setting is very different than at WMA C (also documented in the new report, RPP-RPT-61239).

h. A technical basis is needed for excluding an igneous activity scenario (waste transported by eruption to populated zone) in an area which has seen so much igneous activity. Alterations to or destruction of the grouted tank due to igneous activities would allow contaminants to be transported by alternative means not being currently considered.

The potential for this FEP to influence WMA C was considered in the FEP workshop (see WMA C PA, Appendix H), and was judged to be of vanishingly small probability of occurrence during the 10,000 year sensitivity and uncertainty analysis period, as the most recent igneous activity at Hanford dates to the Miocene era. As noted in WMA C PA Appendix H, FEP 1.2.04, the potential for changes to infiltration as a result of ashfall from regionally significant volcanic activity was also considered. It was concluded in the FEP evaluation that: *"The effect of prior eruptions is included in the paleo record of infiltration. The effects of past ash fall events is therefore included in the uncertainty range in infiltration."*

i. Justification for exclusion of the Native American scenario should be provided, or results for the Native American scenario should be included.

As part of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) process for identifying exposed individuals, DOE made a request for Tribal Nation stakeholders to provide exposure scenarios that reflect their traditional activities. At this time, two exposure scenarios: the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) ("Exposure Scenario for CTUIR Traditional Subsistence Lifeways" [Harris and Harper, 2004] and "Application of the CTUIR Traditional Lifeways Exposure Scenario in Hanford Risk Assessments" [Harris, 2008]); and the Yakama Nation ("Yakama Nation Exposure Scenario for Hanford Site Risk Assessment, Richland, Washington" [RIDOLFI, Inc., 2007]) have been provided.

DOE invited the Tribal Nation stakeholders to provide their perspectives on these exposure scenarios to ensure fair consideration of differing views that can help inform the agency's decision-making process. DOE respects those views and has considered them in the preparation of Remedial Investigation/ Feasibility Study (RI/FS) and Resource Conservation and Recovery Act (RCRA) Facility Investigation/Corrective Measures Study (RFI/CMS) investigations at the Hanford Site. However, inclusion of these perspectives does not necessarily mean or imply that DOE is in agreement with the exposure scenario details.

Along these lines, a letter of direction related to the use of Tribal Nation scenarios in CERCLA documents, dated November 7, 2007, was provided by D. A. Brockman, DOE to CM Murphy, President of Fluor Hanford, Inc. [08-AMCF-0028]. In this letter, DOE notified Fluor Hanford that, through discussion with the Tribes, DOE agreed to include quantitative analyses of the Native American Assessment Scenarios in the RI/FS documents being prepared on the Hanford Site.

In the spirit of the agreements made between DOE and the Tribal Nation stakeholders, impacts from Native American scenarios were quantitatively evaluated along with other CERCLA and Model Toxics Control Act (MTCA)-related exposure scenarios in a risk assessment of vadose zone sediments and soils that were impacted by past tank leaks and losses at WMA C. This specific risk assessment was completed in support of RPP-RPT-58339, *Phase 2 RCRA Facility Investigation Report for Waste Management Area C*. The scenarios proposed by the Tribal Nations and used in this risk assessment are documented in RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*,

Detailed results of those Native American scenario impact evaluations are provided in Attachments C-10 through C-13 in Appendix C and Attachments D7 and D-8 in Appendix D of RPP-RPT-58329, *Baseline Risk Assessment for Waste Management Area C*. Standard CERCLA and MTCA-related scenario impacts were used to identify potential mitigation measures for contaminated vadose zone sediments and soils at WMA C in RPP-RPT-59379, *Waste Management Area C Phase 2 Corrective Measures Study Report*. The Native American scenario impacts were provided in the document as additional risk management information to Tribal Nation stakeholders to assist them in providing potential mitigation measures at WMA C.

RAI 2-3

Comment
An insufficient basis was provided for the inventory assigned to the C-301 Catch Tank. Assumptions regarding residual inventories are not consistent with operational history.

Basis
DOE summarized in Section 4.3.5 of the Draft WIR Evaluation that ancillary structures included within the scope of the assessment include the C-301 Catch Tank, the 244-CR Process Vault (with four small tanks), pipelines, and diversion boxes. DOE indicated that it planned to characterize the C-301 Catch Tank, but for the purpose of the Draft WIR Evaluation the WMA C PA assumes that 90 percent of the waste will be retrieved. It was also assumed that the inventory in the C-301 Catch Tank was comparable to the residual waste inventory in the tank farm.

The C-301 Catch Tank received drainage from four diversion boxes (241-C-151, 241-C-152, 241-C-153, 241-C-252). At least two of these diversion boxes experienced leaks of waste. According to RPP-RPT-45723, the C-301 Catch Tank contained a layer of solids (sludge) approximately 1.17 m thick as of June 3, 1985. The sludge contents of the tank appear to be largely uncharacterized, though liquid samples have been evaluated in 1974 with Cs-137 concentrations of 1E4 to 2.55E4 µCi/gallon (3.8E1 to 9.7E1 µCi/m3). As a result of partitioning, the Cs-137 concentrations in sludge would be anticipated to be considerably higher. Additionally, the thickness of the waste layer is likely to be much larger than other components due to the geometry of the catch tank. Thicker waste layers combined with higher concentrations could be significant to evaluating the impacts to the inadvertent intruder.

Path Forward
Please provide a basis for the estimated radioactivity concentrations in sludge in tank C-301. If the inventory for the C-301 Catch Tank is revised, then the C-301 Catch Tank would need to be classified consistent with RAI 3-2 and an intruder dose assessment should be performed consistent with RAI 2-16.

DOE Response

Basis for Inventory:
Specific information for the C-301 Catch Tank is available to estimate current waste volumes (see RPP-RPT-42323, Rev 4). Based on available measurements, the current estimate of waste volume in the tank is approximately 13,000 gallons. Section 4.4.2.5 of RPP-RPT-42323, Rev. 4 explains the rationale for the estimate. Section A2 (Appendix A) of RPP-RPT-42323, Rev. 4 provides a description of the tank, with additional references to historical information.

No decision has been reached to date regarding the amount of waste that would be removed from ancillary equipment at WMA C, including the C-301 Catch Tank, prior to closure. Retrieval decisions for the C-301 Catch Tank will be based on technical evaluation of the waste composition and inventory estimates developed from characterization data collected prior to closure. However, measurements of waste in the C-301 Catch Tank provide evidence of the existence of liquids (RPP-RPT-58156) that would require retrieval prior to closure of the tank. For purposes of the WMA C PA evaluation, DOE used engineering judgment to assume that 90 percent of the current volumes of liquid and sludge in the C-301 Catch Tank would be retrieved before closure (RPP-RPT-42323, Rev. 4, Section 5.3). Waste remaining after the removal process, which would likely involve sluicing the tank contents, is assumed to be sludge with minimal liquid. Under these assumed closure conditions, the current waste volume (i.e. 13,000 gal) would be reduced to about 1,300 gallons prior to stabilization of the tank with grout.

Because the tank would likely be retrieved using a sluicing removal process, DOE also used engineering judgment to assume that the post-retrieval composition of the residual wastes within this tank could be approximated with the average residual waste concentrations in the WMA C SSTs after retrieval (refer to Appendix C.2 of RPP-RPT-42323, Rev. 4). As the Basis section of this RAI suggests, prior to retrieval, waste sludge in a tank generally exists in layers; each layer reflecting a type of waste that was originally placed in the tank. Characteristics of waste may differ significantly from layer to layer. Experience with retrieval of 16 tanks[9] has shown that as the waste is sluiced, most of the solids in the top layer are suspended and pumped out. The remaining solids from the top layer settle down and mix with solids in the next layer as this layer is sluiced. This process is repeated until completion of sluicing. At the end of sluicing, solids remaining in the tank are expected to be a mixture of less mobile solids from various sludge layers originally in the tank. Thus, DOE believes that the average residual waste concentrations in the WMA C SSTs after retrieval as an assumed composition for the sludge waste left in the C-301 Catch Tank at closure represents a reasonable assumption.

Risk Impacts:
With the waste composition and volume assumed to be left in the C-301 Catch Tank at closure (based on RPP-RPT-42323, Rev. 3), specific estimated impacts from this catch tank in the WMA C PA evaluation were not significant when compared to the impacts from inventories associated with larger SSTs in WMA C. A summary of those impacts are as follows:

- In the groundwater pathway analysis, projected impacts from Tc-99 originating for the C-301 Catch Tank estimated in groundwater at 100 m (328 ft) from WMA C account for less than 0.1 percent of the total impact attributable from Tc-99 (See Figure 7-16 in Section 7 of the WMA C PA). Tc-99 is the key constituent of concern with respect to the dose impacts estimated for groundwater pathway from a closed WMA C.
- In the inadvertent intruder analysis, both acute and chronic dose impacts attributable to intrusion into the C-301 Catch Tank (See Table 9-7 in Section 9 of the WMA C PA) are estimated less than 5 and 6 percent of applicable acute (500 mrem) and chronic (100 mrem/yr) dose performance measures, respectively.

Also, in light of the fact that the amount of waste volume and the waste composition left in the C-301 Catch Tank at closure is uncertain, the WMA C PA effort did evaluate potential impacts of the current volume with the assumed waste compositions in a specific sensitivity case documented in Section 8.2.4 of the WMA C PA. This specific sensitivity case assumes all parameters are the same as those assumed in the base case, except that the assumed inventories were based on the upper bound inventories established in RPP-RPT-42323, Rev. 3 for all tanks and ancillary equipment based on information that was available in that time frame. This case was primarily used to explore the impacts of inventories as they were estimated in the September 2014 time frame, including the impacts from the waste left in the –then partially retrieved Tanks C-102, C-105, and C-111. In RPP-RPT-42323, Rev. 3, the upper bound inventory for the C-301 Catch Tank reflected the current volume of the tanks in September 2014. The impacts from the C-301 Catch Tank are not discussed in this specific case because the impacts from the

[9] Information supporting the general statement about the effect of the sluicing process on wastes can be found in individual tank Retrieval Data Reports (RDRs) prepared after the retrieval process has been completed. Selected RDRs with this type of information include: RPP-RPT-58386, *Retrieval Data Report for Single-Shell Tank 241-C-101*, and RPP-RPT-59631, *Retrieval Data Report for Single-Shell Tank 241-C-102*.

then-partially-retrieved 100-series tanks, particularly the impacts from Tank C-105, dominate the impacts and the impacts from the C-301 Catch Tank were not significant.

Looking Ahead:
Although DOE believes the basis for current inventory estimates in the WMA C PA is sound, and the risk impacts from the C-301 Catch Tank are small, final retrieval and closure decisions will be made based upon actual sampling data. DOE is currently developing a Data Quality Objectives (DQO) report and Sampling and Analysis Plan (SAP) to characterize the contents of the C-301 Catch Tank. DOE expects that as the residual waste inventory for the C-301 Catch Tank is revised, any resultant impacts from this source will be reevaluated using the performance assessment analysis tools[10], allowing the catch tank to be classified consistent with RAI 3-2, and an intruder dose assessment to be performed consistent with RAI 2-16.

[10] A performance assessment is required and maintained pursuant to DOE M 435.1-1. Generally, a performance assessment is a multi-disciplined assessment (e.g., geochemistry, hydrology, materials science, and health physics) which uses a variety of computational modeling techniques to evaluate groundwater concentrations and doses at various points of assessment over time. In doing this assessment, DOE evaluates the impact of natural features (e.g., hydrology, soil properties, groundwater infiltration) and engineered barriers (e.g., closure cap, fill grout, waste tank design) on the release of radionuclides, to estimate, among other things, the potential dose to a hypothetical member of the public and a hypothetical inadvertent intruder. The results of the WMA C PA, as reported here, should not be considered limits or thresholds. As required by DOE M 435.1-1, maintenance of the WMA C PA will include future performance assessment revisions or special analyses to incorporate new information, update model codes and reflect analysis of actual residual inventories.

RAI 2-4

Comment
An insufficient basis for the inventory assigned to the 244-CR Process Vault (with four small tanks) was provided. Assumptions regarding residual inventories are not consistent with operational history. Characterization data of ancillary equipment has not been provided.

Basis
DOE summarized in Section 4.3.5 of the Draft WIR Evaluation that ancillary structures included within the scope of the assessment include the C-301 Catch Tank, the 244-CR Process Vault (with four small tanks), pipelines, and diversion boxes. DOE indicated that it planned to characterize the 244-CR Process Vault. For the purpose of the Draft WIR Evaluation and in the analyses of the WMA C PA DOE assumes that 90 percent of the waste will be retrieved. It was also assumed that the concentration of radioactivity in that system was comparable to the residual waste inventory in the tank farm.

The 244-CR Vault was used for scavenging Cs-137 from tributyl phosphate (TBP)-based waste. The 244-CR Vault and associated tanks and cells were used as the uranium sludge recovery and distribution vault for C-Farm. The 244-CR Vault was also used for the interim storage and transfer of waste from B Plant, Plutonium Uranium Extraction (Plant) (PUREX) and Hot Semiworks. The 244-CR Vault had the capacity to add chemicals, mix solutions and cool the tank contents. Waste was also received from the Hot Semiworks Facility. The 244-CR-003 tank in the 244-CR Vault was used for the interim storage of saltwell waste from C-Farm.

As shown Figure ES-1 from RPP-RPT-24257, the waste in the tanks consists of a high percentage of sludge. In addition, the figure shows waste in the cells outside of the tanks. Based on the complex operational history, the use of present day average tank farm facility waste concentrations to estimate the sludge concentrations in the 244-CR tanks (vaults) may not be reliable or protective. In addition, even after retrieval the remaining waste layer will likely be considerably thicker than that remaining in the 100- and 200-series tanks. Precipitation processes and lessor amounts of mixing could contribute to significantly higher concentrations of radioactivity in the 244-CR vaults than would be estimated using average tank farm concentrations.

Thicker waste layers combined with higher concentrations could be significant to evaluating the impacts to the inadvertent intruder.

Path Forward
Please provide any historical characterization data available for the 244-CR Vault including the four tanks. If no data is available, provide the sampling and characterization plan that will be used to verify the inventory assumptions prior to closure. After the inventory estimate for the CR-244 Vault has been revised, then the components would need to be classified consistent with RAI 3-2 and intruder dose assessment performed consistent with RAI 2-16.

DOE Response

Basis for Inventory:
At the time the WMA C PA was developed, historical information for the CR-Vault tanks was used to estimate current waste volumes (see RPP-RPT-58156*)*. The combined volume in individual tanks within the CR-Vault was estimated at approximately 10,600 gals (40,125 L). The amount of waste estimated to

be sludge in individual tanks varies. Waste contained in Tank CR-011 contains the highest percentage of sludge, which is about 95 percent of the total waste volume.

No decision has been reached regarding the amount of waste that will be removed from ancillary equipment in WMA C, including the CR-Vault tanks. Retrieval decisions for the CR-Vault tanks will be based on technical evaluation of the waste composition and inventory estimates developed from characterization data that will be collected prior to closure.

For purposes of the PA evaluation, DOE used engineering judgment to assume that 90 percent of the then-current volumes of liquid and sludge in the CR-Vault tanks would be retrieved before closure (RPP-RPT-42323, Rev. 3, Section 5.3). Waste remaining after the removal process, which would likely involve sluicing the tank contents, is assumed to be sludge with minimal liquid. Under these assumed closure conditions, the then-current waste volume (i.e. approximately 10,600 gals) would be reduced to about 1,060 gallons prior to stabilization of the tanks with grout.

Because the CR-Vault tanks would likely be retrieved using a sluicing removal process, DOE also used engineering judgment to assume that the post-retrieval composition of the residual wastes within these tanks could be approximated with the average residual waste concentrations in the WMA C SSTs after retrieval (refer to Appendix C.3 of RPP-RPT-42323, Rev 3). As the Basis section of this RAI discusses, the tanks in CR-Vault have unique histories, and prior to retrieval, waste within a given tank may exist in distinct layers reflecting a type of waste that was originally placed in the tank. Characteristics of waste may differ significantly from layer to layer. Experience at the 16 tanks retrieved at WMA C[11] has shown that as the waste is sluiced, most of the solids in the top layer are suspended and pumped out. The remaining solids from the top layer settle down and mix with solids in the next layer as this layer is sluiced. This process is repeated until completion of sluicing. At the end of sluicing, solids remaining in the tank are expected to be a mixture of less mobile solids from various sludge layers originally in the tank. Thus, DOE believes that the average residual waste concentrations in the WMA C SSTs after retrieval as an assumed composition for the sludge waste left in the CR-Vault tanks at closure represents a reasonable assumption.

Risk Impacts:
With the assumed waste composition and low volume of waste left in CR-Vault tanks at closure (see RPP-RPT-42323, Rev 3), specific estimated impacts from these tanks in the PA evaluation were not significant when compared to the impacts from inventories associated with larger SST in the WMA. A summary of those impacts are as follows:

- In the groundwater pathway analysis, projected impacts from Tc-99 originating for the CR-Vault tanks estimated in groundwater at 100 m from WMA C account for less than 0.001 percent of the total impact attributable from Tc-99 (See Figure 7-16 in Section 7 of the WMA C PA). Tc-99 is the key constituent of concern with respect to the dose impacts estimated for groundwater pathway from a closed WMA C.
- In the inadvertent intruder analysis, both acute and chronic dose impacts attributable to intrusion into the CR-Vault (See Table 9-7 in Section 9 of the WMA C PA) are estimated less than 1 percent and 0.5 percent of applicable acute and chronic dose performance measures (i.e. 500 mrem and 100 mrem/yr, respectively).

[11] Information supporting the general statement about the effect of the sluicing process on wastes can be found in individual WMA C tank Retrieval Data Reports prepared after the retrieval process has been completed. Selected RDRs with this type of information include: RPP-RPT-58386, *Retrieval Data Report for Single-Shell Tank 241-C-101*, and RPP-RPT-59631, *Retrieval Data Report for Single-Shell Tank 241-C-102*.

Also, in light of the fact that the amount of waste volume and the waste composition left in the CR-Vault at closure is uncertain, the WMA C PA did evaluate potential impacts of the current volume with the assumed waste compositions in a specific sensitivity case documented in Section 8.2.4 of the WMA C PA. This specific sensitivity case assumes all parameters are the same as those assumed in the base case, except that the assumed inventories was based on the upper bound inventories established in RPP-RPT-42323, Rev. 3 for all tanks and ancillary equipment based on information that was available in that time frame. This case was primarily used to explore the impacts of inventories as they were estimated in the September 2014 time frame, including the impacts from the amount of waste left in the then-partially retrieved Tanks C-102, C-105, and C-111. In RPP-RPT-42323, Rev. 3, the upper bound inventory for the CR-Vault reflected the current volume of the tanks in September 2014. The impacts from CR-Vault are not discussed in this specific case because the impacts from the then-partially retrieved 100-series tanks, particularly the impacts from Tank C-105, dominate the impacts and the impacts from the CR-Vault were not significant.

Looking Ahead:
Although DOE believes the basis for current inventory estimates in the WMA C PA is sound, and the risk impacts from the CR-Vault are small, final retrieval and closure decisions will be made based upon actual sampling data. DOE is currently developing a DQO report and SAP to characterize the contents of the CR-Vault tanks. DOE expects that as the residual waste inventory estimates for the CR-Vault are revised, any resultant impacts from this source will be reevaluated using the PA analysis tools, allowing the facility to be classified consistent with RAI 3-2, and an intruder dose assessment to be performed consistent with the RAI 2-16.

RAI 2-5

Comment
An insufficient basis for the inventory of plugged pipelines was provided. The dose from intrusion into a plugged pipeline may be higher than the dose from intrusion into any other ancillary component or tank.

Basis
Pipelines failed or plugged over time as a result of complex phenomena associated with waste transfers. An earlier report (RPP-RPT-46879 Rev. 2) indicated that approximately 21 pipelines are documented to have been plugged within WMA C. The report RPP-25113 identified ten waste transfer lines that failed at some point due to plugging. The Draft WIR Evaluation has assumed one pipeline is plugged. Intrusion into a plugged pipeline represents one of the highest risk exposure scenarios associated with closure of WMA C. From the documentation provided, it is not clear exactly how many lines are plugged within WMA C and how many lines that were plugged at one point were verified quantitatively to be unplugged prior to being no longer used. The plugging process is unlikely to be discrete and can result from gradual buildup of material in the pipeline.

The line(s) plugged at various times in the past. The waste in the line today would be a decayed version of what was in the line at the time of plugging. The Draft WIR Evaluation assigned average concentrations of the waste in the tank farm today to represent that in the plugged pipeline(s). The waste in the plugged lines could be much more concentrated (e.g., first-cycle extraction type wastes) than assumed in the sensitivity case for the WMA C PA. Report RPP-25113 attempted to identify what transfers were occurring at the time of plugging. Without characterization data, a conservative approach should be taken to ensure public health and safety would be protected from leaving in place plugged pipelines.

The Draft WIR Evaluation and WMA C PA only evaluated plugged pipelines as a sensitivity case, stating that the amount of plugged pipelines represents only 2% of the total pipeline length. At ~ 11 kilometer (km) of pipeline this would represent over 200 m of piping. The 2% argument is a form of risk dilution. If the plugged pipelines were exhumed, they would have to be characterized prior to disposal and then shown to meet the performance objectives of the disposal facility. According to the Draft WIR Evaluation, DOE does not have plans to characterize the lines nor are they considered part of the base case technical analyses. While intrusion into a non-plugged line is more likely, the risk associated with a plugged line, if plugged lines are within the scope of the evaluation, should be calculated as part of the assessment. An acute intruder dose for plugged pipelines with inventory estimated at the time of plugging was not provided in the WMA C PA.

Path Forward
Please provide sufficient basis for the plugged pipelines inventory, taking into account when the pipeline plugged. Perform characterization or provide a characterization plan for determining the inventory of plugged pipelines. After the inventory for the plugged pipelines has been revised, then the pipelines would need to be classified consistent with RAI 3-2 and intruder dose assessment performed consistent with RAI 2-16.

DOE Response
For purposes of creating a waste inventory estimate for the WMA C PA, DOE has assumed one pressurized waste transfer pipeline (V-122) and all eight inter-tank cascade lines to be "fully plugged."

The basis for the resulting inventory estimate is presented here. As will be discussed, DOE believes that this estimate is very conservative.

As discussed in the DOE response to RAI 1-1, the hypothetical "fully plugged pipeline" assumed in the WMA C PA for inventory purposes would represent a source of higher potential dose to an inadvertent intruder than other components within WMA C. Although the WMA C PA base case assumes intrusion into a non-plugged pipeline, Section 9.5 of the WMA C PA describes the sensitivity case where intrusion into a "fully plugged pipeline" is analyzed. Both cases comprise parts of the WMA C PA.

RPP-PLAN-47559 identifies three potentially plugged cascade lines, and RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site*, identifies a single potentially plugged cascade line. Also, as cascade lines are open at both ends, it is highly unlikely the entire length of any of the cascade lines is plugged. Therefore, DOE's assumption of all eight cascade lines being fully plugged would overestimate the residual waste inventory remaining in these lines.

The WMA C PA assumes the concentration of the waste in plugged pipelines is the same as the average concentration of residual waste in retrieved tanks. RPP-ENV-33418, *Hanford C-Farm Leak Inventory Assessments Report*, shows waste types that could be present in potentially plugged cascade lines. The most common waste types were Uranium or TBP waste, and PUREX coating waste (CWP1/CWP2) as indicated in Table 5-3 in RPP-ENV-33418. Compared to the average concentrations of important dose-driving radionuclides (i.e., Sr-90 and Cs-137 under inadvertent intrusion impact scenarios and Tc-99 under groundwater pathway impact scenarios) for retrieved tanks, process knowledge estimates for TBP, CWP1 and CWP2 are all significantly lower than the average concentration of residual waste in retrieved tanks assumed for pipelines. Therefore, the assumption of average residual waste concentrations would appear to overestimate the concentrations of these key constituents for plugged pipelines.

RPP-PLAN-47559 identifies the only plugged pressurized transfer pipeline in WMA C as V-122. This line became plugged in 1968. The waste being transferred at the time was PUREX Supernatant (PSN) waste, or PUREX high level waste (P2 waste). Daily reports in ARH-818, *Chemical Processing Division Daily Production Reports, October 1968 through December 1968* (pp. 133 – 145), show the line was plugged and that attempts to unplug the line at that time were unsuccessful. Information recently discovered in ARH-1945, *B Plant Ion Exchange Feed Line Leak*, reports the same V-122 pipeline discontinued transferring PSN waste a year later in December 1969, when a leak was discovered. Therefore, the line must have been successfully unplugged at some point between these dates. This indicates that previous assumptions were overly conservative in assuming the line was still plugged. The current estimate of waste in the V-122 pipeline assumes that the entire 494 foot [151 m) length of this pipeline is plugged. When compared to a total length of the eight cascade lines of 200 feet (61 m) that are assumed to be plugged, if the V-122 pipeline is assumed to not be plugged, this would reduce the overall "plugged inventory" by about 68 percent. With this new assumption, the entire pipeline volume and inventory would be reduced by about 11 percent. Thus, the overall assumed inventory used in the WMA C PA for all pipelines, and "plugged pipelines" in particular, is extremely conservative.

Based on these explanations and the newly discovered information, DOE believes that the inventory estimate for plugged pipelines in the WMA C PA is very conservative and does not require revision.

RAI 2-6

Comment
Some pipelines were taken out of service or replaced during operations, but the documents do not indicate what happened to a line when it was replaced during operations. The total amount of piping within the scope of the Draft WIR Evaluation has not been sufficiently established.

Basis
The WMA C system has an estimated ~11 km of waste transfer piping in C Farm according to the WMA C PA, though other reports indicate different values (ranging from 6.4 km and 119 pipes to 12.9 km and 230 pipes) (RPP-PLAN-47559). Problems with piping systems occurred and sometimes the lines were abandoned or replaced. For example, RPP-RPT-29191 stated "because of two apparent leaks in this line it has been abandoned as being unusable." Report RPP-RPT-38152 indicated that numerous piping changes involving the 244-CR Process Vault occurred.

The reports don't indicate what efforts DOE took to develop the inventory of piping that will be left in place under the Draft WIR Evaluation, or if a database of replaced and abandoned pipelines has been maintained. Various reports provide different estimates. It is not clear if when problems with piping occurred, that the replaced piping was tracked and has been included in the inventory of piping considered within the scope of the Draft WIR Evaluation.

Path Forward
Please describe the operational history of pipelines that were abandoned or replaced, including when they were taken out of service, if they were left in place, if they were included in the WMA C pipeline inventory, their construction materials, and their geometrical properties. Provide historical records associated with abandoned pipelines in WMA C.

DOE Response
All underground waste transfer pipelines in WMA C have been removed from service. The list of pipelines and pipeline information used in the WMA C PA and Draft WIR Evaluation is based on an extensive review of drawings and operational information documented in RPP-PLAN-47559. This reference is the most accurate listing and description of piping present in WMA C, and is considered authoritative.

Appendix A of RPP-PLAN-47559 summarizes all pipelines built in association with operational phases from 1944 to 1975, and includes available information regarding connecting facilities, diameter, length, depth, construction materials and drawing references for each pipeline. The total length of piping in WMA C is calculated to be 36,304 feet or almost 7 miles (11 km), which was used in the residual waste volume estimates.

RPP-PLAN-47559, Sections 3.2 to 3.6 describe the transfer operations during operational phases. Section 3.7 of RPP-PLAN-47559 discusses plugged and failed pipelines. Failed pipelines were abandoned and left in place. Additional operation details and dates for when specific lines were abandoned could probably be determined for some of the pipelines. However, this information would not result in modification to the waste inventory as all of the pipelines are included and the pipeline residual waste volume and inventory is conservative. Refer to the DOE response for RAI 1-3 and RAI 2-5.

RAI 2-7

Comment
The inventory of waste assigned to pipelines is represented by two assumptions that have insufficient technical basis. First, pipelines are assumed to be 5% full of waste. Second, the piping is assumed to be represented by 7.6 cm diameter lines. Some piping is contained in encasements that can contain much larger amounts of radioactivity than would remain in the pipes themselves, but encasements were not evaluated. The DOE inadvertent intruder analyses for pipelines provides inadequate basis to support limiting the analyses to the 7.6 cm diameter lines and residual inventories based on 5% of the pipeline volume.

Basis
The assumption of 5% waste remaining in the transfer piping is based loosely on observations for much larger diameter piping described in DOE/RL-2003-11. The amount of residual waste in pipelines is likely to be highly variable based on the size of the pipe, the corrosion state of the pipe, and the amounts and types of waste transfers that occurred through the pipes. Pipelines that are “unplugged” today could readily transmit waste under a prescribed head but have a substantial loss in cross sectional area due to build-up of waste. Without characterization data the amount of waste remaining in the piping system is highly uncertain. Characterization work of piping that was done for the plutonium finishing plant noted that build-up of solids in front of the camera eventually prohibited further observation of the piping system (PNNL-14144).

The Hanford piping has a variety of diameters ranging from ~ 4 cm to more than 15 cm with an average diameter of 10.8 cm (RPP-PLAN-47559; Sec. 4.1.5). The amount of residual waste in a 7.6 cm line would only be 25% of the amount of waste in a 15 cm line given the same fractional area of waste. While the 7.6 cm diameter line is most common, sufficient basis was not provided for limiting the evaluation to a single diameter line.

Some piping at Hanford is direct buried while others are encased. The encasements can be substantially larger than the pipe itself. Some of the trough-type encasements contain many pipes in the same encasement, such that multiple pipes could be intersected at once by an intruder. The trough-type encasements have 10 cm berms on either side and can be more than 100 cm wide. One report noted an encasement of 20 cm diameter for a 7.6 cm diameter line (RPP-ENV-33418). Piping has leaked at Hanford and it would not be unexpected that piping has leaked within the encasements of some pipes. Report RPP-RPT-38152 notes an encasement that likely contains waste. At an upper bound, a 7.6 cm diameter pipe that is 5% full of waste would represent only about 0.8% of the waste that would be inside one 20 cm diameter casing (outside of the pipe but inside the casing). Report RPP-RPT-29191 noted a leak that likely transported down an encasement and eventually entered C-101, C-102, and C-103.

The pipeline inventory is an important variable for evaluation of dose impacts to the inadvertent intruder.

Path Forward
Please provide additional basis for the 5% waste volume in the piping, or provide plans to characterize piping (even analogous piping removed from other decommissioned facilities) to verify the waste volume percent assumption for piping. Provide DOE’s plans to verify the 5% assumption. Evaluate intruder impacts to larger diameter piping that may remain in the system. Provide a description of all encasements used for piping in WMA C. Provide characterization data for inventory that may have been released to piping encasements. Evaluate the potential impacts to intruders from waste remaining in pipe encasements.

DOE Response
This RAI contains several different but related issues. These items have been divided into those items in the Path Forward section, and those items in the Basis section, which are addressed separately in the following paragraphs.

Response to Items in the Path Forward section:

Basis for the Assumption of Five Percent Residual Volume:
As discussed in RAI 1-1, RPP-PLAN-47559 is the primary reference document used in the WMA C PA for information regarding pipelines in WMA C. As detailed in RPP-PLAN-47559, the assumption of five percent residual volume in pressured waste transfer pipelines is based on process knowledge as well as limited characterization data from other facilities at the Hanford Site. Examples of this process knowledge include the following:

1. Per WHC-SD-WM-ES-259, *Single-Shell Tank Saltwell Transfer Piping Evaluation*, waste transfers were done under pressure at approximately 80 psig.
2. T0-025-001, *Tank Farm Transfer Procedure – General*, states "*A short specific procedure must be written for any transfer made using this SOP (Standard Operating Procedure). It must cover the route and tanks involved, leak detection information, material balance discrepancy**, flushing instructions** and refer to this SOP."* [emphasis added]
3. WHC-SD-WM-ES-259, Section 4, *Description of The Saltwell Transfer Piping Systems*, states the following: "*The piping is leak tested before use with raw water and flushed with raw water following use."*
4. Pipelines were constructed with a slope which would allow waste to drain into their receiving vessels (Section 4.1.1, RPP-PLAN-47559, *Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation*).

There is limited characterization data for pipelines. For pressurized waste transfer lines, a pipeline sample was taken from two 6-in (15.24-cm) pipelines (SN-285 and SN-286) at 241-SY Tank Farm in FY2011. The purpose of these samples was to document the level of pitting, cracking, and other forms of degradation and corrosion to both the inside and outside surfaces of the pipes with particular attention to the outside surface of the secondary, 6-in. diameter pipe which was in contact with the soil at the SY Tank Farm. To facilitate safe removal of the pipe section, the void areas inside the primary and secondary pipe were filled with urethane foam (Handi-Foam®[12] 2 Quick Cure II-205) before cutting. Prior to corrosion testing, photographs of these samples showing the foam inside the pipe were taken as documented in RPP-PLAN-47559 Figure 4-1. Examination of Figure 4-1 in RPP-PLAN-47559 shows very little to no waste in these pipelines. If five percent residual volume remains in the pipeline, the depth of that waste would be approximately 0.6 in. (1.5 cm) (calculated using Manning Formula Uniform Pipe Flow at Given Slope and Depth given at this website: http://www.hawsedc.com/engcalcs/Manning-Pipe-Flow.php) and would have been visible in RPP-PLAN-47559 Figure 4-1.

[12] Handi-foam is a registered trademark of ICP Building Solutions Group, Andover, MA.

Therefore, based on available process knowledge and (albeit limited) data from characterization, the actual amount of residual waste is expected to be much less than the assumed five percent in pressurized waste transfer lines.

An alternative line of evidence is provided by a characterization study of two vitrified clay pipelines that discharged effluent from the 231-Z Building to the Z Ditches, documented in DOE/RL-2003-11, *Remedial Investigation Report for the 200-CW-5 U Pond/Z Ditches Cooling Water Group, the 200-CW-2 S Pond and Ditches Cooling Water Group, the 200-CW-4 T Pond and Ditches Cooling Water Group, and the 200-SC-1 Steam Condensate Group Operable Units*. These pipelines consisted of 18-in. (45.7-cm) diameter and 15-in. (38.1-cm) diameter gravity flow pipes. The study reported that 1.5 in. (3.8 cm) and 1.25 in. (3.175 cm) of residual waste material existed in these pipelines, respectively. This residual waste represents approximately four percent of the total volume.

Gravity flow pipes represent a flow condition with much lower flow energy than pressurized transfer lines. Therefore, one would expect higher amounts of residual waste to settle within the gravity flow pipes than in a pressurized pipeline (Chapter II Section J, *Sedimentation Engineering, ASCE Manuals and Reports on Engineering Practice No. 54*, [Vanoni, 2006]). The velocity and turbulence of the transported liquid within a pressurize pipeline would not be conducive to having residuals settle out. Considering the differences in the hydraulics and sediment transport mechanisms between the vitrified clay pipe and the steel waste transfer pipeline, it is reasonable to conclude that the residuals observed in the vitrified clay pipe would be much greater than residuals that would accumulate in the pressurized waste transfer pipelines in WMA C. This conclusion is further supported by the fact that pressurized waste transfer lines were routinely flushed after use, whereas the gravity flow pipes were not. Consequently, the assumed residual waste volume of approximately four percent in the gravity fed lines may be considered a highly conservative estimate for the pressurized transfer lines. As an added measure of conservatism, the approximately four percent residual waste found in the gravity flow pipes was rounded up to five percent residual volume in RPP-PLAN-47559.

Additionally, DOE/RL-2003-11 reported an examination of steel drain lines (1.5-in. [3.8-cm] diameter lines) by a small video camera (1.25-in. [3.175-cm] diameter), suggesting that 6.5 percent residual volume would be a maximum residual volume present because the camera would not be able to fit through the pipe for the distances reported if there were large amounts of residual waste left in the pipe. These steel drain lines were gravity-fed lines, so one may expect to have higher volumes of residual wastes compared to pressurized transfer lines. This line of evidence is discussed in greater detail in the response to the Basis section below.

Further Waste Characterization:

With regard to the need to characterize WMA C pipelines, RPP-PLAN-47559 quantified the cost and effort required to conduct further characterization of WMA C pipelines, and concluded that "further pipeline characterization or supplemental closure actions for protection of human health and the environment are not necessary when risks are balanced against the high cost and schedule impacts associated with these actions." The example provided in RPP-PLAN-47559 estimated that adequate characterization would require excavation of approximately 40 sites within WMA C at an estimated cost of approximately $30M to $32M in 2010 dollars and would take 48 months following the retrieval of tanks. The cost and schedule estimates are based on the information developed in RPP-PLAN-31715, *Phase 1 Sampling and Analysis Plan for 200-IS-1 Operable Unit Tank Farm Pipelines*. That document was developed to support the characterization of a select number of SST pipelines near WMA C, but outside of the tank farm fence line. That estimate does not include sampling of any of the cascade lines between the SSTs. The cost for the removal of one cascade line with no sampling was estimated at $28M (RPP-PLAN-47559, Table 6-2).[13]

In summary, RPP-PLAN-47559 did not recommend characterizing the WMA C pipelines for the following reasons:

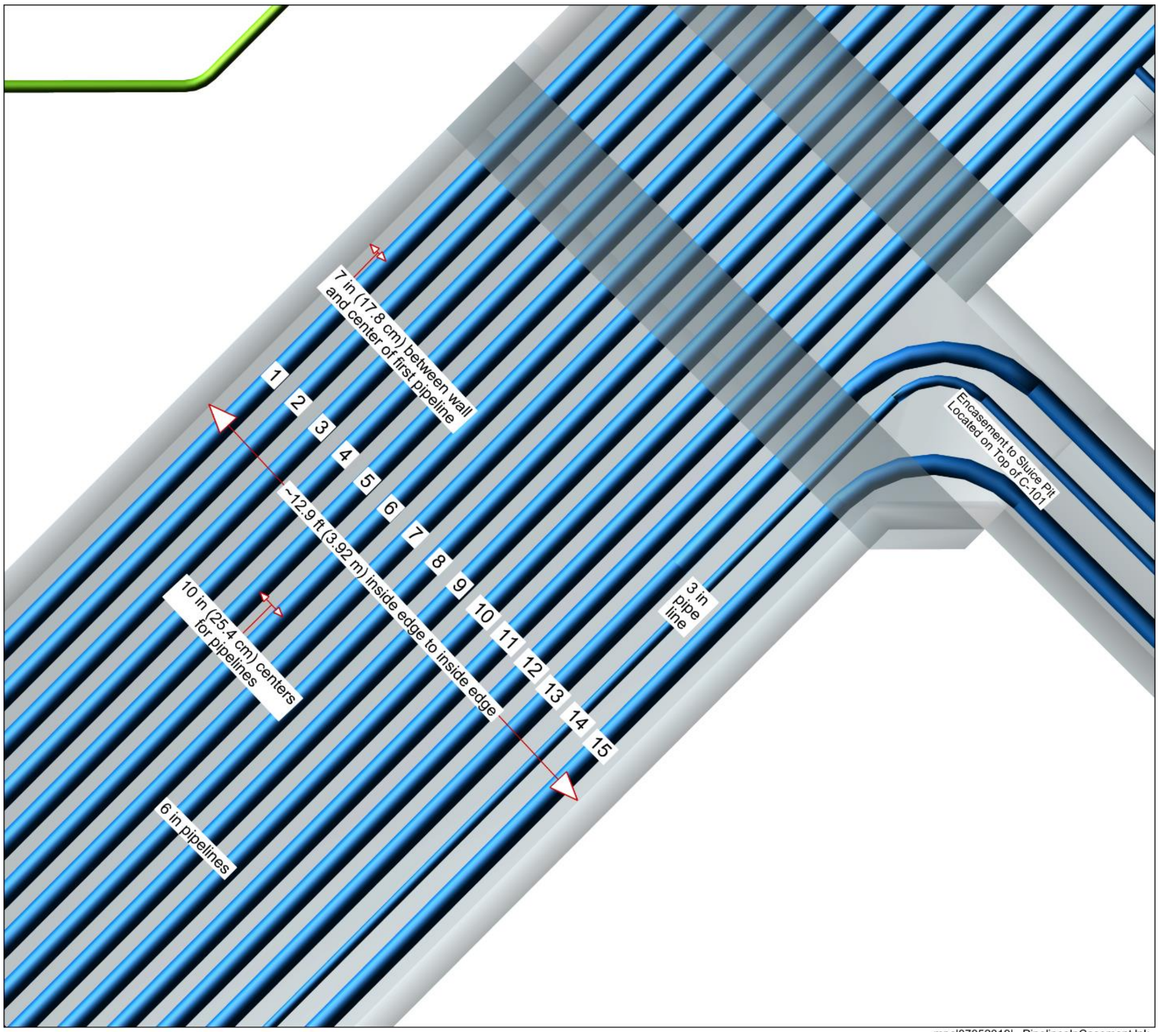
1. *"Obtaining representative samples of in-pipeline residuals in a highly radioactive and congested environment such as WMA C would increase potential worker exposure, would be costly, and would result in significant schedule impacts to closure of the WMA.*
2. *Process knowledge for WMA C provides sufficient information to make closure decisions for pipelines based on long-term impacts (note that other closure actions may be necessary for the purposes of ensuring optimal performance of a landfill cap).*
3. *A technically sound and conservative WMA C pipeline residual inventory has been developed.*
4. *This inventory does not significantly contribute to potential long-term impacts to human health and the environment for either the groundwater or DOE O 435.1 inadvertent intruder pathway based on a scoping analysis using conservative assumptions.*
5. *While the concentrations of hazardous waste extant in the residual inventory do present a threat to human health direct exposure and ecological receptor pathways, further sampling would not change this conclusion. The assumed closure action of placement of an engineered surface barrier will mitigate or prevent risk to these pathways dependent upon its design. Specific design features of the barrier will be determined as part of the RCRA closure plan and permit modification process.*
6. *The residual pipeline inventory present after closure actions have taken place does not significantly contribute to potential long-term impacts to human health and the environment for either the groundwater or DOE O 435.1 inadvertent intruder pathway based on a scoping analysis using conservative assumptions.*
7. *Where feasible, tank farm pipeline samples should be obtained opportunistically during the course of continued safe storage or closure actions to further clarify residual concentrations and inventory, and if warranted, to reexamine the recommendations provided in this report."*

Additional Considerations for Inadvertent Intrusion:
Results of a new sensitivity case where inadvertent intrusion occurs in a pipeline within an encasement are compared to the base case results for the pipeline source (refer to Table 4). The intrusion for the pipeline source in the base case is modeled for a 3-in. [7.6-cm] diameter pipeline, while the intrusion for

[13] For additional information concerning costs of removing pipelines, see response to RAI 1-1.

the sensitivity case is modeled for two 6-in. [15.2-cm] diameter pipelines within the encasement, which is the greatest number of pipelines that can be intruded into by the borehole based on the pipeline spacing (Figure 10).

Figure 10. Schematic of Pipelines within the Encasement Running from CR-152 Diversion Box and Tanks C-101, C-102 and C-103.



mpc|07052019|...PipelinesInCasement.lpk

In both the base case and the sensitivity case, an assumption of five percent residual volume of the pipeline is considered for the purpose of estimating the contaminated inventory in the drill cuttings. Results are provided based on loss of institutional control for two different assumed closure dates in order to illustrate the effect of the time factor. Results show increases for both acute and chronic doses for the sensitivity case with inadvertent intrusion into an encasement compared to the base case. However, in both cases the intruder doses are well below performance measures for acute and chronic exposure (i.e., 500 mrem and 100 mrem/yr, respectively).

Assumptions used in these inadvertent intrusion calculations and associated detailed results are summarized in an EMCF, RPP-CALC-63407, *Process and System Model Calculations Supporting DOE-ORP's Responses to Request for Additional Information Associated with NRC's Review of the WMA C Performance Assessment and WIR Evaluation*.

Table 4. A Comparison of the Acute and Chronic Doses for the Base Case with the New Encasement Intrusion Case, for the Various Inadvertent Intrusion Scenarios Evaluated.

	Acute Peak Dose[1] for Well Driller Scenario (mrem)	**Chronic Peak Dose[2] for Rural Pasture Scenario** (mrem/yr)	**Chronic Peak Dose[2] for Suburban Gardner Scenario** (mrem/yr)	**Chronic Peak Dose[1] for Commercial Farmer Scenario** (mrem/yr)
Assuming Closure at Year 2020 and Loss of Institutional Control at 2120				
Base Case Intrusion into Pipeline	36	8.2	3.9	0.001
Encasement Intrusion Sensitivity Case	72	33.8	10	0.007
Assuming Closure at Year 2068 and Loss of Institutional Control at 2168				
Base Case Intrusion	20	2.5	1.2	0.0005
Encasement Intrusion	40	10.2	3.1	0.003

[1] Performance measure for acute dose from Inadvertent Intrusions is 500 mrem
[2] Performance measure for chronic dose from Inadvertent Intrusions is 100 mrem/yr

Response to additional items in Basis section:
Additional clarifying information to specific examples identified in the Basis section of the RAI are as follows:

Pipeline Characterization:
The Basis section quotes the following:

> *"Characterization work of piping that was done for the plutonium finishing plant noted that build-up of solids in front of the camera eventually prohibited further observation of the piping system (PNNL-14144)."*

PNNL-14144 is titled "*Retrieval and Pipeline Transfer Assessment of Hanford Tank 241-AN-105 Waste.*" A careful reading of this document along with a word search through it found no mention of the following words: "camera", "build-up", "front", "plutonium finishing." It does not appear to be the correct reference for this sentence. DOE believes the correct reference is the description provided in RPP-PLAN-47559, Section 5.3.2, p. 5-17, paragraph 4 which states the following:

> *"The camera was then slowly pushed into the pipe for a distance of 63.3 ft. At that point the camera lens became obscured by a thick sludge-like material in the pipe. The camera was left in the pipe temporarily while a recovery plan was devised."*

Section 5.3.2 of RPP-PLAN-47559 provides a summary of the document WHC-SD-NR-ER-103, *Final Report for the Remote CCTV Survey of Abandoned Process Effluent Drain Lines 840 and 840D in Support of the 200 West Area Carbon Tetrachloride ERA.* For this work, two miniature color video cameras were inserted into two gravity fed drain lines (not pressurized waste transfer lines) running from the plutonium finishing plant to the 216-Z-9 trench, to examine the condition of these drain lines. The drain lines were 1.5 inches [3.8 cm] in diameter, while the camera was 1.25 inches [3.175 cm] in diameter and 13 inches long. Thus the clearance to accommodate the diameter of the camera (1.25 in) in relationship to the diameter of the pipe (1.5 in.) was only 0.25 in. [6.35 mm] of inch from the pipe wall. For Drain Line 840D, using fiberglass rods the camera was slowly pushed to a distance of 347.9 ft [106 m] before the friction load on the camera cable and fiberglass rods could not be overcome. That was approximately half the total pipe length. The video for this pipeline noted pockets of localized debris at several locations, which the operator was able push and pull the camera through until the debris is broken up enough to allow the camera to pass, up to 312 ft [95 m] where a sludge-like deposit is observed. For Drain Line 840 the camera was pushed to a distance of 61.6 feet [18.9 m]. At this point the material on the bottom of the pipe begins to undulate as the camera is pushed along, indicating that there is a liquid beneath the material. At 61.8 feet [18.8 m] the camera was pulled back slightly, and the debris piled up in front of the camera appears to be sludgy. At 62.8 feet [19.1 mm] the sludge pile begins to get on the camera lens. At 63.3 feet [19.3 m] the lens is obscured by the material. This camera was removed to wipe off the lens. However, the camera lights were shorted during the removal and a second camera was inserted, but again at the sludge build up in front of the lens at 63.3 ft prevented further observations.

Examining the assumption of five percent waste volume against the pipe and camera dimensions, if the residual consists of a rind/skin on the interior wall of the pipe, interior rind would have a thickness of less than 0.02 inches (0.51 mm). However, if the residual is a layer in the bottom of the pipe, the height of that residual layer would be approximately 0.146 in. (3.71 mm) (calculated using the Manning Formula Uniform Pipe Flow at Given Slope and Depth) which implies that there would be less than 0.1in (2.54 mm) of clearance at the top of the pipe for the camera. Given the tight clearances for between the camera and the side walls, it is unlikely there would be a large volume of residuals remaining in either of these pipes and still be able to push the camera. Furthermore, an upper bound for residual sludge waste volume remaining in a pipe can be estimated by assuming that a camera could still be pushed as long as the clearance between the camera and the pipe wall is greater than 0.075-in (2 mm). This calculation indicates the maximum residual waste volume would be approximately 6.5 percent. Even then, the distance between the pipe wall and the camera would still be very tight considering there would be bulges in the pipe wall at locations where two sections of pipe are welded together.

Potential Residual Waste in an Encasement:

As commented on in the Basis section, there could be the possibility of waste remaining in the encasement after a pipeline leak. However, as discussed in RAI 1-3, these encasements had drains within them that connected the encasements to the pump pits, which drain into the SSTs. There is only one known instance of a pipeline leak within an encasement at WMA C. In March of 1965, a 6-in. [15-cm] transfer line (Line #8041) failed and permitted coating waste from the PUREX Plant to the leak into the encasement between the 152-CR diversion box and Tank C-102 and drain to Tanks C-101, C-102, and C-103 via the tank pump pits (RL-SEP-405-DEL, *Chemical Processing Department Monthly Report for March*, p. B-2). It was noted in the monthly report that a liquid level rise in Tank C-103 was caused by a failed line in the encasement. It is possible that not all the waste drained into the SSTs and some remained in the encasement. However, given the observation that there was a liquid level rise in Tank C-103 resulting from this incident, it appears that the drain was functional, and the amount of material potentially left behind in the encasement would be minimal.

It should also be noted that the waste associated with this leak is a PUREX coating waste and/or condensate (RPP-ENV-33418, p 4-4) with low Cs-137 content. Intruding into this waste would therefore not yield a significant intruder dose because of the low concentrations of radionuclides. Table X provides a comparison between the average concentrations for the radionuclides that have the largest impact on intruder dose (all scenarios) used for the pipeline residuals and the concentrations found in PUREX coating waste, which would be the waste in the encasements. Table 5 indicates that doses would be considerably less for this waste, than the average used in the pipelines estimate.

Table 5. Comparison between Average Pipeline Residual Concentrations and PUREX Coating Waste

Radionuclide	Average[1] (Ci/L)	Coating Waste[1] (Ci/L)
^{90}Sr	0.81759	2.55E-04
^{137}Cs	0.06537	2.88E-04
^{240}Pu	0.00082	1.43E-04
^{241}Am	0.00110	4.04E-06

[1] Decayed to the Year 2020

Pipeline Inventory:

As commented on in the Basis section, the pipeline inventory is important for evaluation of dose impacts to the inadvertent intruder. The maximum dose calculated in the WMA C PA for intrusion into a pipeline within WMA C comes from the sensitivity case in which a 3-in. [7.6-cm] diameter cascade pipeline connecting two SSTs is assumed to be 100 percent filled with tank waste. For this sensitivity case, the dose from evaluating the rural pasture chronic exposure scenario is 160 mrem/year at 100 years after closure, which is above the 100 mrem/year DOE performance measure. As discussed in the DOE response to RAI 1-1, because of on-going activities in the immediate vicinity, the assumed facility closure date of 2020 used in the WMA C PA is conservative. For example, if the closure date is adjusted to the assumed closure date for the nearby double-shell tanks (approximately 2068), the dose for this sensitivity case would go down by roughly 70 percent (from 160 to approximately 48 mrem), or less than half of the 100 mrem/year performance measure, due primarily to decay of Sr-90 and Cs-137 whose half-lives are 28.8 and 30.2 years, respectively.

RAI 2-8

Comment
The amount, type, and impact of chelating agents in waste residuals were not provided.

Basis
Sorption of radionuclides to vadose zone and aquifer materials is a key process to limiting the risk to members of the public from residual wastes remaining in WMA C. Chelating agents have the potential to significantly alter expected radionuclide transport.

Organic compounds are present in waste and most were introduced as chelating agents (DOE, 1987). Some of the chelating agents used include hydroxyacetic acid, citric acid, hydroxyethyl ethylene diamine triacetic acid (HEDTA) and ethylene diamine tetraacetic acid (EDTA). Most of the organics and their degradation products are found in organic complexant waste.

NRC's low-level waste regulations (10 CFR Part 61) as well as waste acceptance criteria for DOE disposal facilities (e.g., The Environmental Restoration Disposal Facility Waste Acceptance Criteria [DOE, 2015]) explicitly prohibits most chelating agents in waste because of the potential impacts on system performance.

Observations from a low-level waste disposal facility found the in-situ Kd's for Co, Ru, and Sb isotopes were found to be significantly lower than published Kd's based on laboratory measurements (Fruchter, 1985). Complexes with both natural and manmade organic compounds in the groundwater were implicated, particularly with Co-60 (Fruchter, 1985).

Path Forward
Please provide the total quantity of each type of chelating agent present in WMA C wastes. Provide any experimental measurements at Hanford to quantify chelating agents concentrations and total organic content of waste residuals. Provide any experimental data generated at Hanford to assess the impact of chelating agents and organic wastes on radionuclide transport and grout durability, with particular emphasis on setting and curing. Discuss or demonstrate how the presence of chelating agents have been adequately incorporated into the WMA C PA.

DOE Response
Several chemical separation processes were operated at the Hanford Site that required use of organic solvents such as methyl isobutyl ketone, tributyl phosphate, normal paraffin hydrocarbon, bis-(2-ethylhexyl)-phosphoric acid, and carbon tetrachloride. Besides these extraction solvents, other organic complexants were introduced as chelating agents[14] for additional processing and recovery of certain radionuclides (e.g., strontium recovery processing at B plant). The principal organic complexants were glycolic acid, citric acid, hydroxyethylethylenediaminetriacetic acid (HEDTA), and ethylenediaminetetraacetic acid (EDTA). Other complexants, such as, nitrilotriacetic acid (NTA) and oxalic acid were also used, but in lesser quantities.

As noted by Fruchter et al. (1985), organic compounds can act as ligands for certain radionuclides and can potentially enhance subsurface transport when present in anionic or non-ionic forms. Some organic compounds can form strong chelating agents and can enhance the mobility of radionuclides such as Co-60

[14.] A chelating agent is a substance whose molecules can form several bonds to a single metal ion. In other words, a chelating agent is a multidentate ligand.

in the soil. However, most of the chelating agents in WMA C tanks have been retrieved or degraded, as described below, and chelating agents are not expected to impact radionuclide transport in the environment or grout durability.

HNF-3588, *Organic Complexant Topical Report*, provides significant information on the organic complexants in the tanks for the Hanford Site. Based on the process waste histories, HNF-3588 Table 4-11 categorizes the single-shell tanks into high complexant, medium complexant, low complexant, no complexant, and special case tanks. For WMA C specific tanks, C-104, C-105, C-106, C-107 are categorized as high complexant waste as these tanks received direct transfers of process wastes containing organic complexants. Tanks C-108, C-109, C-110, C-111, and C-112 are categorized as low complexant waste as these tanks did not receive direct transfers of complexant waste but might have received secondary (dilute) tank-to-tank transfers that contained organic complexants. Tanks C-101, C-102, C-103, C-201, C-202, C-203, and C-204 are categorized as special case tanks due to unique process histories. These special case tanks received predominantly organic solvent wastes such as normal paraffin hydrocarbons and tributyl phosphate. In addition, C-200 series tanks were known to have received small waste transfers from the strontium semi-works at B Plant.

As described in HNF-3588, the available experiments and analyses of tank samples indicate that organic complexants decompose to low energetic compounds such as formate, oxalate, and carbonate under the chemical and radiological conditions found in the Hanford Site tanks. The thermal and radiolytic degradation of organic complexants has been studied extensively and a summary of various studies and experiments is provided in Section 4.3.2.1 of HNF-3588. The studies indicate that HEDTA and glycolate would degrade to produce various actetates, formate, oxalate, hydrogen, nitrogen, nitrous oxide, and ammonia gases; oxalate and formate are eventually oxidized to carbonate ion. Given that the organic complexants have been stored in tanks for more than 20 years and were exposed to radiation, high temperatures, and reactive chemical environment, it is predicted that most, if not all, of the organic complexants have undergone decomposition to low energetic compounds. This is validated by sampling results as discussed below.

Many tank waste samples have been analyzed for total organic carbon (TOC) and oxalate ion (an aging byproduct) and wastes with high TOC concentrations were extensively analyzed for other organic constituents. Table 4-4 of HNF-3588, reproduced below as Table 6, summarizes the TOC content for various single shell tanks along with the oxalate content. The sampling data for Tanks C-104 and C-106 shows a mean TOC of 1% and 1.34% (wet weight) respectively with oxalate accounting for 11 percent and greater than 99 percent of the TOC. Results of detailed organic speciation conducted on various tank samples obtained through 2001 indicate that some of the original complexants such as citrate, EDTA, glycolate, and HEDTA are either non-detects or a small fraction of the TOC, while the degradation products such as citrate, glycolate, formate, and oxalate have significantly higher fractions (Table 4-5 of HNF-3588). These measurements indicate extensive degradation has occurred of the original chelating agents.

Table 6. Total Organic Carbon and Oxalate in Single-Shell Tanks (Table 4-4, HNF 3588)

Tank	Mean TOC[1] (wt%, wet)	TOC Inventory[2] (kg)	Oxalate Inventory[3] (kg)	Average TOC as Oxalate[4] (wt%)(sd)[5]
A-101	0.31	19,600	31,300	44 (7)
A-102	1.11	3,910	3,140	22 (2)
AX-101	0.62	3,050	4,250	38 (33)
AX-102	1.87	3,290	1,450	12 (1)
AX-103	0.52	3,260	5,130	43 (2)
BX-110	0.15	2.070	4,710	62 (34)
BY-101	0.48	12,300	33,400	74 (25)
BY-102	0.38	6,940	30,400	>99 (33)
BY-104	0.67	6,810	13,100	52 (21)
BY-105	0.73	24,200	84,300	95 (52)
BY-106	0.51	11,500	31,800	75 (15)
BY-107	0.52	7,630	22,000	79 (19)
BY-108	0.39	5,820	9,750	46 (11)
BY-109	0.33	11,900	37,100	85 (70)
BY-110	0.64	16,700	26,300	43 (11)
BY-111	0.55	16,700	52,800	86 (33)
BY-112	0.71	13,600	47,700	96 (44)
C-104	1.00	16,100	6,390	11 (4)
C-106	1.34	15,200	60,200	>99 (25)
S-101	0.22	5,160	10,200	52 (38)
S-102	0.33	11,800	25,400	57 (17)
S-106	0.23	6,110	13,000	58 (16)
S-107	0.20	4,150	10,200	67 (11)
S-111	0.17	6,600	17,300	71 (19)
SX-101	0.53	15,800	32,400	56 (41)
SX-106	0.39	13,300	17,600	36 (39)
U-102	0.74	15,900	10,300	18 (3)
U-103	0.64	24,000	7,690	9 (2)
U-105	1.23	30,200	24,100	22 (3)
U-106	2.16	29,600	12,700	12 (2)
U-107	0.18	4,950	6,860	38 (16)
U-108	0.42	12,900	12,700	27 (3)

Notes: [1] Mean TOC concentration calculated from the best basis inventory.
[2] TOC inventory presented in the current tank characterization reports.
[3] Oxalate ion inventory calculated from the information in the current tank characterization reports.
[4] Average % carbon as oxalate ion evaluated from inventory or sampling data.
[5] Uncertainty calculated using the following:

$$sd = \sqrt{\left(\frac{a}{b}\right)^2 \left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{b}{a}\right)^2 \left(\frac{\sigma_b}{b}\right)^2}$$

where sd = standard deviation, a = TOC measurements, and b = oxalate measurements.

It is important to note that the organic complexants used at the Hanford Site were extremely soluble and were originally disposed to the tanks as aqueous (liquid) waste. Waste simulant experiments that investigated the solubility of organic compounds in the highly saline liquid waste report EDTA solubility in the range of 0.7 to 1.4 M (84,000 to 168,000 mg/L of TOC) and solubility of HEDTA of 1.1 to 1.8 M (180,000 to 216,000 mg/L of TOC) (Table 4-6 of HNF-3588), which would result in most of the organic compounds to be present in the supernatants. During waste retrieval, almost all of the supernatant was removed from the WMA C tanks and pumped into DSTs. Therefore, the residual inventory of these complexants is expected to be negligibly small. The Tank Waste Information Network System (TWINS) sample data base currently shows that all EDTA and HEDTA results for WMA C tank farm samples are below detection limits (TWINSb). The primary organic compound in the residual tank waste at WMA C is TBP with an inventory of < 1 kg in the 100-Series tanks and 5 to 67 kg for the 200-Series tanks.

RPP-RPT-61301, *Process Knowledge Concerning Organic Chemicals in Hanford Tank Waste Supernate*, summarizes the results of the analyses of organic compounds present in the DSTs. RPP-RPT-61301 Table 9 provides average concentrations of TOC and degradation products of organic complexants present in supernatants of the DSTs. The TOC content ranges from ~900 mg/L to ~41,000 mg/L with the majority of TOC contributed from small organic acids due to their high solubility and their occurrence as degradation products. The percentage of carbon contributed from acetate, formate, glycolate, and oxalate to TOC ranges from approximately 3 percent to 82 percent with an average of 44 percent.

Based on the relatively high concentration of TOC (and organic complexant degradation products) in the DST supernates and the lack of detection of EDTA and HEDTA within the WMA C tanks, it appears that the principal organic complexants were either removed during tank retrieval operations or have degraded from aging. Consequently, the impact of any remaining chelating agent on radionuclide transport from the tank or on grout durability following closure is expected to be insignificant.

RAI 2-9

Comment
An insufficient basis is provided for the assignment of the H2 sand hydraulic properties to the degraded grout infill for the grout infill degradation sensitivity case analyses

Basis
For its base case, DOE has assumed that the grout infill within the waste tanks at closure remains intact and impermeable to flow throughout the 10,000-year analysis period. DOE conducted four sensitivity analyses to assess the impact of degradation of the grout infill that would allow advective flow of net infiltration through the degraded grout infill at 0, 500, 1,000 and 5,000 years post closure.

In these sensitivity case simulations, the grout infill is assumed be impermeable until the assumed failure time is met. Once the failure time is met, the grout infill is assigned the same hydraulic properties that are used for the H2 sand.

The modeling results for these sensitivity cases indicate that the assignment of the H2 sand hydraulic properties to the grout infill results in a contrast of hydraulic properties between the failed grout infill and the surrounding materials such that the flow of net infiltration is largely diverted around the tank waste residuals that underlie the grout infill. This may be a modeling artifact based on the contrast in properties. These results therefore suggest that the dose at the receptor location may be underestimated if the assumed hydraulic properties of the degraded grout infill are not accurate.

Path forward
Please provide additional support for the assignment of the H2 sand hydraulic properties to the failed grout infill or alternatively, conduct simulations that assign hydraulic properties to the failed grout that do not result in flow being diverted around the tank waste residuals. Provide the net infiltration depth profiles for these simulations.

DOE Response
The assignment of hydraulic properties of the H2 sand used for the analysis of conditions post-failure was an arbitrary choice, intended to approximate an extremely conservative representation of the hydraulic properties of tanks that exclude the stabilized (i.e., grouted) tank safety function. There are no known FEPs or combination of FEPs that could produce degradation so severe that it would transform tank structure and in-fill grout into something like sand or gravel. However, as recommended in the Path Forward section of the RAI, an additional sensitivity case of this safety function's removal was simulated. In this additional case, the hydraulic properties for the stabilized tank are assigned values the same as the gravel-dominated backfill material. This assumption removes the contrast in permeability between the degraded tank and in-fill grout and the surrounding backfill material. It is important to emphasize that the assumption of either H2 sand or gravel-dominated backfill material hydraulic properties to represent the nonfunctioning safety function is completely arbitrary, and that there are no known FEPs or combination of FEPs that could produce this condition. This analysis is solely intended to evaluate the loss of the flow safety function of the stabilized tank.

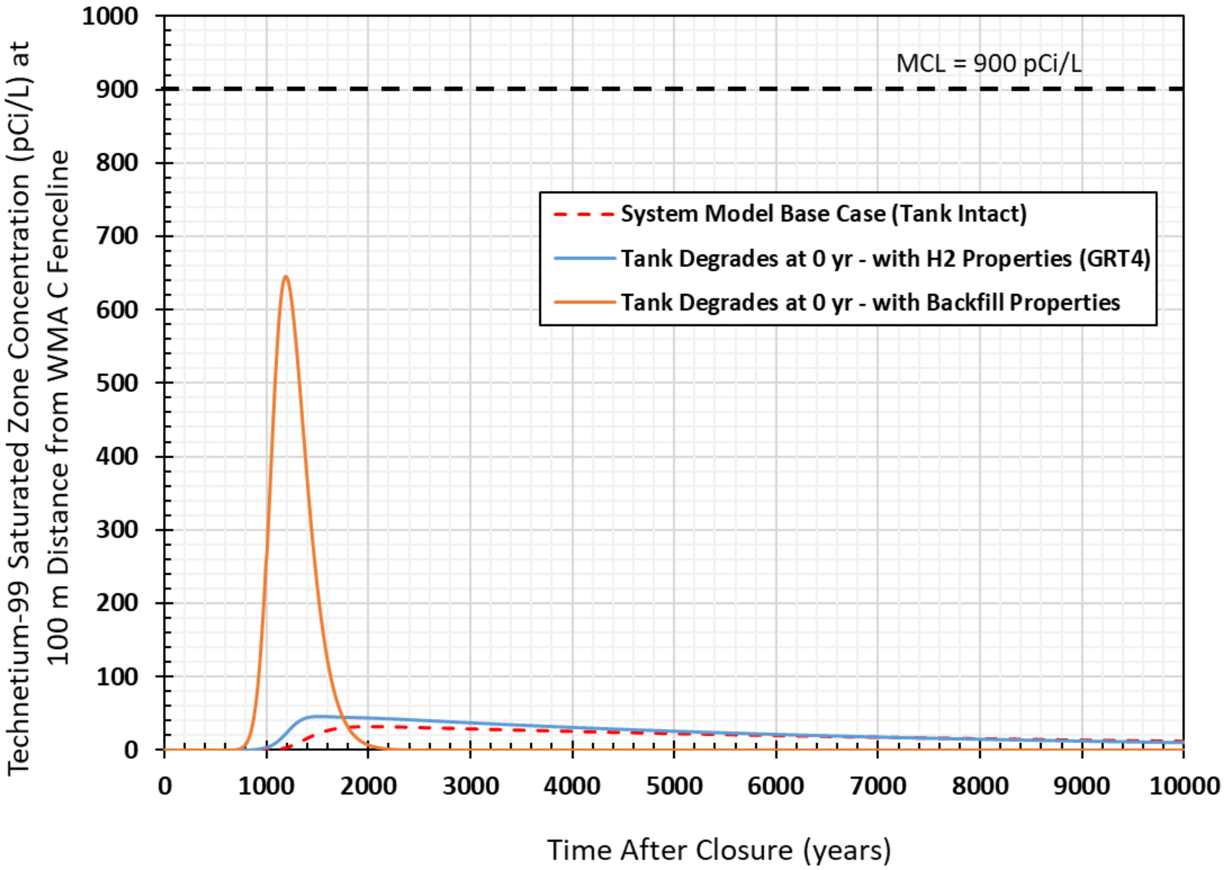
The additional sensitivity case, which assumes that degraded stabilized tank has hydraulic properties of gravel dominated backfill, was carried out in the same way as in the original sensitivity case which assumed H2 sand hydraulic properties (GRT4). Both cases assume no functionality of the tank and in-fill grout at the time of assumed WMA C closure (i.e. Year 2020).

A comparison of Tc-99 concentration results at 100 m [328 ft] down-gradient of WMA C for the additional sensitivity case with both the sensitivity case GRT4 and the Base Case are presented in Figure 11. The use of backfill hydraulic properties results in less flow being diverted around the tank. The increased flow through the stabilized tanks increases the Tc-99 release rate from tank waste residuals, and reduces travel time required for peak releases of Tc-99 to reach the underlying groundwater. These increases in Tc-99 release rates and earlier arrivals in groundwater result in an increase of about a factor of 14 in Tc-99 concentrations at 100 m down-gradient of WMA C, compared to the results generated in sensitivity case GRT4. The new sensitivity case results in a peak Tc-99 groundwater concentration of about 640 pCi/L at approximately 1200 years after assumed WMA C closure in 2020. In contrast, the sensitivity case GRT4 results in a peak Tc-99 concentration of about 46 pCi/L around 1500 years after assumed WMA C closure in 2020. The base case, with its assumed intact stabilized tank structure safety function, results in a peak Tc-99 concentration of about 30 pCi/L at about 2000 years after assumed WMA C closure in 2020.

Therefore, even these highly conservative analyses of the stabilized tank safety function lead to concentrations less than the groundwater resource protection Maximum Contaminant Level (MCL) of 900 pCi/L(40 CFR 141). Calculated results at 100 m can also be compared with performance objectives for the all pathways dose (i.e., 25 mrem/year) within and beyond the 1,000 year period of compliance. The maximum dose within the 1,000 year compliance period for the new sensitivity case is about 0.83 mrem/year, while the peak dose at 1200 years is about 2.2 mrem/year, which is a factor of ten lower than the 25 mrem/year performance objective (DOE-STD-5002-2017, “DOE Standard - Disposal Authorization Statement and Tank Closure Documentation”). The peak dose is lower for the two comparison cases presented in Figure RAI-2-9-1. For the GRT4 sensitivity case, the peak dose is approximately 0.15 mrem/yr. For the base case, the peak dose is approximately 0.1 mrem/year, proportional to the peak concentration of Tc-99 in groundwater.

The assumptions used in these calculations and associated detailed results are summarized in an EMCF, RPP-CALC-63407.

Figure 11. A comparison of Tc-99 concentrations in groundwater downgradient of WMA C based on assumed complete tank degradation at the time of assumed WMA C closure (Year 2020) for the Base Case, the H2 sand hydraulic properties (GRT4) sensitivity case, and the additional sensitivity case assuming gravel-dominated backfill properties for degraded tanks.



RAI 2-10

Comment
Additional information is needed to support a technical basis for using a relatively high hydraulic conductivity value for the unconfined aquifer.

Basis
The saturated hydraulic conductivity and the hydraulic gradient of an aquifer are important parameters for determining the degree of contaminant mixing and dilution in that aquifer.

The amount of dilution in the aquifer is a key safety function with respect to protection of offsite members of the public. Section 8 in the WMA C PA shows that the saturated zone Darcy flux is an important parameter.

The scale used to determine the input parameter value can have a large influence on the final parameter value. DOE provided a figure in the WMA C PA (Figure C-1) which illustrates this fact for hydraulic conductivity values. DOE stated that, "Measurements of hydraulic conductivity appear to be dependent on the test scale, and increase as the scale increases, particularly in heterogeneous media." DOE further states that individual well-based slug and pump tests provide information at a relatively small-scale while the effects of large-scale heterogeneity on flow and determination of media properties can therefore be inferred most effectively by using regional scale groundwater.

DOE relied on a large-scale pump or treatability test, documented in DOE/RL-2015-75, and the calibrated values from the Central Plateau Groundwater (CPGW) model (CP-47631). The treatability test, as described in DOE/RL-2015-75, evaluated whether 189 and 379 liter per minute pumping rates could be sustained in the unconfined aquifer near the B Complex northeast of WMA C. The derived hydraulic properties from this treatability test were used to update part of a Central Plateau to Columbia River model. The distances of the particle pathlines within the simulated capture zone were generally well over a kilometer long. The model domain of the CPGW model encompasses much of the Hanford Site and is well over 20 km long and 10 km wide. The scale of interest for this WMA C PA are the points of calculations 100 m downgradient from WMA C. It is not clear why DOE decided that the hydraulic conductivities derived from a calibrated model on the scale of kilometers are regarded as more reliable than direct measurements by slug test or pump tests. In addition, there are differences in the conceptual hydrogeological models of the CPGW model and the STOMP model as discussed in RAI 2-13 which makes a direct comparison between the Hanford Site model and the WMA C model questionable.

Section 6 in the CPGW model document (CPP-47631, Rev. 2) discusses limitations of that model. Two of these limitations included:

- *"The flow model is regional in nature. Hydraulic property variation is generally recognized at the scale of HSUs [hydrostratigraphic units] (km to 10s of km horizontally). At the scale of the HSUs down to the model grid scale (100 m), the eastern portion of the model is geologically more complex than the western portion of the model. Especially in the eastern portion of the model domain, these limitations of the scale at which variation is represented limits the scale that simulated results should be considered reliable as evidenced by two observations:*
  - *Model calibrations indicate that there are some regions of kilometer scale, such as the northeast corner of the model domain, where flow is not well-represented.*
  - *Review of flow simulations in the 200 East Area, at less than a kilometer scale, have revealed very poor agreement with interpreted flow directions.*

- *The model grid represents the aquifer with cells of dimension 100 by 100 m. It is expected that the model is most suitable for making predictions of heads, hydraulic gradients, and groundwater flow rates over areas that comprise many model cells, and that predictions of these quantities on scales smaller than 100 m are not reliable except in circumstances of uniform hydraulic gradients."*

As shown in Figure C-6 of the WMA C PA, until recently, most DOE documents and sources provided a range of hydraulic conductivity values that were lower than the current average WMA C PA value of 11,000 meters per day (m/d). Previously, RPP-RPT-46088, Revisions 0, 1, and 2 (in Section 5) had given the general range of saturated hydraulic conductivity values for the unconfined aquifer as between 1000 to 3000 m/d with a recommended parameter value of 3000 m/d and using a recommended minimum and maximum of 100 m/d and 7000 m/d, respectively (RPT-46088, Rev. 1).

The Darcy flux sensitivity analysis in the WMA C PA uses a minimum value (4200 m/d) that is above the hydraulic conductivity values that were being recommended until recently. The uncertainty analysis uses minimum values that go down to 1000 m/d; however, the values used do not encompass a range that would capture the uncertainty associated with the saturated zone Darcy flux.

Path Forward

Please provide additional information to support the technical basis for the hydraulic conductivity value used for the unconfined aquifer beneath WMA C, or increase the range of parameter values for the saturated zone hydraulic conductivity in the uncertainty and sensitivity analysis so as to encompass the range of estimated or recommended values from recent WMA C saturated zone documents.

DOE Response

DOE agrees that the amount of dilution in the aquifer at WMA C is a key safety function with respect to protection of offsite members of the public. Estimating contaminant concentrations requires an estimate of the overall groundwater flow rate through the unconfined aquifer being modeled. The flow rate determines the dilution at the local scale, and the local flow rate must be consistent with the overall mass balance of water across the Central Plateau. Local values of hydraulic conductivity must be consistent with the overall mass balance, and with local observations of the hydraulic gradient observed in the aquifer. The overall conceptual approach used in the WMA C PA was to identify local aquifer flow rates at WMA C needed to maintain mass balance at the Central Plateau scale, and to constrain the hydraulic conductivity to maintain consistency with the observed aquifer gradient.

To address the questions and assertions presented in the Basis section of this RAI, DOE will address the following issues in addition to the overall comment on hydraulic conductivity:

- The use of the calibrated Central Plateau Groundwater Model (CPGWM) as the primary basis for establishing local-scale hydraulic conductivities at WMA C, rather than using direct estimates of hydraulic properties based on pump and slug tests.
- The use of the calibrated large-scale CPGWM as the primary basis for establishing local-scale hydraulic conductivities at WMA C because of differences in the geological conceptualizations and the scales of the two models.
- Reliance upon a large-scale pump test near B Complex to provide a partial basis for establishing hydraulic conductivities at WMA C.
- The range of values for hydraulic conductivity used in the sensitivity and uncertainty analyses.

The use of the calibrated CPGWM as the primary basis for establishing local-scale hydraulic conductivities at WMA C, rather than using direct estimates of hydraulic properties developed based on pump and slug tests.

The general technical literature supports the use of calibrated modeling results and parameter estimates that are conditioned or inverse upscaled by available data as superior to estimates derived from test measurements. General technical literature referenced as part of the WMA C PA that support the use of calibrated modeling results and parameter estimates can be found in Appendix C of the WMA C PA, such references include: Scheibe et al. 2015, "An Analysis Platform for Multiscale Hydrogeologic Modeling with Emphasis on Hybrid Multiscale Methods"; and MASSFLUX-1, *Use and Measurement of Mass Flux and Mass Discharge*.

Permeameter, slug, and pumping tests are limited in their ability to quantify non-localized spatial averages or trends, and are less likely to produce central measures of flow magnitudes than a regional model (See Appendix C in WMA C PA). Using hydraulic conductivities estimated from such hydraulic testing to simulate groundwater flow and contaminant transport in a model can often produce simulated values of hydraulic heads, flows, and contaminant concentrations that poorly match historical observations (Tiedeman and Hill, 2007). "Predictive modeling of flow and transport in a two-dimensional intermediate-scale, heterogeneous porous medium" (Barth et al., 2001) concluded that the results of their experiment indicated that models calibrated with sufficient observations produce more accurate predictions than those based on smaller scale estimated hydraulic conductivity values developed from hydraulic testing.

The CPGWM represents the most recent culmination of understanding of the unconfined aquifer under the Central Plateau at the time the WMA C PA was published (CP-47631). The CPGWM estimates take into account the general understanding of the geologic framework and hydrology of the unconfined aquifer, including the hydraulic impacts that occurred in response to historical wastewater discharges, as observed in wells monitoring the unconfined aquifer (see Section C-3, Appendix C of WMA C PA). The CPGWM is considered to be the most suitable basis for estimating or predicting flow or flux and hydraulic parameterization because of the rigorous nature of the development effort and the success of the results in matching historical measurements. CPGWM Version 3.3 and Version 6.3.3 (CP-47631) results represent improvement over previous versions, particularly in the match of 200 East Area well data. The CPGWM results adequately reproduce measured water level data from 420 wells distributed over the Central Plateau region throughout its calibration period[15]. Figure C-11 in the WMA C PA illustrates an excellent comparison between the CPGWM-simulated hydraulic heads and observed hydraulic heads for the wells located up-gradient and down-gradient of WMA C for a time period spanning over 20 years. The agreement over such a large period of time lends credibility to the reasonableness of the regional flow conditions and associated hydraulic properties simulated by the CPGWM at both the scales of 200 East area and WMA C.

The use of the calibrated large-scale CPGWM as the primary basis for establishing local-scale hydraulic conductivities at WMA C because of differences in the geological conceptualizations and the scales of the two models.

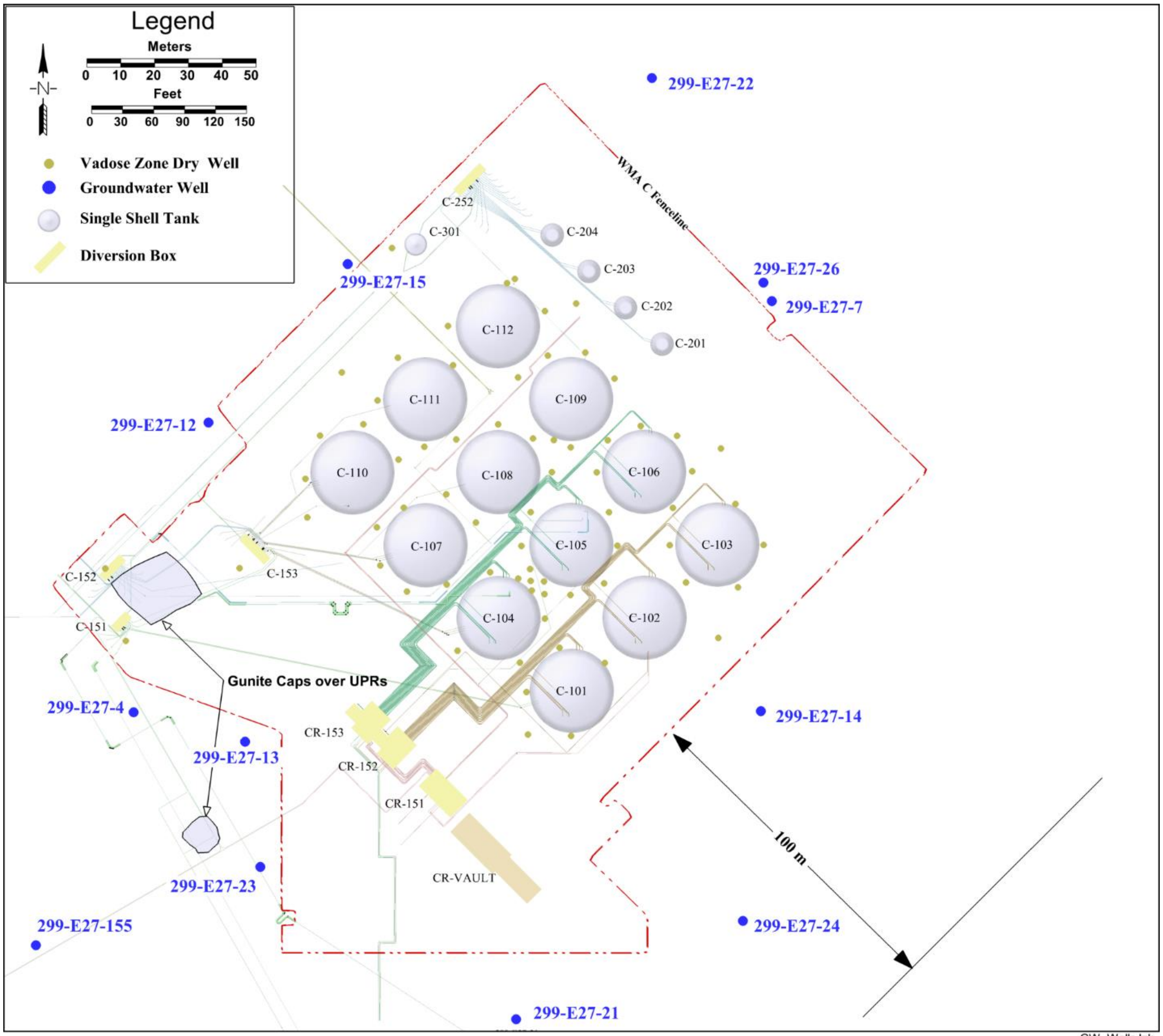
Regardless of the scale of the two models, the best geologic data and information available for wells in the vicinity of WMA C support the general geological conceptualization of the existence of a

[15] Section 4.5.5.3 of CP-47631 presents comparisons of measured and simulated hydraulic gradients, and Appendix A of CP-47631 presents comparisons of measured and simulated water levels.

paleochannel in this area of the Central Plateau model domain. This consistency in geologic interpretations between the two model domains support the use of the calibrated large-scale CPGWM as a basis for establishing hydraulic conductivities at WMA C.

The geologic descriptions given for the twelve groundwater monitoring wells (See Figure 12) surrounding WMA C indicates the unconfined aquifer beneath WMA C resides wholly within buried paleochannels containing high-permeability flood gravels (Bjornstad and Last, 2007, "Effects of Ice Age Flooding on the Hydrogeology of the Hanford Site").

Figure 12. Location of Groundwater Wells Surrounding WMA C.



Five of the twelve groundwater monitoring wells were drilled in the 1980s (Well No. 299-E27-7, 299-E27-12, 299-E27-13, 299-E27-14, and 299-E27-15). Well Construction and As Built Reports are the only available data which describe the geology for each of these monitoring wells. These reports indicate gravel to sandy gravel to muddy, sandy, gravel within the unconfined aquifer. Of these five early wells installed in the 1980s, only one report for Well No. 299-E27-7 which was installed in 1982 calls out the Ringold formation which is known to occur approximately 16 to 20 ft below the water table surface. [Note: geologic logs for these specific wells were prepared before the site standards for describing the geology were developed; thus, these logs may not have been performed by a registered geologist].

The remaining seven wells (Well No. 299-E27-4, 299-E27-21, 299-E27-22, 299-E27-23, 299-E27-24, 299-E27-26, and 299-E27-155) were drilled between 2003 and 2016. The description of the geology for these wells use the site standard terminology. The first four of these wells are documented in PNNL-14656, *Borehole Data Package for Four CY 2003 RCRA Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299- E27-23 at Single-Shell Tank, Waste Management Area C, Hanford Site, Washington*, and were installed in 2003. The description of the Hanford H3 unit for well 299-E27-22 (p. 3) states the following:

> *"The sandy gravel to gravel of the lower Hanford H3 unit comprises the sediments from approximately 185 feet bgs to 268 feet bgs. Although, the Cold Creek unit (CCU), as defined in Wood et al. (2003), may be present, there is no contact within this gravel unit that can be identified between the lower Hanford formation Unit 3 and the CCU. If the CCU is present, it is not clearly defined."*

Similar statements are made for the other three wells in this report (299-E27-4 p. 6, 299-E27-21 p. 8, and 299-E27-23 p. 10).

The next well installed was well 299-E27-155 (C5852) in 2007 and documented in SGW-37384, *Borehole Summary Report for the Installation of Two Groundwater Monitoring Wells at the 200-BP-5 Operable Unit, CY2007*. This report states the following (pg.3-4):

> *"The unconfined aquifer beneath the project area is also contained within the Hanford formation sediments directly overlying the upper-most basalt unit. The unconfined aquifer thickness in the vicinity of well C5852 is about 55 ft and approximately 3.7 ft at well C5861."*

Well 299-E27-24 was installed 2010 and is documented in SGW-48722, *Borehole Summary Report for the ARRA Installation of Five RCRA Groundwater Monitoring Wells in the 200 Areas, FY 2010*. Below is the description of the transition from Hanford formation to the undifferentiated Hanford LG/CCU/Ringold (pg. 16):

> *"The transition from Hanford to undifferentiated Hanford LG/CCU/Ringold was marked by a decrease in basalt content between 209 and 218 ft bgs. Sand grading into silty sand was observed from 218 to 250 ft bgs and interbedded sandy gravel to gravel was observed from 250 to 315 ft bgs. The Elephant Mountain Basalt was encountered from 315 ft bgs to the TD of 317.8 ft bgs."*

Note, the top of the water table occurs at 265 ft below ground surface (i.e. well below the identified silt layer).

In 2016, the last well installed just outside WMA C was well 299-E27-26; this well was installed as a replacement monitoring well for well 299-E27-7 which had been monitored since 1982. The description of the geology for this well is given in SGW-59346, *Borehole Summary Report for the Installation of Eight M-24 Tri-Party Agreement Groundwater Monitoring Wells FY 2015* (p. 3-7).

> *"The subtle change in gravel characteristics noted at 255 ft bgs may be interpreted as the contact between the Hanford formation and CCU. Review of the geophysical Log Data Report indicates no discernable log signature at the presumed contact; therefore, no contact can be interpreted or confirmed based on geophysical data. Without the presence of the CCU silt, it is difficult to definitively identify the Hanford formation and CCU contact at this location. At 270 ft bgs, the sandy gravel grades into a well-sorted gravel unit with 10 percent sand and trace amount of silt. Basalt was encountered at 280.8 ft bgs."*

This is the only well in which an attempt to differentiate Hanford H3 unit from the CCU has been made. Without solid evidence to break out the top and bottom of the CCU, or the different units of the Ringold Formation, it is not possible to include these units as separate units with different hydraulic properties in the WMA C hydrogeologic model or in the STOMP model of the unconfined aquifer. The principal rock type found within the unconfined aquifer are gravels.

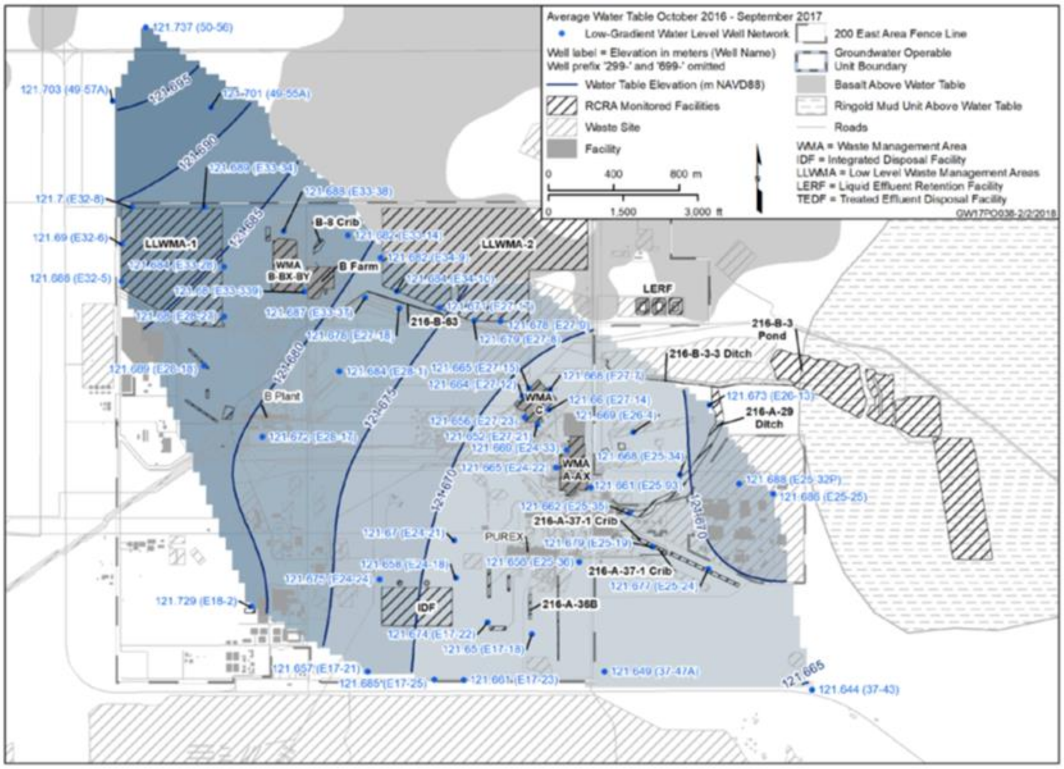
Therefore, based on these observations, the key feature of the subsurface that needs to be represented in both models is the paleochannel. The CPGWM does include the paleochannel beneath WMA C; however, the boundary of the channel within the CPGWM is different than that in the WMA C specific STOMP model due to the different model scales and differences in the grid block size between the two models. The grid block size was 100 m x 100 m (328 ft x 328 ft) for the CPGWM in the vicinity of the paleochannel, while the grid block size used to interpolate the geology at WMA C in RPP-RPT-56356, *Development of Alternative Digital Geologic Models of Waste Management Area C*, varied from 2 x 2 m (7 ft x 7ft) to 10 m x 10 m (33 ft x 33 ft). The grid block size was varied at WMA C to accommodate the large number of boreholes within the fence line WMA C and fewer boreholes outside WMA C.

Clarification of some points related to the selected limitations of the applicability of the CPGWM included in CP-47631 as mentioned in the Basis section of this RAI is also in order. In the second bullet about model limitations in the Basis section of this RAI, the following limitations are mentioned related to model scale:

> *"The model grid represents the aquifer with cells of dimension 100 by 100 m. It is expected that the model is most suitable for making predictions of heads, hydraulic gradients, and groundwater flow rates over areas that comprise many model cells, and that predictions of these quantities on scales smaller than 100 m are not reliable* ***except in circumstances of uniform hydraulic gradients****." [emphasis added]*

The bold text at the end of this bullet supports the use of the calibrated CPGWM as a basis for hydraulic properties in the WMA C PA effort. The 200 East Area, and WMA C in particular, are located in an area of the CPGWM domain with relatively uniform hydraulic gradients as shown in Figure 13 below.

Figure 13. Average Water Table for the 200 East Area, October 2016 through September 2017.
(from DOE/RL-2017-65, Figure 2-6)



The summary provided in the Basis section of the RAI did not include the other information from the same section on Model Limitations (See Section 6 of CP-47631, Rev. 2) that is relevant to the use of CPGWM in the WMA C PA effort including:

> *"The CPGW Model is limited in intent and purpose to the simulation of saturated flow in the unconsolidated aquifer above the underlying basalts. As a result, the model is suitable for calculating water levels, hydraulic gradients, and groundwater flow directions and rates throughout the Central Plateau.* ***Predictions made with the CPGW Model will be most reliable in those areas that with a high density of water level data that were incorporated in the model calibration, and for those areas where model outputs correspond closely with the measured data.*** *Conversely, model predictions will be less reliable in those areas where fewer water level data are available, as well as in those areas where model predictions do not closely correspond to measured data." [emphasis added]*

The information presented in bold would indicate that it is appropriate in the WMA C PA effort to use of the calibrated CPGWM area as basis for hydraulic properties. The area of the WMA C PA domain is in a sub-region of the CPGWM domain where there is a high density of water level data considered in the model calibration, and model outputs from the CPGWM correspond closely with the measured data.

Reliance upon a large-scale pump test near B Complex to provide a partial basis for establishing hydraulic conductivities at WMA C.

The estimate of hydraulic conductivity used in the WMA C PA was not derived solely from the single aquifer test identified (DOE/RL-2015-75, *Aquifer Treatability Test Report for the 200 BP 5 Groundwater Operable Unit*) as inferred in the Basis section of the RAI. The calibration of the Central Plateau Groundwater Model (CP-47631) provides the basis for the hydraulic conductivity estimates for the HSUs present within the aquifer. The issuance of CP-47631, published in July 2015, predates issuance of DOE/RL-2015-75, published in September 2016, by more than a year. The 30-day constant-rate test did not conclude until November 2015 (DOE/RL-2015-75). Neither CP-47631 (2015), the WMA C PA, nor RPP-RPT-58949, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA C Performance Assessment and RCRA Closure Analysis*, include the results of the aquifer testing presented in DOE/RL-2015-75.

Appendix C of the WMA C PA includes discussion of the slug and pumping test data available and presented in SGW-54508, *WMA C September 2012 Quarterly Groundwater Monitoring Report*. These values range from 100 to 2,100 m/day (330 to 6,900 ft/d). Excluded from this range are unpublished slug test results from Well No. 299 E27-24 that range from 3,650 to 51,500 m/day (12,000 to 169,000 ft/d) and results from Well No. 299-E27-22 that range from 1,888 to 6,888 m/day (6,200 to 22,600 ft/d), respectively. SGW-54508 excludes the results from Well No. 299 E27-24 from the range because the open interval and well radius were not controlled and sloughing conditions existed before testing.

The range of values for hydraulic conductivity being used in the sensitivity and uncertainty analyses, and recommendations that lower values should be included in these analysis.

The 3-D STOMP model domain has a large areal extent (approximately 738 m by 795 m [2,421 ft by 2,608 ft]), and needs to use scale-appropriate flow properties when representing the aquifer as an equivalent homogeneous medium (EHM). Local scale properties derived from slug tests and small-scale pump tests are not appropriate for application directly without proper upscaling. The hydraulic conductivities derived from calibrated model(s) are regarded as more reliable for application to the WMA C PA model domain rather than direct measurements by permeameter, slug tests, or local scale pump-tests as such tests only investigate a very small portion of the aquifer that is not necessarily representative of the length scales evaluated in WMA C PA modeling.

The weighted average hydraulic conductivity of the calibrated CPGWM provides the base case estimate. Because calibrated hydraulic properties are based on inverse-modeling, these parameters have associated variance. In recognition of this uncertainty, along with lack of complete knowledge of hydraulic conductivity at various length scales within the flow domain, the uncertainty in saturated zone hydraulic conductivity was chosen to range from 1,000 m/day to 21,000 m/day. This range was deemed bounding for an EHM model that has length scales of >700 m (2,297 ft).

As discussed in Section 8.1.3.6 of the WMA C PA, while the uncertainties in hydraulic conductivity and hydraulic gradient can be defined independently, the parameters need to be considered together as they result in determination of Darcy flux, which is the parameter that is used in the system model. Consequently, the uncertainty in hydraulic conductivity and gradient is propagated by developing uncertainty in the Darcy flux relative to the base case value. This is implemented as a multiplicative factor to the base case Darcy flux at the up-gradient boundary of the WMA C system model.

The effects of groundwater dilution are further evaluated through selected sensitivity cases using the process-level model (see Section 8.2.2 of WMA C PA). Results from the sensitivity analysis in Table 8-17 of the WMA C PA indicate that the groundwater concentrations are inversely proportional to the groundwater flux. The peak concentrations of Tc-99 increased by a factor of approximately 2.6 using the 5th percentile flux value, which is about 2.6 times less than the base case value, and decreased by a factor of approximately 1.6 using the 95th percentile flux value, which is about 1.6 times greater than the base case value, compared to the base case results. Regardless, the peak concentrations of Tc-99 remained well below the drinking water standards.

RAI 2-11

Comment
The mass loading and soil ingestion parameters assigned to the acute intruder exposure scenarios may not be appropriate for the Hanford site.

Basis
DOE used a mass loading value of 6.66E-5 grams per cubic meter (g/m3) based on NCRP Report No. 129. It is not clear that this value is appropriate for an arid environment where construction-type activities are taking place. For comparison, in development of the waste classification tables found in 10 CFR Part 61 NRC used a value of 5.65E-4 g/m3 for a humid southeastern site to represent an acute intruder (NRC, 1981). The value NRC used for a chronic intruder was comparable to the value used by DOE. Chronic values tend to be lower due to the longer time periods without disturbances. In an arid environment soils are more easily suspended in the air and can be inhaled. Some drilling technologies are very "dusty" when limited drilling fluids are used. Likewise, the soil ingestion rate used was 100 milligrams per day based on OSWER Directive 9285.6-03. DOE used a larger soil ingestion rate for the offsite receptor.

Inhalation is an important exposure pathway for the inadvertent intruder.

Path Forward
Please provide additional technical basis that the mass loading and incidental soil ingestion rates are appropriate for the acute intruder exposure scenario at Hanford. Provide any relevant and available measurements from Hanford or analog locations to support the mass loading and soil ingestion values used in the WMA C PA.

DOE Response
Monitoring of particulate matter (PM) mass concentrations in air at the Hanford Site began in 2001 following a wildland fire in the previous year. The PM_{10} concentration (concentration of particulate matter with aerodynamic diameters less than or equal to 10 µm) data have been collected since then at the Hanford Meteorology Station. PNNL-6415, *Hanford Site National Environmental Policy Act [NEPA] Characterization*, Section 4.1.7.5, provides details on the daily average monitoring data for PM_{10} concentrations in 2002. The observed annual average was 17 µg/m^3, with intermittent higher daily averages occurring on days with high winds (maximum of 408 µg/m^3). The observed annual average PM_{10} concentration in 2007 was 14 µg/m^3. Both observed annual average PM_{10} concentrations, 14 and 17 µg/m^3, are typical of the annual average concentration measured in recent years (PNNL-17063, *Hanford Site Environmental Report for Calendar Year 2007*).

HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment*, Section A3.2.1, mentions 20 µg/m^3 (2E-5 g/m^3) as a typical annual average outdoor airborne mass loading at the Hanford Site. These values form the basis for the chronic, undisturbed values of mass loading factor.

However, for the purpose of calculating acute inhalation during well drilling (Acute Well Driller scenario) this report uses a resuspended dust concentration of 100 µg/m^3 (or 0.1 mg/m^3), but then reduces the waste inhaled by a factor of 10 by assuming that only 10 percent of the exhumed waste is available for inhalation. This reduction in dust concentration takes into account that not all of the resuspended soil is in the inhalable size range. Therefore, this reference document puts the inhalable contribution from the resuspended dust (or mass loading) to the air inhaled by the Well Driller effectively at 10 $\mu g/m^3$.

In the WMA C PA calculations, the mass loading of 66.6 µg/m3 (6.66E-5 g/m^3) was selected for the Acute Well Driller exposure scenario. In the absence of site-specific mass loading factor, this was identified as an appropriate value. However, recognizing the uncertainty in the value, it was not corrected for an inhalable fraction, as in HNF-SD-WM-TI-707. Furthermore, to compensate for the disturbance of the surface soil caused by the drilling activities, an enrichment (or enhancement) factor was included in calculating the dose from inhalation of the soil particulates (see Equation 9-5 in RPP-ENV-58782). The enrichment factor (value of 4 given in Table 9-3 in RPP-ENV-58782) accounts for potentially elevated concentration of radionuclides in the fine portion of airborne particulate matters due to the drilling disturbance. Therefore, the effective mass loading factor used in the analysis is 266.4 $\mu g/m^3$ (2.66E-4 g/m^3), which is similar to the value cited in NUREG-0782, *Draft Environmental Impact Statement on 10 CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste,* but higher than value used for intrusion scenarios evaluated at Hanford. For example, Section 3.1 of PNL-6312, *Definition of Intrusion Scenarios and Example Concentration Ranges for the Disposal of Near-Surface Waste at the Hanford Site*, recommended a value of 1E-4 g/m^3. Compared to alternative sources of information for this parameter, DOE's assessment is that the dose resulting from inhalation of soil in the Acute Well Driller scenario is reasonably conservative.

The soil ingestion rate of 100 mg/day for the Acute Well Driller Scenario is appropriate given that inadvertent soil ingestion refers to trace amounts associated with soil dust that adheres to hands and lips and then transferred to food or cigarettes. Deliberate soil ingestion that may occur with children is not considered in the calculations of dose to the adult driller. In addition, it is quite likely that the driller will wear some kind of personal protective equipment (e.g., gloves, household dust mask, etc.) given the "dusty" conditions that may be anticipated during drilling.

In the All Pathways Farmer scenario the intake rates for a Reference Person are estimated in a conservative manner leading to soil ingestion rate of 108.6 mg/day. As indicated in the footnote of Table 6-28 in RPP-ENV-58782, the intake rates for the Reference Person are generally calculated based on age- and gender-weighted fractions, and the 95th percentile of the reported intake rates were used in dose calculations. For soil ingestion rate, the rate published for children and adults is used with simple age weighting. This approach results in slightly higher soil ingestion rate (~9% higher) compared to the Inadvertent Intruder Scenario.

RAI 2-12

Comment

An insufficient basis was provided to demonstrate that the WMA C PA model is a valid representation of the system. It has not been demonstrated that the simplified WMA C PA model includes the real-world features in a sufficient or conservative manner to support decision-making.

Basis

The NRC staff has performed a risk-informed review of the Draft WIR Evaluation and WMA C PA. In order for the risk-informed process to be effective, the WMA C PA model should sufficiently represent the system. This RAI has two main components: simplification of real-world features and demonstration that the WMA C PA model is capable of generating results consistent with real-world observations, especially from past leaks and releases. Staff acknowledges that traditional model validation is generally not possible for performance assessment models, however model support is a necessary component of the assessment process.

Various reports document in-leakage (advection) to the tanks during past operations and that in-leakage continues into the present day (RPP-RPT-29191). Though the tanks are to be filled with grout for closure, the paths of in-leakage are not going to be specifically sealed. One of the most poorly-sealed parts of the systems appear to be the spare inlet ports (RPP-PLAN-47559, Rev. 0, Table 3-1) which in some cases are sealed with wood. The report RPP-RPT-29191 indicates that waste entered tanks from an external leak via tank pump pits. It appears that there are numerous advective pathways that are active in the systems that are not modeled as part of the base case, making the base case potentially insufficiently supported. Advective pathways combined with phenomena such as grout shrinkage may lead to release processes different and more rapid than the 1-D vertical diffusion simulated by DOE.

A number of past leaks and spills have occurred at WMA C. For example, Figure 4-5 of RPP-ENV-33418 Rev. 3 shows depth profiles of Co-60, Cs-137, and Eu-154. Model support for flow and contaminant transport may be developed by simulating past leaks and spills with the WMA C PA. The WMA C PA model, with modification to prescribe operational infiltration rates, should be able to generally replicate the observed transport profiles (relative transport of each isotope) over the observed timeframe. The WMA C PA model generally produces doses only from Tc-99 under ambient recharge conditions. Under select cases uranium isotopes can also produce impacts. The WMA C PA model should be able to roughly generate the observed vadose and saturated zone plumes when adjusting for recharge history but with minimal other changes.

The report RPP-CALC-60793 documents WMA C flow and contaminant transport model simulations supporting scoping analysis and future projected impacts of past waste releases. The simulations in this report were developed in an attempt to match observed temporal and spatial contamination and to obtain a reasonable approximation of the timing and magnitude of Tc-99 arrival in most of the monitoring wells surrounding WMA C. The results showed that the 10th percentile aquifer flux and the transient aquifer conditions with a counterclockwise rotation of the hydraulic gradient provided a reasonable approximation of the timing and magnitude of Tc-99 arrival in most of the monitoring wells surrounding WMA C.

Path Forward

Please provide additional model support for the WMA C PA model. Provide comparisons of key intermediate model outputs to observations of system performance made during the approximately 70 years of operations. For example, comparisons could be made to observed vs. simulated in-leakage to tanks and the 244-CR vault (i.e., compare the Darcy fluxes through and below the waste layer in the base and degraded cases to in-tank and in-vault leakage rates consistent with water level changes). The report RPP-ENV-33418, Rev. 3 provides subsurface contaminant characterization data that may be used to develop model support for the WMA C PA model, especially contaminant transport.

DOE Response

As noted in the RAI Basis section, "...traditional model validation is generally not possible for performance assessment models; however, model support is a necessary component of the assessment process." There is substantial agreement in the literature that it is possible to develop confidence that performance assessments provide an adequate basis for decision making in the absence of comparisons of the model with data (see NCRP Report No. 152, *Performance Assessment of Near-Surface Facilities for Disposal of Low-Level Radioactive Waste*, Section 3.5.2). Approaches to developing confidence in the performance assessment are summarized in Section 6.4 of the WMA C PA. One of the key facets of the confidence development is the evidence to support the vadose zone modeling approach. As discussed in Section 4 of the WMA C PA, the primary model of the vadose zone is based on the equivalent homogeneous medium (EHM) framework with upscaled parameters. As noted in Appendix B of RPP-ENV-58782, the EHM approach is firmly supported by comparisons with field data from the Sisson and Lu Site (PNNL-13795, *Vadose Zone Transport Field Study: Soil Water Content Distributions by Neutron Moderation*, and "Stochastic analysis of moisture plume dynamics of a field injection experiment" [Ye et al., 2005]) located nearby in 200 East Area..

Nevertheless, also as noted in the RAI Basis section, at WMA C, conditions resulting from operations represent a potential for testing parts of the performance assessment model. Any such test needs to be relevant to the analysis conditions in the performance assessment. The example provided by NRC (i.e., comparing measurements of inflow into open tanks during operations to modeling of inflow in grouted tanks under post-closure conditions) is not considered to be an appropriate example for model validation since the source of the water inflow into current tanks is unknown and cannot be explicitly considered in the performance assessment modeling. Thus, this specific example of inflow into current tanks for model validation was not considered further. However, the existence of unplanned releases (leaks) during operations opened the potential to compare the performance assessment modeling results against contaminant concentration data associated with the leaks as observed in the subsurface.

As discussed in RPP-RPT-59197, a wide variety of contaminant concentration data associated with past leaks have been collected that could potentially be compared to model outputs. These data can be broadly grouped into two types, each with associated advantages and disadvantages:

- Vadose zone data derived from dry wells and direct pushes.

  As discussed in Chapter 2 of RPP-RPT-59197, potentially relevant vadose zone data for model comparisons include spectral gamma logging data for Co-60 and geochemical sampling for Tc-99. The major advantage to the Co-60 data is that there are abundant measurements. However, there are many disadvantages to using the Co-60 data as listed below:

  a. It is not possible to positively identify which leak produced the location and timing of observed contamination measurements in the environment. Most of the dry wells were installed in the 1970s and early 1980s. Most of the unplanned releases (from Tanks C-101, C-104, C-105, C-108, UPR-81 and UPR-82) occurred in the mid- to late-1960s before the installation of the drywells around the tanks. Prior to 1970, WMA C had only seven dry wells to monitor for leaks; six of these were located around the perimeter of WMA C with only one well (Well No. 30-08-03) located between tanks.

b. As a result of its short half-life (i.e., 5.27 yrs), Co-60 concentrations are strongly dependent on time, further exacerbating the difficulty in interpreting the data and linking it to a particular source.

c. Co-60 is neither a long-term direct contact nor groundwater pathway risk as a result of past leak or the tank waste residual releases from WMA C

d. It has been suggested that Co-60 could be used as a surrogate for Tc-99. However, comparison of geochemical sampling for Tc-99 in the vadose zone at borehole C4297 showed that its occurrence does not correlate with Co-60. Tc-99 was found at depths greater than 100 ft (30.5 m) below ground surface (bgs), while Co-60 was not. Both Tc-99 and Co-60 were found at shallower depths (less than 65 ft [20 m] bgs), but in this region their peaks did not match. When co-located, the peak for Co-60 was shallower than Tc-99, suggesting that Co-60 was slightly adsorbed onto the sediments.

e. Measured concentrations in the vadose zone can be locally influenced by fingering and other kinds of local spreading, so that it is difficult to determine the extent of a plume.

- Groundwater data derived from monitoring wells near WMA C.

  Section 2.3.3.3 of RPP-ENV-59197 provides a description of available data from the groundwater monitoring network at WMA C. An advantage to the use of these groundwater data for model testing are that, owing to dilution in the aquifer, the plumes are more regular and homogeneous than in the vadose zone. A disadvantage to these data is that the aquifer gradient has been changing in magnitude and direction as a result of the dissipation of the groundwater mound at WMA C. A brief discussion of these transient changes are summarized in Section 2.3.3.1 of RPP-RPT-59197. Since the aquifer is locally very highly conductive, the gradient is very flat, and head measurements are insufficiently accurate to determine the direction of the gradient. Rather, the changing gradient has been deduced from the observed changes in well concentrations; the rise and fall of contaminant concentrations in a well appears to be the result of the gradient directing contamination to the well, then shifting away. This is a different and more complex situation than if the gradient were at a steady state in a fixed direction. Discussion of the some of the difficulties involved in replicating transient changes to the unconfined aquifer and its implications in accurately estimating plume behavior and contaminant concentrations are provided in Section 5 of RPP-RPT-59197.

Of these data, attention is focused on Tc-99 concentrations in groundwater, since Tc-99 is a key risk driver and the contamination levels observed in groundwater monitoring wells are unambiguously the result of WMA C past leaks. The approach to using these data was to evaluate the arrival times and concentration levels of Tc-99 observed in WMA C monitoring wells. Arrival times are influenced only by processes occurring in the vadose zone and in the leaks themselves, whereas the concentration data also include saturated-zone processes.

A substantial effort was undertaken to model the past leaks (see RPP-RPT-59197). The purpose of the modeling was primarily to support risk assessments associated with the leaks, not to provide corroboration for the post-closure performance assessment of residual wastes (RPP-RPT-58329). Furthermore, the past leaks analysis was completed after the post-closure performance assessment, so its findings are not discussed in the WMA C PA, and hence have not been reviewed by NRC. Consequently, a brief discussion is presented here on the amount of corroboration provided by the past leaks analysis (see RPP-RPT-59197) for the performance assessment model. Caution must be exercised in using past leak information to support the post-closure performance assessment, because:

- When the leaks occurred, the surface of the facility was maintained as vegetation-free gravel, thus the infiltration was substantially higher than that anticipated after closure. Flow in the vadose zone is non-linear with respect to moisture content, so testing the model under operational conditions does not necessarily represent a test of its behavior in the post-closure period, in which the surface barrier decreases vadose-zone flow rates.
- There is substantial uncertainty in the timing, magnitude, and composition of the leaks. This means that it is difficult to make specific inferences linking any particular leak with particular measurements of environmental contamination.
- Liquid discharges from nearby cribs and trenches caused a mound in the water table, which changed the magnitude and direction of groundwater flow underneath WMA C. The groundwater mound is currently partly dissipated, and the mound will not exist in the post-closure period (see RPP-RPT-59197 Section 2.3.3.1). This feature of the system complicates comparisons with data.
- Those nearby discharges contributed to contamination of groundwater beneath WMA C, making the contribution of WMA C to the groundwater contamination uncertain for most of the contaminants identified in monitoring wells near WMA C; only Tc-99 has WMA C as its sole and unambiguous source (See RPP-RPT-59197 Section 2.3.3.3).

Despite the above cautionary notes, the results of the past leaks analysis do provide some (albeit limited) corroboration of the vadose zone model. As discussed in Section 3.2 of RPP-ENV-59197, the primary model used for the residual waste performance assessment was used directly in the analysis of past leaks, with two modifications:

- The leaks were introduced at the times, locations, inventories, and volumes indicated by the current best estimates of past leaks, as presented in RPP-ENV-33418, Hanford C-Farm Leak Inventory Assessments Report.
- The height of the water table was adjusted to reflect the conditions that existed at the time contamination reached groundwater.

It is emphasized that no other input data were changed in this primary model from the post-closure assessment model. In addition to the primary model, additional sensitivity cases were evaluated to determine the effect of alternative geological structures and alternative input parameters. The approach was to identify which model conditions (geological representations and input parameters) were consistent and which were inconsistent with the groundwater data.

It was found that several of the scoping analysis cases produced results that were inconsistent with the groundwater data. The remaining analysis cases, including the primary model, produced comparable results to each other, and none were obviously superior to others in terms of explaining the observed well data. When uncertainties in groundwater fluxes were taken into account, these analyses were capable of producing both arrival times and concentrations consistent with observed monitoring well data for Tc-99 (see Section 4.0 of RPP-RPT-59197).

Therefore, the representation of the vadose zone used in the post-closure performance assessment was found to be consistent with the data. However, this is not a unique solution, and other sensitivity cases were also found to be consistent with data. Therefore, the comparison with data provides some support for the performance assessment model, but it is not definitive (see Section 4.0 of RPP-RPT-59197).

RAI 2-13

Comment

Differences in the conceptual hydrogeological models near WMA C between the regional CPGW model and the WMA C STOMP model are considerable and some of the techniques for abstracting information and data from the CPGW model to the STOMP model require additional information. Additional information is needed on the calculated groundwater flux into the STOMP model and on the water budget from that model.

Basis

The saturated hydraulic conductivity and the hydraulic gradient of an aquifer are important parameters for determining the degree of contaminant mixing and dilution in that aquifer. The amount of dilution in the aquifer is a key safety function with respect to protection of offsite members of the public. WMA C PA Section 8 shows that the saturated zone Darcy flux is an important uncertain parameter.

The Darcy flux is obtained by multiplying the hydraulic conductivity of the hydrostratigraphic unit by the hydraulic gradient. The CPGW model provides calibrated hydraulic conductivity estimates for the hydrostratigraphic units present within the saturated zone (CP-47631) and the STOMP model obtains its parameter values by applying the equivalent homogeneous medium (EHM) approach to the calibrated CPGW model values so that the STOMP saturated zone is represented with the weighted average hydraulic conductivity values (Table C-1 in the WMA C PA) from the CPGW model. The CPGW model and the STOMP model, however, have different hydrostratigraphic units representing the saturated zone under WMA C. The hydrogeology for the base case in the WMA C PA assumes the existence of a paleochannel and an unconfined aquifer composed of undifferentiated gravels. The CPGW model assumes that distinct layers with different hydraulic properties (Figure C-9 in the WMA C PA) are present. It is not clear how the calibrated hydraulic conductivity values of the CPGW model would have changed if the STOMP stratigraphy had be used in CPGW model near WMA C. The number of cells in the CPGW model layers 6 and 7 are evenly divided and represented by the Ringold A formation, the Cold Creek unit, and the coarse-grained Hanford formation at WMA C. Since DOE is relying on the calibrated hydraulic conductivity values from the CPGW model, it is not clear to NRC staff why the distinct hydrostratigraphy of the CPGW model was not adopted in the WMA C PA. In addition, it is not clear if the entire upper 5 m of the CPGW model aquifer is located in Hanford formation at the points of calculations 100 m downgradient from WMA C.

The calibrated hydraulic conductivities of the Cold Creek unit (400 m/d) and the Ringold A formation (4.8 m/d) from the CPGW model (CP-47631) are considerably less than the calibrated Hanford formation values. Calculations of the weighted average hydraulic conductivity values change the original CPGW model values of both these units to an equivalent hydraulic conductivity for the entire layers to 5802 m/d. The upper aquifer layers (layers 4 and 5) of the CPGW model include the Cold Creek unit with a calibrated value of 400 m/d. The resulting equivalent hydraulic conductivities for those layers are 5,933 to 14,233 m/d.

Additional information is needed on the approach for deriving groundwater flux for use in the STOMP model. By evaluating the water budget in the CPGW model through a planar rectangular window similar to the WMA C flow domain over the unconfined aquifer thickness, a Darcy flux is estimated. This CPGW model volumetric flux calculation window does not align with the orientation of the northern boundary of the WMA C STOMP model used in the WMA C PA (Figure C-5 in the WMA C PA). It is not clear how much this misalignment influences the groundwater flux estimate since the greater the angle of misalignment the less realistic the flow estimate will become.

Additional information is needed on the approach whereby the original prescribed upgradient flux (saturated hydraulic conductivity x hydraulic gradient) for the northwest boundary condition in STOMP is increased by 53% to account for a thickening of the unconfined aquifer along the flowpath due to the uneven elevation of the top of the basalt from the northwest to southeast STOMP boundaries. Since dose is directly influenced by the degree of groundwater dilution, and the approach increases the groundwater flux, a technical basis for the approach is required. Although WMA C PA Section D4.1.1 and Table 6-12 discuss and demonstrate the mechanics of the approach, references pertaining to the applicability the approach or as its use as standard practice were not provided.

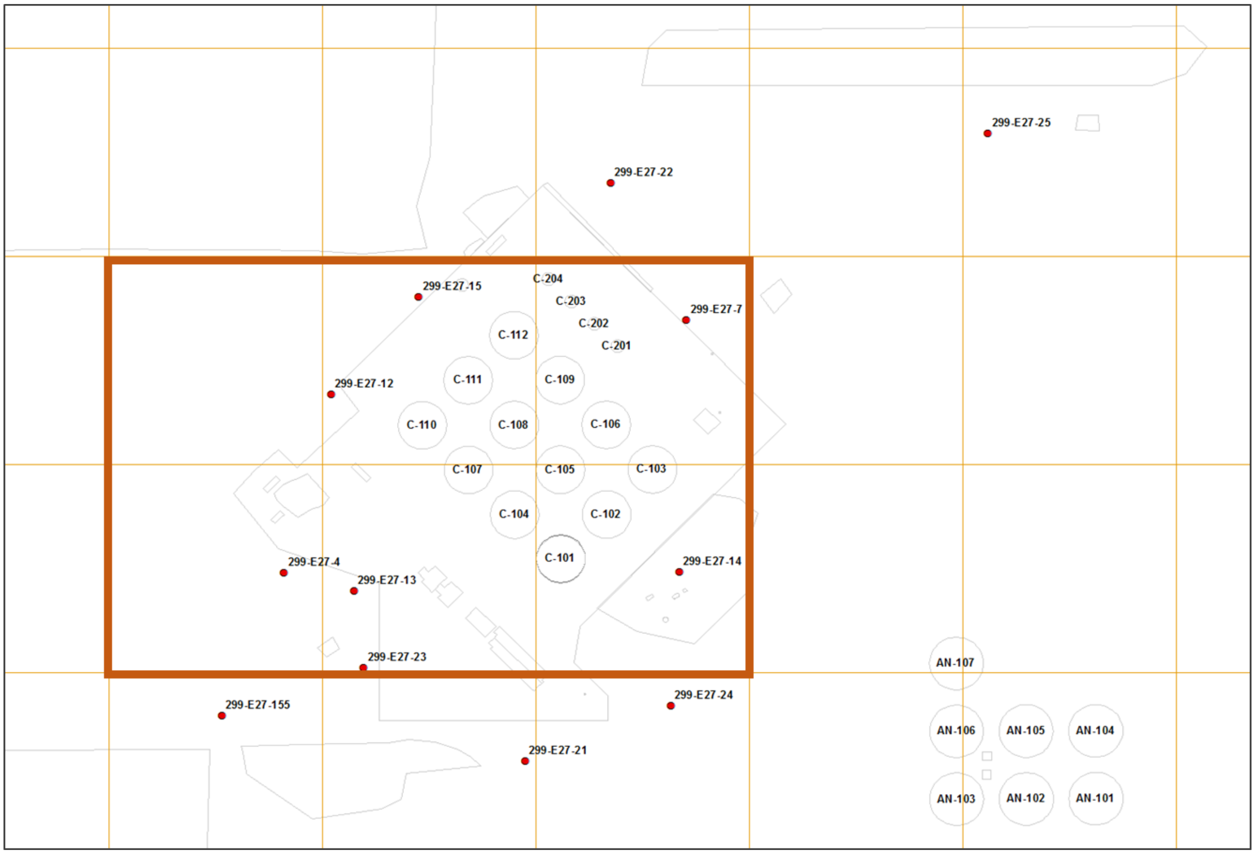
The WMA C PA did not provide water budget tables for the STOMP model at intermediate and steady states. The balance between the inflow and outflow, or the imbalance between the two, can be a good indicator for potential numerical difficulties.

Path Forward
Please provide information demonstrating that the EHM approach for obtaining saturated hydraulic conductivity values in the STOMP model does not result in excess aquifer dilution. Provide information demonstrating that the misalignment between the CPGW model volumetric flux calculation window and the northern boundary of the WMA C STOMP model does not significantly affect performance.

Provide a technical basis for the applicability of the approach that increased the Darcy flux into the STOMP model by 53% over that provided by the CPGW model. Provide a water budget table for the STOMP model at intermediate and steady states, or at different time steps, that includes inflow at the surface and inflow/outflow at the five aquifer boundaries whereby three boundaries are assumed to be no-flow.

DOE Response
The overall approach for evaluating dilution in the performance assessment has been specifically designed to maintain consistency with the amount of aquifer dilution that would be estimated by the Central Plateau Groundwater Model (CPGWM), CP-47631, 2015, *Model Package Report: Central Plateau Groundwater Model Version 6.3.3*. The aquifer boundary conditions approximate the Darcy flow rates in the aquifer in the area around WMA C produced by the CPGWM (Figure 14). The hydraulic gradient is specified to support these flow rates, and the hydraulic conductivity is assumed to equal the average of the CPGWM values.

Figure 14. Plan View of the Central Plateau Groundwater Model Waste Management Area C Flux Calculation Window.



The DOE response to RAI 2-10 addresses the evaluation of the applicability and appropriateness of the use the CPGWM as the basis for the aquifer hydraulic parameterization. The response to this RAI addresses the quantitative evaluation of the aquifer hydraulic conductivity and gradient and the upgradient boundary flux using the results from the CPGWM, and the evaluation of the WMA C PA model water balance along the aquifer boundaries.

The hydraulic conductivity and gradient estimates were derived from the flow calculated to occur through a rectangular volume excerpted from the CPGWM. The orientation of the CPGWM model cells is offset by 45 degrees from the WMA C PA model cells, but the amount of dilution occurring in the aquifer depends on the volumetric rate of flow in the direction of flow. In both the CPGWM and the WMA C PA models, the direction of groundwater flow estimated for post-closure conditions in the vicinity of WMA C is generally the same. Only the quantity of water affects the dilution; the orientation of the flow does not. Therefore, the offset between the two models does not adversely impact the calculation of the aquifer properties for the purpose of estimating aquifer dilution.

The CPGWM rectangular calculation window is 300 m × 200 m (980 ft × 660 ft) and with a depth of 11 m (36 ft), and the volume encompasses most of WMA C (Figure 14). The effective hydraulic conductivity for the equivalent homogeneous medium (EHM) model is the average of the CPGWM model layer values weighted according to the layer thickness. The discretization of the different saturated zone HSUs within the selected model layers of the CPGWM in the vicinity of WMA C are shown in Figure C-9 of RPP-RPT-58949, *Model Package Report Flow and Contaminant Transport Numerical Model used in WMA C Performance Assessment and RCRA Closure Analysis*. The equivalent hydraulic conductivity for a given layer within the rectangular area (approximate extent of WMA C) ranges between 5,802 m/day and 17,000 m/day (19,035 ft/day and 56,000 ft/day) (See Table 7 and Figure C-9 of RPP-RPT-58949), and the weighted average is 11,000 m/day (36,000 ft/d) (Table 7). Therefore, the value of 11,000 m/day (36,000 ft/d) is the EHM hydraulic conductivity estimate for the aquifer. The DOE response to RAI 2-10 further addresses the evaluation of the magnitude of this hydraulic conductivity value.

Table 7. Calculation of Weighted Average Hydraulic Conductivity Value and Volumetric Water Flux from the Central Plateau Groundwater Model (Table C-1 in RPP-RPT-58949).

Year	Model Layer	Predicted Volumetric Water Flux (m^3/day)	Length of Window (m)	Layer Thickness (m)	Hanford Unit Calibrated Horizontal Hydraulic Conductivity (m/day)	Calculated Gradient (m/m)
2014	3	277.1	300	3	17,000	1.81E-05
2014	4	319.1	300	3	14,233	2.49E-05
2014	5	253.4	300	3	5,933	4.75E-05
2014	6	143.1	300	1	5,802	8.22E-05
2014	7	52.5	300	1	5,802	3.02E-05
2100	3	161.3	300	3	17,000	1.05E-05
2100	4	238.4	300	3	14,233	1.86E-05
2100	5	188.7	300	3	5,933	3.53E-05
2100	6	104.6	300	1	5,802	6.01E-05
2100	7	38.5	300	1	5,802	2.21E-05
Layer Thickness Weighted Hydraulic Conductivity (m/day, rounded):						11,000
Hydraulic Gradient 2014 (m/m, rounded):						3E-05
Hydraulic Gradient 2200 (m/m, rounded):						2E-05

The calculation of the WMA C PA hydraulic gradient and boundary condition flux is based on the gross flow calculated to occur through the CPGWM rectangular volume approximately 100 years into the future. By Year 2100, according to the CPGWM results, the groundwater flow has achieved steady state. The flow through the CPGWM rectangular volume is divided by the vertical cross-sectional area of the CPGWM aquifer and the EHM hydraulic conductivity value to calculate the EHM hydraulic gradient.

For Year 2100 (approximating post-closure steady state conditions), the CPGWM calculated flow through the window is approximately 730 m^3/d (25,800 ft^3/d), which divided by the cross-sectional area of 3,300 m^2 (35,500 ft^2) associated with the CPGWM, yields a Darcy flux of 0.22 m/d (0.72 ft/d). Dividing the Darcy flux by the EHM hydraulic conductivity of 11,000 m/day (36,000 ft/d) yields a hydraulic gradient of 2×10^{-5} (Table 7). The hydraulic gradient value is comparable to the estimates included in RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C*, and DOE/RL-2017-65, *Flow and Transport in the Natural System at Waste Management Area C*, and with the gradient estimated from the 1944 hindcast water table map as indicated in Figure 3-5 in RPP-RPT-58949.

The Darcy flux of the upgradient boundary condition of the WMA C PA model was increased from the CPGWM amount to account for the spatial variability of the thickness of the aquifer. The flux through the WMA C PA model domain varies spatially because the no-flow basalt base of the aquifer varies in elevation. The flux through the aquifer portion of the WMA C PA model domain averages 0.22 m/d (0.72 ft/d) (same as the CPGWM) with a hydraulic conductivity of 11,000 m/day (36,000 ft/d) and hydraulic gradient of 2×10^{-5}. Along the upgradient boundary of the WMA C PA model, the aquifer cross-sectional area is 6151.04 m^2 (66,209 ft^2), and along the downgradient boundary, the aquifer cross-sectional area is 13997.55 m^2 (150,668.4 ft^2). The average cross-sectional area through the domain, calculated on the basis of the cross-sectional area of the aquifer cells, is 9439.56 m^2 (101,607 ft^2). To maintain the average flux throughout the model domain, the flux at the upgradient boundary must increase according to the proportion of the cross-sectional areas:

$$q_{up} = q_{avg} \frac{Area_{avg}}{Area_{up}}$$

where q_{up} is the flux at the upgradient boundary, q_{avg} is the average flux through the aquifer portion of the model domain, $Area_{avg}$ is the average cross-sectional area of the aquifer in the model domain, and $Area_{up}$ is the cross-sectional area of the aquifer at the upgradient boundary. Inserting the values for average flux (q_{avg}), average cross-sectional area ($Area_{avg}$), and upgradient cross-sectional area ($Area_{up}$) of the aquifer into the equation yields:

$$q_{up} = 0.22\ m/d\ \frac{9439.56\ \text{m}^2}{6151.04\ \text{m}^2} = 0.338\ m/d = 123.3\, m/yr$$

for the upgradient flux necessary to maintain the flux of 0.22 m/d (0.72 ft/d) throughout the aquifer portion of the model domain.

At steady-state, the flow that enters the model domain should equal the flow that exits the model domain. Truncation, round-off, and convergence tolerances all introduce potential discrepancies in the computation of flow that enters, exits, and remains within the model domain. Calculation of the volume balance error provides one indication of the level of error in the solution of the mass conservation equations[16] and the overall accuracy of the results. After 1000 years (Year 3020), the water flow has been at steady state for a substantial period of time, so the flow rates into and out of the aquifer should balance. Flow rates include recharge entering the top of the aquifer, and flow into or out of the aquifer (saturated portion) of the model domain. Flow into or out of the aquifer only occurs along the upgradient and downgradient boundary faces of the aquifer. No flow occurs into or out of the model domain along the other two boundary faces. No flow occurs into or out of the model domain in the vadose zone along any

[16]The use of the calculated volume(s) of water (instead of mass) in the water balance evaluation is acceptable because the model is constant-temperature and the water density is constant.

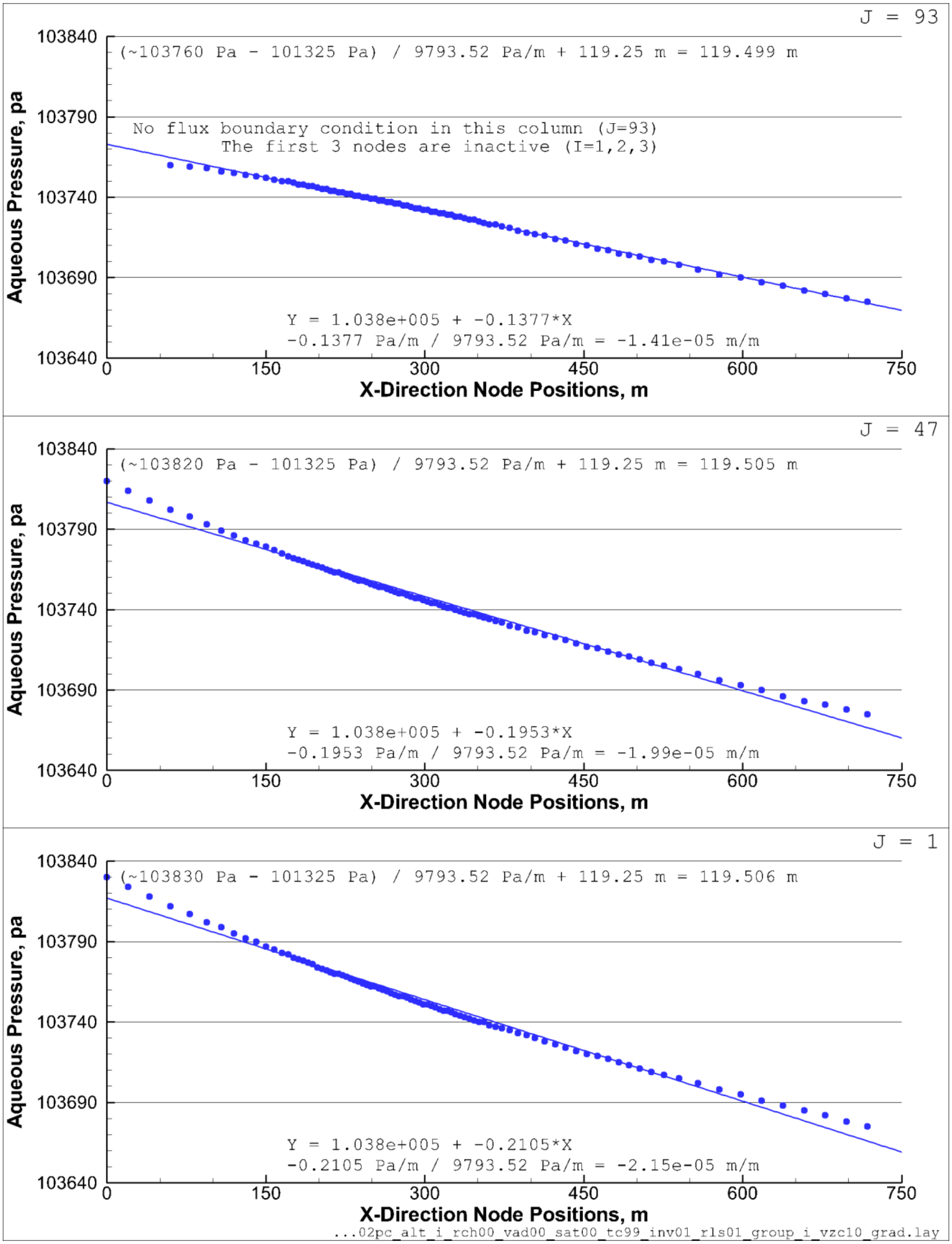
of the vertical boundary faces. The relative error in the water budget is very small and indicates that flow rates into and out of the aquifer balance (Table 8).

Table 8. Post-closure steady-state water balance.

Calendar Year (assumed WMA C closure in 2020)	Flow from vadose into water table (L/yr)	Flow from NW boundary into aquifer (L/yr)	Total flow into aquifer (L/yr) (including flow from vadose zone)	Flow exiting aquifer out of SE boundary (L/yr)
3020	2.05E+06	7.58E+08	7.61E+08	7.61E+08
	Total flow into aquifer (L/yr)	**Total flow out of aquifer (L/yr)**	**Difference (L/yr)**	**Percentage (%) of Total**
Water Balance	7.61E+08	7.61E+08	1.02E+04	1.34E-03
Note: Values are rounded to three significant digits.				

Figure 15 provides approximations of the hydraulic gradient through the domain and estimates of the upgradient hydraulic head. The figure shows that the flux applied to the upgradient boundary maintains the hydraulic head of approximately 119.505 m (392.077 ft) at the upgradient boundary, and an approximate gradient of approximately -2E-05 m/m that is relatively uniform throughout the model domain.

Figure 15. Hydraulic Gradient and Estimates of Upgradient Hydraulic Head along Three Rows in the Waste Management Area C Performance Assessment Model.



The water budget also provides an indication of the average flux within the aquifer and the flux at the boundaries. Table 9 presents the calculations of flux at the upgradient and downgradient boundary faces of the aquifer, and the average flux within the domain. At the upgradient boundary, the flux exceeds the flux indicated by the EHM hydraulic conductivity (11,000 m/day [36,000 ft/d]) and hydraulic gradient (2×10^{-5}) (i.e., 0.338 m/d [1.1 ft/d] versus 0.22 m/d [0.72 ft/d]). At the downgradient boundary, the flux is less than the flux indicated by the EHM hydraulic conductivity and hydraulic gradient (i.e., 0.149 m/d [0.49 ft/d] versus 0.22 m/d [0.72 ft/d]). Averaging the flow into the upgradient and out of the downgradient boundary faces of the aquifer, and dividing by the average cross-sectional area of the aquifer yields a flux of 0.22 m/d (0.72 ft/d), which equals the flux indicated by the EHM hydraulic conductivity and hydraulic gradient. This equality indicates that no excess aquifer dilution occurs because of the proportionality of the upgradient boundary condition.

Table 9. Post closure steady state water flux.

	Flow (L/yr)[1]	Area (m^2)	Flux (m/yr)	Flux (m/d)
NW boundary into aquifer	7.58E+08	6151.04	123.31	0.338
SE boundary exiting aquifer	7.61E+08	13997.55	54.33	0.149
Average	7.60E+08	9439.56	80.46	0.220
[1] Values are rounded to three significant digits.				

In summary, the information presented demonstrates that the EHM approach for estimating aquifer properties in the WMA C PA model maintains consistency with the CPGWM and does not result in any additional aquifer dilution. The aquifer conditions in the WMA C PA model approximate the Darcy flux and hydraulic gradient in the aquifer produced by the CPGWM, and the estimate of effective hydraulic conductivity is appropriate.

RAI 2-14

Comment
The approach to sensitivity and uncertainty analyses does not provide a complete assessment of uncertainty and variability.

Basis
DOE developed a deterministic base case model which uses the code STOMP for flow and contaminant transport. Best estimate parameter values were used in the deterministic base case model. The performance assessment model was developed with the software package GoldSim to integrate the STOMP results and produce radiological dose estimates. The base case model was supplemented with a probabilistic system model (developed in GoldSim) to evaluate parameter uncertainty. In addition, alternate cases were evaluated to examine other sensitivities.

There are a large number of uncertainties that are not reflected in the base case, limiting its usefulness for decision-making. Some of these include but are not limited to:

- Long-term infiltration rates (e.g., sand dune formation, plant evolution)
- Performance of the yet to be designed engineered cover
- Erosion performance of the engineered cover
- In-leakage to systems and advective release
- Lateral diffusion from the source term
- Grout shrinkage of the yet to be designed grout
- Organics impacts on waste release and retention of radionuclides
- Sulfate impacts on grout
- Presence of chelating agents in the waste
- Corrosion of penetrating steel
- Integrity of the basemat concrete
- Seismic impacts on performance
- The representativeness of tank sampling
- The uncertainty in the inventory modeling systems
- The uncertainty in the saturated zone hydraulic conductivity

The DOE sensitivity analysis was primarily focused on parameter variability and to a lesser extent epistemic uncertainty. The sensitivity cases were generally one-at-a-time evaluations to look at specific uncertainties, such as grout performance. Because the Hanford site is complex and there are a large number of uncertainties (both parameter and model/conceptual), this approach may not identify key combinations of uncertainties that are risk-significant. Uncertainties and variabilities normally can’t be evaluated in isolation in a system model. For example, the sensitivity case presented in WMA C PA Figure 8-49 examined the impact from the amount of Tc-99 released from the waste instantaneously. The response should scale almost linearly with the release fraction, however there is no impact going from 6%

to 100%. This is because the Tc-99 that has been released from the waste and is available for transport must diffuse out of the system. With no advection assumed there is no impact on the results. Any uncertainties associated with advective flow in the system would potentially be additive with the uncertainties on the Tc-99 release fraction, but they wouldn't be identified unless the uncertainties are evaluated in combination.

Path Forward

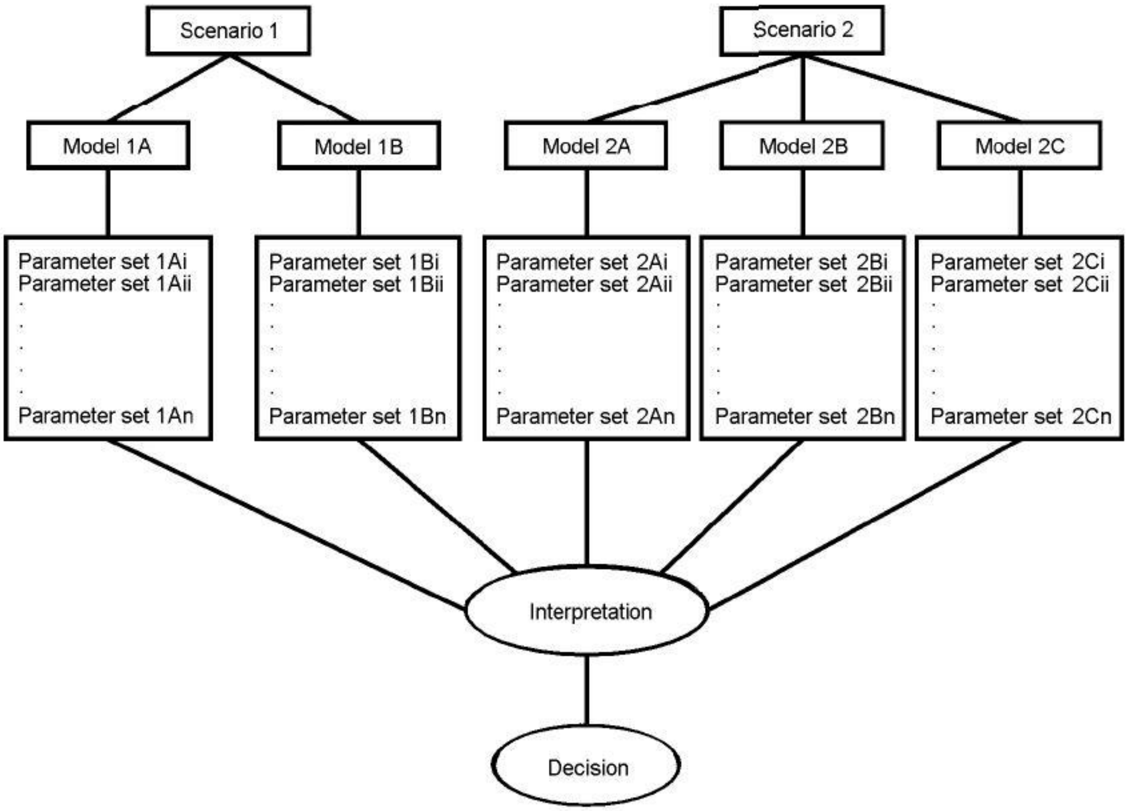
Please perform a global sensitivity analysis combining both parameter and model/conceptual uncertainty. A full probabilistic uncertainty analysis including model uncertainty would provide key risk insights without compounding conservative assumptions. NRC staff understands the computational limitations associated with performing probabilistic simulations with the STOMP model. The global sensitivity analysis could be performed with the GoldSim system model.

DOE Response

The Basis section of this RAI suggests a misunderstanding of DOE's framework for evaluation of uncertainties. This response will clarify the significance of the approach to uncertainty, and how it addresses the overall uncertainties of concern in this RAI. Additional information on the framework for identifying sensitivity analysis cases and their significance in the WMA C PA is presented in the DOE response to RAI 2-2.

An overall analysis of uncertainties in performance assessment have long been regarded as comprising three types: future (or scenario) uncertainties, model uncertainties, and parameter uncertainties (NCRP Report 152, "Performance Assessment of Near-Surface Facilities for Disposal of Low-Level Radioactive Waste"). A structure of such an overall analysis is shown in Figure 16. A performance assessment generally needs to address these three types of uncertainty to provide adequate information to decision makers.

Figure 16. Structure of Uncertainty Analysis (after NCRP, 2005).



As stated in Appendix H of the WMA C PA:

> *"The safety concept is the overall approach by which a disposal system is intended to provide the performance required in regulation. The safety concept can be thought of as the set of safety functions, acting together in concert, to provide that performance. Ideally, the safety functions represent multiple and redundant barriers, so that the loss of one or some of the safety functions continues to result in adequate performance of the overall system. …* ***The goal of the PA is to evaluate these safety functions, to provide reasonable assurance of performance even when some of the safety functions are lost or degraded through time or disruptive events*** *[emphasis added]."*

This statement of the goal of the analysis explicitly says that overall uncertainties in the performance of the facility are within the scope of the performance assessment. To meet this goal, a multifaceted modeling approach was undertaken. As noted in the Basis section of this RAI, this modeling approach comprises three main elements:

- A deterministic base case model
- A probabilistic version of the base case model, and
- A suite of sensitivity analyses.

The deterministic base case model represents a best estimate of the future performance of the closed facility in the post-closure period, using the best available knowledge and science to project a single estimate of performance. It represents the situation in which the safety functions behave as expected for the assumed duration, and input parameters are set to their most credible values. DOE strongly disagrees that such an analysis is limited in usefulness for decision making. However, DOE agrees that it cannot be the sole basis for decision making, and that it must be supplemented by analyses that quantify uncertainties in facility performance. However, it remains a key piece of information used in informing decisions.

The probabilistic version of the base case model is intended to quantify the effects of input parameter uncertainties on the base case analysis. This analysis supports the deterministic base case model, and puts it in context. By comparing the deterministic base case results with those of the probabilistic analysis, decision makers can understand where the base case analysis fits within the range of parameter uncertainties.

As discussed in Appendix H and Chapter 8 of the WMA C PA, the suite of sensitivity analyses are intended to quantify the effects of scenario and conceptual model uncertainties. As discussed in the DOE response to RAI 2-2, this is done by evaluating safety functions, cross referenced with FEPs, to identify how the facility would behave if the various components of the safety concept do not function as anticipated. In some cases, representing the alternative behavior requires implementation of an alternative model, as in the advective release model and the alternative geological representations. In other cases, the degraded safety function can be represented by a simple change in one or more parameters in the model. For instance, degradation of the surface barrier can be represented by a change in a single parameter (i.e., net infiltration). Changes in net infiltration may be used to represent a wide variety of scenarios and alternative models, acted upon by diverse FEPs, as shown in Table H-1 of the WMA C PA.

The sensitivity analysis has been misconstrued in the Basis section as an investigation of aleatory uncertainty (parameter variability). Quite the contrary, DOE regards the sensitivity analyses as explicit representations of epistemic uncertainties in model structure and future evolution of site conditions.[17] Moreover, DOE recognizes that epistemic uncertainties predominate in performance assessments, and that aleatory uncertainties are typically subsumed by associated epistemic uncertainties.

Therefore, the uncertainty analysis presented in the WMA C PA addresses the three sources of uncertainty discussed above: scenarios, conceptual models, and parameters. Furthermore, DOE has considered the potential for failure of multiple safety functions in the performance assessment, but has only included those for which there is a common FEP that could potentially act on multiple safety functions (as discussed in the DOE response to RAI 2-2).

The example included in the Basis section regarding the Tc-99 leaching sensitivity case involves both instantaneous release of Tc-99 from the grout and advective flow through the grout. These are unrelated safety functions without any common potentially deleterious FEPs, making their joint occurrence very unlikely. The Basis section provides incorrect reasoning for the lack of difference between the base case and the sensitivity case results, and therefore reaches an incorrect conclusion about the effect of combining the two sensitivity cases. The results of the base case and instantaneous release case are

[17] As noted in the DOE response to RAI 2-2, some of the sensitivity analyses were included to honor commitments to stakeholders, and do not strictly follow this methodology. Regardless, DOE considers that those sensitivity analyses also explore epistemic uncertainty.

essentially identical because all of the Tc-99 is released over a few months in the base case release model. Over performance assessment time scales, the “slow release” leaching model in the base case is effectively identical to the instant release model of the sensitivity case. Leaching data from actual residual wastes do not support a long-lasting slow release of Tc-99 from the waste, and the base case incorporates this relatively quick release.

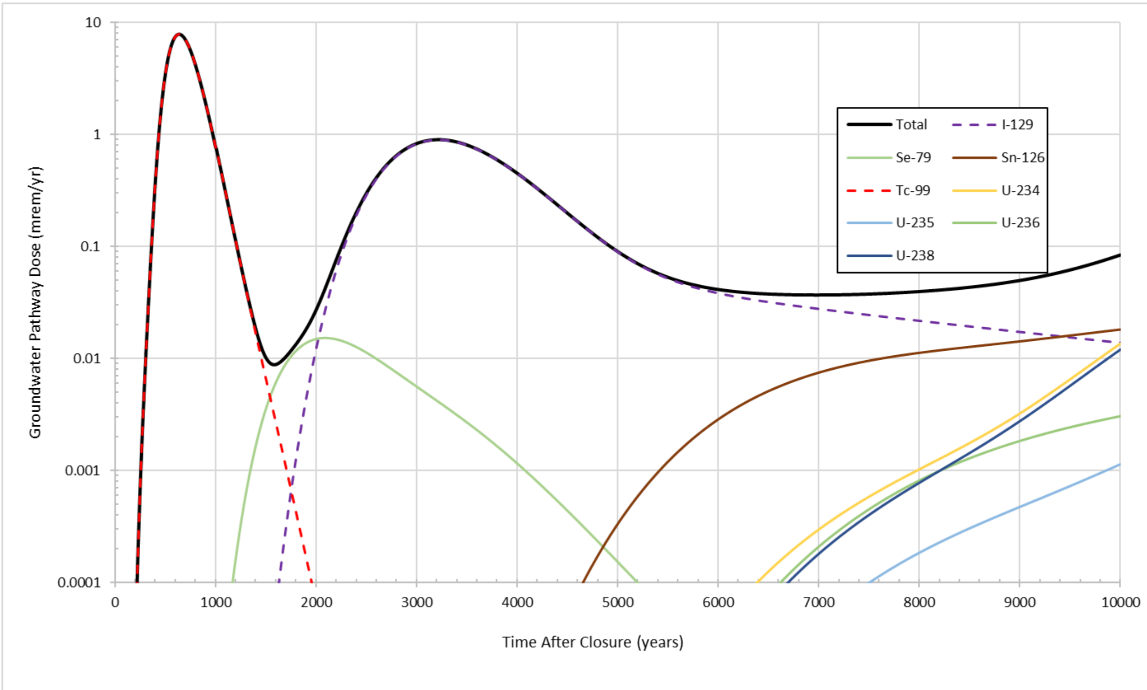
As discussed in the DOE response to RAI 2-2, the projected performance of WMA C has been found to be very robust in comparison to performance objectives. The sensitivity analyses have been conducted as very conservative representations of alternative conceptual models and scenarios. As a result, combining the effects of alternative cases can quickly lead to excessive conservatism. Nevertheless, as a demonstration of system robustness, a new combined alternative conceptual model sensitivity case has been conducted to respond to this RAI, which combines failure of multiple safety functions, as follows:

- An assumption of no surface barrier for the duration of the analysis, with the infiltration rate set to its upper bound of 5.2 mm/year;
- An assumption that the grout and base mat behaves as sand, so that releases are by advection from the beginning of the analysis;
- An assumption that all of the residual waste is available for leaching at the beginning of the analysis; and
- An assumption that minimum dilution occurs in the aquifer, with the groundwater flux set at 5th percentile value.

DOE emphasizes that this is not an analysis that represents a credible representation of system behavior, as there is substantial evidence supporting the base case assumptions. Furthermore, this type of extreme analysis is not generally valuable for decision making. This analysis provides an overly conservative estimate of facility performance and may lead to an unduly pessimistic idea of system performance. However, specifically for WMA C, this analysis has been conducted to demonstrate the robustness of the system performance, and to demonstrate that the uncertainty analysis presented in the WMA C PA is appropriate for its purpose.

The results of the new combined alternative conceptual model sensitivity case analysis are presented in Figure 17. Dose distribution for the new combined alternative conceptual model sensitivity analysis case for the combined failure of multiple safety functions.. The maximum total dose of 7.8 mrem/year occurs at about 640 years after assumed closure date of 2020, and the primary dose contributing radionuclide is Tc-99. The peak dose remains far below the performance limit of 25 mrem/year for the all-pathways scenario within the 1000 year compliance period. As the dose contribution from Tc-99 declines, the contributions from I-129 and Se-79 increases resulting in a second peak of 0.90 mrem/year in the post-compliance time period. Uranium isotopes contribute to the dose only after 5000 years.

Figure 17. Dose distribution for the new combined alternative conceptual model sensitivity analysis case for the combined failure of multiple safety functions.



Assumptions used in this new combined alternative conceptual model sensitivity case and associated detailed results are summarized in an EMCF, RPP-CALC-63407.

RAI 2-15

Comment
The approach to inventory uncertainty does not reflect all important sources of uncertainty in the estimates of radionuclide inventory remaining in waste residuals.

Basis
DOE propagated variability in measured concentrations, densities, and volume to derive the uncertainty distributions in waste inventories, but did not include any uncertainty associated with the representativeness of waste tank sampling or uncertainty associated with use of the Hanford Tank Waste Operation Simulator and the Hanford Defined Waste (HDW) models (Higley, 2004).

In most cases, approximately two samples were obtained from each tank. Those samples reflect material that is removable and accessible by tank sampling equipment. Approximately 30% of the waste is fixed to the walls and stiffener rings. DOE indicated that they attempted to sample different types of waste residuals based on color, but that obstructions and reach of the sampling equipment created limitations. DOE is assuming that the samples obtained are completely representative of the waste residuals without any additional uncertainty propagation. The material on the walls may represent material strongly influenced by chemical and physical processes resulting from the temperature gradients on the tank boundaries.

The HDW model is used to provide inventory values for ~20 radionuclides. Comparison of pre-sampling waste radionuclide concentration estimates from HDW with post-sampling waste concentrations from measurements show high uncertainty associated with use of HDW estimates, for some isotopes orders of magnitude. That uncertainty has not been included in the uncertainty analysis. The amount of uncertainty in DOE's approach is much lower.

DOE has developed estimates of the inventory of key radionuclides in WMA C over the past two decades. Those estimates show relatively high volatility.

Path Forward
Please provide a full uncertainty evaluation for radionuclide inventory that includes the representativeness of the tank samples and use of the HDW model. Provide sampling results of material from other tank farms or removed equipment or piping that supports the assumption that the composition of waste sampled is representative of material that can't be sampled, such as material hardened onto walls at the operational interface between the waste layer and the void space. Examination of the time series of estimates of key radionuclide concentrations in WMA C waste residuals may provide insights of the temporal uncertainty in inventory estimates.

DOE Response

Representativeness of the Tank Residual Samples:
This section provides the basis for the approach used in sampling tank waste residuals following retrieval to provide some context regarding the representativeness of the samples.

The overall approach for sampling residual waste in SSTs to support closure was developed by using the EPA DQO process (see EPA/240/B-06/001, *Guidance on Systematic Planning Using the Data Quality Objectives Process - EPA QA/G-4*, and EPA/600/R-96/055, *Guidance for the Data Quality Objectives Process - EPA QA/G-4*). The DQO team consisted of personnel from Ecology, DOE, and the Tank Farms contractor. In developing the sampling approach, the team took into consideration a number of factors, including the following:

- Knowledge of tank waste prior to retrieval,
- Effects of retrieval on tank waste solids,
- Access constraints due to tank configurations,
- Available sampling technologies for wastes in various locations within the tank,
- Radiation exposure to the workers (operations and laboratory technicians), and
- High cost associated with sampling and analysis of highly radioactive samples.

The final sampling design (i.e., number of samples and sample locations) for the residual waste in each tank was developed by balancing the need to collect sufficient samples to estimate the variability of the waste and the strong desire to minimize radiation exposure to the workers. Rationale for the sampling approach used in WMA C tanks is discussed below.

Prior to retrieval, waste sludge in a tank generally exists in layers with each layer composed of a precipitated phase based on the tank composition and prevailing physical and chemical conditions. Characteristics of waste may differ significantly from layer to layer. Typically, as the waste is sluiced, a majority of the solids in the top layer become suspended from mixing effects and get pumped to the receiving DST. The unretrieved solids from the top layer would settle down and mix with solids in the next layer. As that layer gets sluiced the majority of mixed solids will become resuspended and be removed with some left behind. This process of removal and mixing gets repeated until completion of sluicing. At the end of sluicing, solids remaining in the single-shell tank are considered a mixture of the less mobile or “unpumpable” solids from various sludge layers originally in the tank. If additional retrieval is necessary at this point, the solids may be softened or dissolved in hot water, acid, or caustic. The dissolved solids and some undissolved solids are then sluiced to the DST, resulting in additional mixing. The solids are further mixed during the final triple rinse as they are washed by high-pressure water. Although the residual solids are not expected to be homogeneous, they are certain to have undergone significant mixing during retrieval operations. While these processes will have less effect on the waste clinging to the walls and stiffener rings, those wastes were not sampled, and are assumed to have similar composition to the unpumpable solids which have been dislodged and settled during sluicing, softening, and rinsing. For example, Tank C-103 residual solids sample results show solids at all nine sample locations to be predominantly composed of aluminum and iron oxides/hydroxides with Cs-137, Sr-90, and Pu-239/240 concentrations; however, concentrations of these constituents vary somewhat at different locations (RPP-RPT-33060, *Retrieval Data Report for Single-Shell Tank 241-C-103*).

With variability of the waste significantly reduced by mixing during retrieval operations, a small number of samples may be used to capture the reduced waste variability while achieving reasonable minimization of worker radiation exposure. The sampling designs for residual solids in WMA C tanks varied from tank to tank based on the final configuration of the waste. Table 10 below summarizes the number of residual solids samples collected from WMA C tanks.

Table 10. Summary of Residual Waste Sampling of the Tanks.

Tank	Number of Samples	Comments
C-101	4	• Analyzed Individually. • ORSS[1] failed during sampling – collected 4 out of 9 planned.
C-102	4	• Sampled by ERSS[1]-Clamshell Method – analyzed individually
C-103	9	• Sampled by ORSS • Three composites prepared
C-104	4	• Sampled by ORSS • Two samples each from each solids mass – analyzed individually
C-105	5	• Sampled by ERSS-Clamshell method – analyzed individually
C-106	8 grabs	• Sampled by clamshell • All grabs from the same riser • Two composites prepared
C-107	9 grabs	• Sampled by drag sampler • Three composites prepared
C-108	6 before dissolution and 9 after	• Sampled by ORSS • Three composites prepared from the nine samples
C-109	9	• Sampled by ORSS • Three composites prepared
C-110	4	• Sampled by FoldTrack-Clamshell method – analyzed individually • Waste only available on north side
C-111	4	• Sampled by ERSS-Clamshell method – analyzed individually
C-112	2	• Sampled by ERSS-Clamshell method– analyzed individually • Only took 2 out of 4 samples because finger trap failed and solids crusher did not work due to PVC sleeve found in riser used for sampling • Ecology agreed no further sampling required
C-201	5 grabs	• Pre-retrieval samples from one riser were all empty because not enough materials were present under the riser. • Retrieval mast failed – no post retrieval samples
C-202	9 grabs	• Sampled by retrieval mast • Two composites prepared
C-203	8 grabs	• Sampled by retrieval mast • Two composites prepared
C-204	10 grabs	• Sampled by retrieval mast • Two composites prepared

Notes:
1. These data are summarized out of the RDRs for each tank as previously referenced in the Draft WIR Evaluation
2. ORSS = Off-Riser Sampler System
3. ERSS = Extended Reach Sluicer System

As indicated in Table 10, composite samples were sometimes prepared when a larger number of field samples were collected from a tank. This practice resulted in fewer sample analyses and, therefore, less radiation exposure to the workers during laboratory analysis. Use of a sample compositing approach (also known as a tiered approach) was encouraged by the EPA (see EPA-230-R-95-005, *EPA Observational Economy Series, Volume 1: Composite Sampling*).

A completely random sampling scheme was not possible due to access and sampling equipment limitations; instead, a subjective sampling scheme was used. This sampling scheme allowed the samples to be purposely spaced apart and/or to target solids with different observable characteristics such as coarse or fine particles, yellow or gray colors, etc. The objective was to capture a wide variety of materials from different locations in a tank in order to achieve adequate estimates of sample data uncertainty. A 95 percent confidence interval based on sample to sample variability was developed for each given analyte and propagated in the PA as part of the uncertainty analysis.

Discussion of HDW Model Uncertainty:
As noted, for some radionuclides the differences between HDW model-based (process knowledge) concentration and sampling-based concentrations are significant. This is because the HDW model concentrations are based on tank farm process flow-sheets and tank transaction records with simplified assumptions related to interactions of waste streams within the tanks. The HDW model is a spreadsheet-based engineering estimate of the chemical and radionuclide content and considers simple mixing models for estimating the composition in the supernatant and sludge layers from addition of various waste streams. In general, the HDW model tends to oversimplify the actual behavior of waste in the tanks. Numerous limitations exist in predicting the concentrations within HDW. For a more thorough discussion, see Section 7 of RPP-19822, *Hanford Defined Waste Model – Revision 5.0*. For these reasons, HDW model estimates were used only when sample data were not available.

Out of the 46 radionuclides tracked in the BBI, twelve radionuclides (Ni-59, Nb-93m, Zr-93, Ru-106, Cd-113m, Cs-134, Sm-151, Ra-226, Ac-227, Th-229, Sn-126 and U-232) are not required analytes for tank closure (see RPP-23403, *Single-Shell Tank Component Closure Data Quality Objectives*), and therefore no analytical results are available. For these radionuclides the HDW model estimates are used in the BBI. For other radionuclides that are sampled and found to be non-detects, the HDW model estimate is used if the detection limit is higher than the HDW model concentration. In conclusion, the HDW model estimates are applied to radionuclides that are unlikely to be the risk/dose drivers. If the radionuclide is deemed important to PA results and is above the detection limits, then sampling-based uncertainty is propagated. This is the approach adopted in the WMA C PA as described in Section 8.1.3.2. The typical range of uncertainty in inventory of radionuclides varies over a factor of four and is deemed representative for the purpose of system model evaluations.

The WMA C PA used available sample results through September 1, 2014. At that time, three of the tanks were still being retrieved (Tanks C-102, C-105 and C-111), and post-retrieval sample results were not available for three other tanks (Tanks C-101, C-107 and C-112). Many of the HDW model estimates were used for these tanks as documented in RPP-RPT-42323, Rev. 3. These estimates will be replaced by post-retrieval residual sample analytical results in future PA revisions now that post-retrieval sampling information is available for all the tanks.

As shown in Table 11, radionuclide inventories for key constituents and total radionuclide inventories based on post-retrieval sample results are lower than the previous inventory estimates documented in RPP-RPT-42323, Rev 3. The updated estimates based on post-retrieval sampling are now documented in RPP-RPT-42323, Rev 4.

Table 11. Comparison of WMA C Inventory Estimates Based on Pre-Retrieval and Post-Retrieval Sampling.

Analyte	Units	Best Inventory Estimates On September 1, 2014 Before All Retrieval Sampling Was Completed (RPP-RPT-42323, Rev. 3)	Best Inventory Estimates On January 1, 2019 After All Retrieval Sampling Was Completed (RPP-RPT-42323, Rev. 4)
I-129	Ci	7.08E-02	1.39E-02
Cs-137	Ci	1.82E+04	9.20E+03
Sr-90	Ci	4.25E+05	1.90E+05
Tc-99	Ci	1.45E+01	2.31E+00
Total Radionuclides	Ci	9.09E+05	4.26E+05

Notes: Decay Date 1/1/2020

Examination of the time series of estimates of key radionuclide concentrations in WMA C waste residuals is of limited value because prior to retrieval these estimates would have been based on either HDW model results or sample-based templates (from other tanks with similar process history). Due to the previously stated limitations of the HDW model, the estimates of radionuclide concentrations prior to retrieval would have large uncertainties, as discussed in Section 8.1.3.2 of the WMA C PA. These uncertainties would reduce with post-retrieval sampling and therefore direct comparison would be misleading.

RAI 2-16

Comment
DOE did not provide the acute intruder doses from disturbance of a plugged pipeline, or from intrusion into diversion boxes. The thickness of waste used to assess the inadvertent intruder in the 244-CR Vault appears to be too low. Intruder dose calculations may need to be revised pending resolution of other requests for additional information.

Basis
DOE indicated that the dose to a chronic intruder (rural pasture exposure scenario) is 160 mrem/year at 100 years from intrusion into a plugged pipeline. DOE did not provide any results for impacts to the acute intruder. It is not clear why the rural pasture exposure scenario would be most limiting exposure scenario when for every other source type the suburban gardener exposure scenario is the most limiting of the chronic exposure scenarios. The acute driller dose impacts are larger than the chronic dose impacts by a factor of 2.5 to 3.8.

The evaluation of the 244-CR vault assigned an area of 162.4 m^2 which results in an average waste layer thickness of 2.5 cm. The waste layer in tank CR-011 inside the 244-CR vault is much thicker and at the assumed 90% waste removal would be anticipated to be much thicker than 2.5 cm used in the analysis.

Path Forward
Please provide the acute intruder dose impacts from disturbance of a plugged pipeline. Explain why the rural pasture exposure scenario is most limiting. Revise the thickness of the waste layer inside the 244-CR vault to show the different impacts depending on where the drilling could occur. Revise all intruder dose calculations following resolution of other issues raised by NRC.

DOE Response
As requested in the Path Forward section, this response is subdivided into separate discussions of inadvertent intrusion into a plugged pipeline and into Tank TK-CR-011 within the CR-Vault.

Inadvertent intrusion into a plugged pipeline:
The acute intruder dose for the plugged pipeline is the same as for any other pipeline source shown in Figure 9-6 in the WMA C PA. The acute intruder dose is based on the radionuclide concentrations in the drill cuttings which is calculated per Equation 9.3 in the WMA C PA. The concentration in the residual waste is multiplied by the ratio of the waste thickness to the vadose zone thickness in order to calculate the radionuclide concentration in the drill cuttings. Because the contaminated zone within the pipeline is assumed to be distributed evenly across the 3-inch [3.62-cm] diameter, a constant waste thickness is considered for all pipelines (including plugged pipelines). This approach reflects a conservative simplification for the acute well driller scenario dose calculation and provides a bounding value for the pipelines. Consequently, the peak dose for the plugged pipeline for the acute intruder scenario is 36 mrem, as presented in Table 9-7 and Figure 9-6 in the WMA C PA.

A comparison of the acute and chronic inadvertent intruder doses for the base case pipeline source against a plugged cascade line for the various scenarios evaluated is provided in Table 12. The chronic intruder scenario doses for the fully plugged pipeline (100% full) is different from other pipelines (5% full) because the calculations are based on radionuclide inventory in the drill cuttings rather than the radionuclide concentrations. Therefore, the dose for the fully plugged pipeline is about a factor of 20 higher. Dose results are provided for two time periods of assumed loss of institutional control to illustrate the effects of a revised closure date assumption.

The relative contribution of various pathways for each intruder scenario is presented in Table 9-8 of the WMA C PA. The primary pathway for the rural pasture intruder scenario is milk ingestion of Sr-90, while that for the suburban garden intruder scenario is vegetable ingestion. The milk pathway makes the rural pasture intruder scenario limiting. This observation must be understood in the context of the DOE response to RAI 1-1. As discussed in the DOE response to RAI 1-1, the WMA C PA assumed a closure date of 2020. As a consequence of the assumed 2020 closure date, short-lived Sr-90 influences the results of the intruder calculation significantly. If a later closure date is assumed, doses from Sr-90 will become less important, and the key contributing pathways will change. As an example, the 2068 closure date shown in Table 12 represents the approximate closure date for the nearby DSTs, as discussed in the DOE response to RAI 1-1.

Table 12. Comparison of the acute and chronic doses for the base case with inadvertent intrusion into a plugged pipeline for the various scenarios evaluated.

	Acute Peak Dose[1] for Well Driller Scenario (mrem)	**Chronic Peak Dose[2] for Rural Pasture Scenario** (mrem/yr)	**Chronic Peak Dose[2] for Suburban Gardner Scenario** (mrem/yr)	**Chronic Peak Dose[1] for Commercial Farmer Scenario** (mrem/yr)
Assuming Closure at Year 2020 and Loss of Institutional Control in Year 2120				
Cascade Pipeline (100% plugged)	36	160	80	0.02
Other Pipeline (5% full) [3]	1.8	8.2	3.9	0.001
Assuming Closure at Year 2068 and Loss of Institutional Control in Year 2168				
Cascade Pipeline (100% plugged)	20	50	25	0.01
Other Pipeline (5% full) [3]	1	2.5	1.2	0.0005

[1] Performance measure for acute inadvertent intruder dose is 500 mrem
[2] Performance measure for chronic inadvertent intruder dose is 100 mrem/yr
[3] Estimated acute dose is 1/20th of plugged pipeline acute dose if assumed effective waste thickness in the pipeline is made consistent with the pipeline being 5% full.

Inadvertent Intrusion into Diversion Boxes:
Information on diversion boxes is provided in the DOE response to RAI 1-3. These structures were routinely flushed or otherwise decontaminated whenever entries were required. Based on these operational practices and available records, diversion boxes (and pits) are expected to contain no measurable volume of waste beyond surface contamination. Thus, impacts from inadvertent intrusion into 100- and 200-series tanks, the C-301 Catch Tank, the CR-Vault and waste transfer pipelines would significantly bound the impacts of intrusion into diversion boxes, and no specific inadvertent intrusion into diversion boxes was evaluated. Although there is no evidence of more than superficial amounts of residual waste within pits and diversion boxes, DOE expects to perform video inspections and radiation surveys as part of the detailed closure planning process for these components.

Inadvertent intrusion into Tank TK-CR-011 within the CR-Vault:
The CR-Vault is a two-level, multi-cell reinforced-concrete structure constructed below grade, which contains four underground tanks (Tanks TK-CR-011, TK-CR-001, TK-CR-002, and TK-CR-003) along with overhead piping and equipment. Figure 3-47 of the WMA C PA presents the volume estimates for these tanks from 2005. Approximately 98 percent of the liquid volume in the cells was removed in early 2010. However, an amount of sludge remains within the four underground tanks. The waste volume remaining in the CR-Vault tanks has been estimated based on waste level data recorded in the Surveillance Analysis Computer System (SACS) and as described in RPP-RPT-58156, *Basis for Miscellaneous Underground Storage Tanks and Special Surveillance Facilities Waste Volumes Published in HNF-EP-0182 Revision 320 "Waste Tank Summary Report for Month Ending August 31, 2014."* The waste volume estimates for CR-Vault tanks (see Sections 3.45 through 3.52 of RPP-RPT-58156) are given as: 3,990 gallons (15,104 L) for Tank TK-CR-011, 3,636 gallons (13,764 L) for Tank TK-CR-001, 753 gallons (2850 L) for Tank TK-CR-002, and 2,310 gallons (8,744 L) for Tank TK-CR-003. Very small waste volumes also exist in the sumps for each of the tank cells. More recent evaluations have updated the numbers slightly, but the waste volume (sludge) associated with Tank TK-CR-011 has remained unchanged at 3,990 gallons. Given that this tank has the largest amount of remaining waste (sludge), the inadvertent intruder analysis for this tank was chosen to provide the bounding value for 244-CR-Vault.

The estimated thickness of the waste in Tank TK-CR-011 is 92.1 cm (36.25 in.) of sludge (RPP-RPT-58156). At the assumed 90 percent waste removal, the amount of residual sludge volume will be 1510 L (399 gal) and the maximum waste thickness at the center of the dished bottom is anticipated to be about 28.6 cm (11.25 in.) based on the relationship between waste volume and waste-level in Tank TK-CR-011 (RPP-RPT-58156). While the residual waste thickness is about 11.4 times thicker than the 2.5 cm (1 in.) used in the base case inadvertent intruder analysis for the CR-Vault, the residual waste volume has decreased by a factor of 0.37 (from 4,100 L [1083 gal] used in the base case to 1,510 L [399 gal] for the Tank TK-CR-011).

The acute and chronic doses for this inadvertent intrusion is compared with the base case for the various scenarios in Table 13. Results are presented at 500 years after closure[18] based on assumed closure date of 2020. Because the dose at this time is dominated by Pu-239 (Section 9.4, *Intruder Analysis Results* in WMA C PA), which is relatively long-lived radionuclide, these dose results are not as sensitive to the assumed facility closure dates as the pipeline scenarios.

[18] In accordance with guidance contained in NUREG-1854, facility components with a robust intruder barrier are not assumed to be intruded into until 500 years after facility closure, versus the 100 years for more vulnerable components. The grouted CR-Vault represents a robust intruder barrier.

Table 13. A comparison of the acute and chronic doses for the base case with inadvertent intrusion into Tank 244 CR-011 for the various scenarios evaluated.

	Acute Peak Dose[1] for Well Driller Scenario (mrem)	**Chronic Peak Dose[2] for Rural Pasture Scenario** (mrem/yr)	**Chronic Peak Dose[2] for Suburban Gardner Scenario** (mrem/yr)	**Chronic Peak Dose[2] for Commercial Farmer Scenario** (mrem/yr)
Dose at 500 years [1] after assumed closure date of 2020				
CR-Vault Intrusion (Base Case)[3]	3.91	0.496	1.03	0.007
TK-CR-011 Intrusion[4]	44.2	1.05	2.2	0.015

[1] Performance measure for acute inadvertent intruder dose is 500 mrem
[2] Performance measure for chronic inadvertent intruder dose is 100 mrem/yr
[3] Assumes a waste thickness of 2.5 cm
[4] Assumes a waste thickness of 28.6 cm

These comparisons show the increases for both acute and chronic doses for an inadvertent intrusion into Tank TK-CR-011 over the base case. However, the calculated doses remain well below performance measures for acute and chronic exposure (i.e. 500 mrem and 100 mrem/yr, respectively).

Assumptions used in these inadvertent intrusion calculations and associated detailed results are summarized in an EMCF, RPP-CALC-63407.

4.0 ASSESSMENT OF WASTE CONCENTRATION AND CLASSIFICATION

RAI 3-1

Comment
DOE's basis for concluding that the waste will be incorporated into a solid physical form is insufficient.

Basis
Some wastes, such as residuals remaining in tanks or other ancillary equipment, are in liquid form. DOE plans to fill the tank structures with an as yet to be determined grout formulation to fill the void space. DOE did not discuss how their closure plans will ensure liquids are incorporated into a solid physical form.

Path Forward
Please describe the amount of liquids expected to be present in each tank and ancillary equipment at closure. Provide DOE's basis that residual liquids will be incorporated into a solid physical form.

DOE Response
The estimated amount of liquid expected to be present in each tank or vault cell previous to grout placement is shown in Table 14. The design process for grout formulation and placement includes accounting for the total amount of liquid in the system, whether added to the grout or existing within the residual waste. When grout is placed in tanks or other structures, all liquid remaining within the residual wastes, along with the free water associated with grout preparation and placement, will be absorbed within the grout as the cement hydrates, or evaporated by the heat of hydration. The resulting grouted mass will be a solid physical form. A supporting calculation is being prepared to document the basis for this conclusion, with reference to the liquid volumes shown in Table 14.

Table 14. Estimated Liquid Remaining in WMA C Components at Closure.

Tank / Cell	Residual Liquids (Gallons) [1]
C-101 [1]	845
C-102 [1]	2588
C-103 [1]	247
C-104 [1]	1272
C-105 [1]	177
C-106 [1]	85
C-107 [1]	5297
C-108 [1]	232
C-109 [1]	890
C-110 [1]	1287
C-111 [1]	890
C-112 [1]	3366
C-201 [1]	2
C-202 [1]	2
C-203 [1]	15
C-204 [1]	11
C-301 [2]	1140
CR-001 [2]	520
Cell 1 [3]	2
CR-002 [2]	27
Cell 2 [3]	1
CR-003 [2]	170
Cell 3 [3]	2
CR-011 [2]	0
Cell 11 [3]	1

Notes:
1: Data summarized from RPP-RPT-42323, Rev. 4, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates.*
2: As documented in the WMA C PA, residual wastes in the C-301 catch tank and CR-Vault tanks are assumed to be 90% retrieved prior to closure, resulting in volumes shown.
3: The CR-Vault cells are periodically pumped out; volumes shown are latest reported (2010).

Other ancillary equipment in WMA C such as pits, diversion boxes, pipelines and encasements are all sloped and designed to drain to tanks; no appreciable liquids are expected to remain, even in “plugged” pipelines. Therefore any waste residuals in this equipment are solids. Pits, diversion boxes and some encasements will be grouted to prevent subsidence; pipelines will not be grouted except for the extent to which grout may flow into them incidentally as connected structures are filled.

RAI 3-2

Comment

DOE's calculations that demonstrate the waste residuals do not exceed the applicable concentration limits for Class C low-level waste as set out in 10 CFR 61.55 were incomplete. All components remaining in WMA C were not classified.

Basis

DOE used site-specific averaging factors to estimate the concentration of radionuclides remaining in the system to compare against Class C limits. In Section 6 of the Draft WIR Evaluation, DOE did a good job describing the approach they used, based off the information provided in NUREG-1854 (NRC, 2005). As described on page 6-9, they used a ratio of the concentrations found in 10 CFR 61.55 to the waste concentrations after drilling by the intruder multiplied by the ratio of their estimated intruder dose to 500 mrem.

The NRC had developed an approach for staff to use to review DOE waste determinations that accounts for the differences in disposal configuration of the waste (i.e. deeper and possibly less accessible) as well as the use of modern dosimetry. The 10 CFR 61.55 concentrations are based on ICRP-2 dose methodology and limiting organ doses, as well as a large number of other assumptions. In the approach provided by NRC in Appendix B of NUREG-1854, the guidance is not clear.

Whereas the output concentrations of the NRC analysis performed in 1981 corresponded to limiting organ doses (e.g., 500 mrem whole body, 1500 mrem liver), those concentrations had a variety of modifications based on public comment and other technical considerations (NRC, 1982). For example, it was assumed that not all the waste that is disposed in a low-level waste facility would be at the Class limit. As a result allowable concentrations were increased by a factor of 10. While these modifications are embedded in the factors discussed and known to NRC staff, they are generally not as well known by external stakeholders. In other words, some of those assumptions should be "backed out" for the approach used by DOE.

The simplest approach would be for DOE to use the concentration of each radionuclide in each residual waste layer and calculate the ratio to the Class A limits, then use a sum of fractions approach. The Class A limits assumed access at 100 years. The difference between the Class A values and the Class C values are primarily an extra 400 years of decay. However as previously noted, the Class C values were also increased from what was calculated to take credit for the assumptions that not all the waste would be at the class limit and the waste would be more inaccessible. Next, DOE could account for the different dilution factor and accessibility of the waste by calculating the drilling dilution factor (for example a 2.5 cm waste layer divided by a 79 m aquifer depth would be a factor of 0.00032) divided by the product of the two dilution factors embedded in the Part 61 calculations (0.254*0.5 = 0.127) (NUREG/CR-1759 Vol. 3).

Finally, for waste that is more inaccessible DOE could calculate the radioactive decay from 100 to 500 years for each radionuclide, followed by a sum of fractions on the results.

DOE did not provide classification calculations for diversion boxes, pits, and plugged pipelines. Because the intruder calculations for the 244-CR vault used an average waste thickness, each tank within the 244-CR vault should be classified using known waste thicknesses and not the average over the whole area of the vault.

Path Forward

Please revise the waste classification calculations to properly account for the assumptions embedded within the original Part 61 calculations. Provide the classification of the diversion boxes, pits, and plugged pipelines. Revise the classification calculations for the 244-CR vault.

DOE Response

DOE provided comparisons to the Class C concentration limits in the Draft WIR Evaluation. In the analysis, DOE used a ratio of the concentrations found in 10 CFR 61.55 to the waste concentrations after drilling by the intruder multiplied by the ratio of the estimated intruder dose to 500 mrem. This analysis was based on the understanding that the Class C limits led to an intruder dose of 500 mrem as stated in Appendix B of NUREG-1854 (Page B-2).

As noted in NUREG 1854 (page 3-27), NRC derived the Class C concentration limits by qualitatively accepting a higher allowable calculated dose from more inaccessible waste. In the Basis section the NRC further explained that, "while these modifications are embedded in the factors discussed and known to NRC staff, they are generally not as well known by external stakeholders."

The derivation of averaging expression equations, based on NUREG-1854 guidance for the comparison of the WMA C residual wastes to the NRC Class C concentration limits, is further complicated by the difference in intruder dose methodologies used in each analysis. For example, the derivation of NRC 10 CFR 61.55 concentration limits was based on the intruder basement excavation scenario, which involved several assumptions and modifications to account for the various waste types and disposal methods that were assumed. In contrast, the intruder scenario for the WMA C residual wastes involved a drilling scenario. While a drilling scenario was considered in the development of the NRC waste classification system, it was not limiting, and did not form the basis for the concentration limits. The drilling scenario results in far less waste being excavated to the surface compared to the basement excavation scenario. This reduced volume of waste correspondingly reduces the waste area and activity to which the intruder is exposed, with consequent reduction in calculated doses. An additional difference in the scenarios involves the time to which the acute intruder is exposed to the waste material. Finally, the intruder analyses used to develop 10 CFR Part 61 were based on the (then current) ICRP 2 dosimetry standard, with has been superseded several times in the intervening decades by improved understanding of dosimetry.

With these considerations in mind, DOE and NRC technical staff conferred on an approach to develop revised averaging expressions for the Class C calculations. These revised averaging expressions are set forth at the end of this response to RAI 3-2, and provide a method to evaluate both acute and chronic intruder scenarios consistent with the Category 3 approach and NRC guidance provided in NUREG-1854. The results of the revised Class C calculations provided below (Table 23) show that the residual wastes meet the Class C concentration limits for all tanks, vaults, pits, diversion boxes, pipelines, plugged pipelines, and their residuals. The largest sum-of-fractions (SOF) was calculated for the plugged pipeline under the acute averaging expression, which resulted in a SOF of approximately 1.0. Therefore, DOE has shown that the WMA C retrieved tanks, ancillary structures and their residuals meet Class C concentration limits using the revised averaging expressions.

As an alternative, the WMA C PA provides intruder doses based on site-specific factors. This information is provided in Table 15 below. DOE believes this approach is consistent with the provisions of 10 CFR 61.58:

> *"The Commission may, upon request or on its own initiative, authorize other provisions for the classification and characteristics of waste on a specific basis, if, after evaluation, of the specific characteristics of the waste, disposal site, and method of disposal, it finds reasonable assurance of compliance with the performance objectives in subpart C of this part."*

DOE M435.1-1 Chapter II, Section B2(a) similarly states that waste incidental to reprocessing:

> *"Are to be managed, pursuant to DOE's authority under the Atomic Energy Act of 1954, as amended, and in accordance with the provisions of Chapter IV of this Manual, provided the waste will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration limits for Class C low level waste as set out in 10 CFR 61.55, or will meet alternative requirements for waste classification and characterization as DOE may authorize."*

NRC also provides for the use of an independent analysis under 10 CFR 61.58 (NUREG-1854, Page 3-23):

> *"Appropriate concentration averaging may indicate that waste exceeds Class C concentration limits. Waste that exceeds Class C concentration limits may be suitable for near-surface disposal, but the evaluation of the suitability must involve independent analysis such as would be performed by the NRC under 10 CFR 61.58. NRC staff would evaluate the safety of the near-surface disposal of waste that exceeds Class C concentration limits on a case-by-case basis. Waste concentration is, in some cases, only one of many factors that can influence risk. Waste that is greater than Class C may be determined to be incidental waste and may be safely managed with near-surface disposal if it can be demonstrated that the performance objectives of 10 CFR Part 61, Subpart C, are satisfied."*

DOE M 435.1-1 and NUREG-1854 are both stating that waste may be suitable for disposal, using alternative approaches consistent with 10 CFR 61.58.

On this basis, the WMA C PA and the Draft WIR Evaluation set forth alternative analyses that provide reasonable assurance that the tanks, ancillary structures and their residuals meet the intruder performance objective and measures, as shown in Table 15.

Table 15. WMA C PA Intruder Dose Results

Equipment[a]	PA Acute Intruder Dose (mrem)[b]	PA Chronic Intruder Dose (mrem/yr)[c, g]
C-101	1.24	0.32
C-102	4.59	1.20
C-103	0.41	0.11
C-104	0.58	0.17
C-105	3.80	1.23
C-106	3.47	0.96
C-107	14.90	3.90
C-108	0.06	0.02
C-109	0.03	0.01
C-110	0.08	0.02
C-111	7.47	2.13
C-112	0.35	0.14
C-201	14.50	3.75
C-202	12.80	3.32
C-203	0.46	0.13
C-204	0.06	0.02
C-301	21.20	5.57
CR-Vault	3.91	1.03
Pits	--	--
Boxes	--	--
Pipelines	1.8[e]	8.21[e]
Plugged Pipelines	36[d]	160[d,f]

[a] The WMA C PA used an assumed closure date of 2020; intruder doses were calculated at 100 years post-closure for pipelines, and 500 years post-closure for tanks and other structures with robust intrusion barriers.
[b] The DOE M 435.1-1 performance measure for the acute intruder scenario is 500 mrem TEDE.
[c] The DOE M 435.1-1 performance measure for the chronic intruder scenario is an annual dose of 100 mrem.
[d] The PA intruder dose presented in the WMA C PA was based on a plugged pipeline.
[e] These intruder doses do not appear in the WMA C PA, and are based on plugged pipeline intruder doses that are reduced to the 5% inventory (i.e., plugged pipeline intruder doses divided by 20).
[f] Bounding sensitivity case in the PA for the plugged pipeline is based on the inventory 100 years after an assumed closure date of 2020. The dose is less than the performance measure of 100 mrem/yr when the assumed closure date of 2068 is considered.
[g] The chronic doses are based on the suburban gardener scenario, except for the pipelines, which are based on the rural pasture scenario.

In summary, in this RAI response DOE has presented two alternative approaches to evaluating whether the retrieved tanks, ancillary structures and their residuals in WMA C meet concentration limits for Class C low-level radioactive waste. These two approaches are: (1) an analysis based on discussion with NRC and NRC guidance in NUREG-1854; and (2) an analysis based on the site-specific intruder results set forth in the WMA C PA. Both analyses show that the wastes meet Class C concentration limits.

Revised Class C Calculations:
DOE, in consultation with NRC, developed revised averaging expressions for the Class C calculations. Consistent with the Category 3 approach and NRC guidance provided in NUREG-1854, the averaging expression used to determine the individual radionuclide contribution to the SOF based on the acute drilling scenario is represented by the following equation:

$$SOF_i = \frac{C_{Ri}}{Table_{Value_i}} * \left(\frac{Waste_{thickness}}{Drill_{depth}}\right) * \left(\frac{Exposure_{drill}}{Exposure_{NRC}}\right) * \left(\frac{1}{0.254 * 0.5}\right)$$

Where:

SOF_i = Radionuclide "i" contribution to the sum of fractions

C_{Ri} = Concentration of radionuclide "i" at closure (i.e., using the assumed 2068 date discussed previously) decayed 400 years[19] for all tanks, C-301, CR-Vault tanks and cells, and no decay after closure for the pipelines, valve pits and diversion boxes (Ci/m^3 or nCi/g)

$Table_{Valuei}$ = Class A concentration limit from 10 CFR 61.55 Table 1 or Table 2 for radionuclide "i"

$Waste_{thickness}$ = thickness of the residual waste for radionuclide "i" (m)

$Drill_{depth}$ = total depth of the well at WMA C tank farm (m)

$Exposure_{drill}$ = time of exposure for the WMA C PA acute drilling scenario (hours)

$Exposure_{NRC}$ = time of exposure for the NRC acute excavation scenario (hours)

0.254 = NRC dilution factor assumption for Class C intruder analysis – areal mixing of excavation material and waste (dimensionless)[20]

0.5 = NRC dilution factor assumption for Class C intruder analysis – waste barrels on 50% full of waste (dimensionless)[19]

Where:

$$C_{Ri} = \frac{I_{Ri}}{V_w} \; or \; \frac{I_{Ri}}{M_w}$$

I_{Ri} = Inventory of radionuclide "i" at closure (i.e., assumed closure date of 2068) decayed 400 years for all tanks, C-301, CR-Vault tanks and cells, and no decay after closure for the pipelines, valve pits and diversion boxes (Ci or nCi)

[19] Intrusion is assumed to occur 500 years after facility closure for components with a robust barrier. Because the Class A limits from 10 CFR 61.55 have a 100 year delay accounted for in their derivation, another 400 years is added for components with a robust barrier; no further delay is added for pits, diversion boxes, and pipelines.
[20] Value provided by NRC staff.

V_w = Residual waste volume (m^3)

M_w = Residual waste mass (g)

Consistent with the Category 3 approach and NRC guidance provided in NUREG-1854, the averaging expression used to determine the individual radionuclide contribution to the SOF based on the chronic post-drilling scenario is represented by the following equation:

$$SOF_i = \frac{C_{Ri}}{Table_{Value_i}} * \left(\frac{V_{w,drill}/V_{T,drill}}{V_{w,NRC}/V_{T,NRC}}\right) * \left(\frac{1}{0.254 * 0.5}\right)$$

Where:

SOF_i = Radionuclide "i" contribution to the sum of fractions

C_{Ri} = Concentration of radionuclide "i" at closure (i.e., assumed closure date of 2068) decayed 400 years for all tanks, C-301, CR-Vault tanks and cells, and no decay after closure for the pipelines, valve pits and diversion boxes (Ci/m^3 or nCi/g)

$Table_{Valuei}$ = Class A concentration limit from 10 CFR 61.55 Table 1 or Table 2 for radionuclide "i"

$V_{w,drill}$ = volume of waste brought to the surface from drilling (m^3)

$V_{T,drill}$ = total volume of soil brought to the surface from drilling (m^3)

$V_{w,NRCl}$ = volume of waste brought to the surface from NRC excavation scenario (m^3)

$V_{T,NRC}$ = total volume of soil brought to the surface from NRC excavation scenario (m^3)

0.254 = dilution factor assumption for Class C intruder analysis – areal mixing of excavation material and waste (dimensionless)

0.5 = dilution factor assumption for Class C analysis – waste barrels on 50% full of waste (dimensionless)

The WMA tanks, CR-Vault tanks and C-301 Catch Tank were decayed an additional 400 years after the closure date of 2068 due to the depth of the waste being greater than 5 m and also have robust intrusion resistance in accordance with NUREG-1854. The pipelines, valve pits, and diversion boxes were not decayed after the assumed closure date of 2068 because the depth of the waste is less than 5 m and they lack robust intrusion barriers.

Parameter Input Values:
Table 16 provides the input data used for the calculations presented in the remainder of this section.

Table 16. Alternative Class C calculation input parameter values.

Parameter	Notation	Value	Reference
Radionuclide inventory	I_{Ri}	Tables 17 through 20	WMA C PA
Waste volume	V_w	See Table 21	See table footnotes
Waste mass	M_w	See Table 21	See table footnotes
Waste thickness	$Waste_{thickness}$	See Table 21	See table footnotes
Drill depth	$Drill_{depth}$	79 m	WMA C PA
Exposure time for drilling	$Exposure_{drill}$	40 hr	WMA C PA
Exposure time for NRC scenario	$Exposure_{NRC}$	500 hr	NUREG-0782
Volume of waste from drilling	$V_{w,drill}$	See Table 21	See table footnotes
Volume of waste for NRC scenario	$V_{w,NRC}$	150 m^3	NUREG-0782
Total Soil Volume from drilling	$V_{T,drill}$	375 m^3	WMA C PA
Total Soil Volume for NRC scenario	$V_{T,NRC}$	600 m^3	NUREG-0782
10 CFR 61.55 limits	Table $value_i$	See Table 22	10 CFR 61.55

References:
10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

Table 17. Residual inventory (Ci) decayed to 2468 for the 100-series tanks.

Nuclide	C-101[b]	C-102[b]	C-103[a]	C-104[a]	C-105[a]	C-106[a]	C-107[b]	C-108[a]	C-109[a]	C-110[a]	C-111[b]	C-112[b]
C-14	3.32E-03	7.80E-03	6.62E-03	2.92E-03	4.60E-02	7.78E-03	2.98E-02	7.75E-03	7.25E-04	1.43E-03	3.69E-03	1.65E-02
Ni-59	9.14E-04	2.59E-03	1.12E-01	8.60E-02	4.39E-01	1.05E+01	1.71E-03	9.26E-04	6.43E-04	1.82E-04	3.78E-04	1.38E-03
Nb-94	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc-99	7.86E-01	3.99E+00	4.47E-02	3.04E-01	7.82E+00	1.64E-01	8.82E-02	4.86E-02	8.76E-03	4.45E-02	4.96E-02	2.83E-01
I-129	2.72E-03	2.60E+00	3.00E-03	4.84E-04	8.95E-03	6.31E-04	2.98E-03	3.81E-05	2.65E-05	2.65E-04	1.56E-05	5.70E-05
Np-237	5.85E-03	2.54E-02	1.40E-02	8.06E-02	3.19E-03	6.08E-02	2.54E-02	1.20E-04	6.86E-04	1.10E-03	2.11E-03	2.37E-02
Pu-238	8.80E-03	1.56E-02	3.78E-02	1.71E-02	2.18E-02	6.91E-02	2.88E-03	1.27E-04	4.53E-04	4.53E-04	2.45E-03	1.06E-02
Pu-239	1.90E+01	6.22E+01	4.93E+00	5.08E+00	5.21E+01	1.65E+01	1.58E+01	6.59E-01	3.96E-01	1.16E+00	2.50E+00	6.19E+00
Pu-240	1.96E+00	5.65E+00	9.92E-01	1.48E+00	9.92E+00	3.41E+00	1.66E+00	6.93E-02	4.16E-02	1.21E-01	2.62E-01	6.51E-01
Pu-241	9.27E-09	3.67E-09	7.76E-10	4.92E-09	7.55E-09	7.94E-09	5.82E-10	3.41E-11	2.20E-10	1.54E-10	9.27E-11	4.44E-09
Pu-242	2.83E-05	2.00E-06	3.24E-05	1.97E-02	3.14E-04	4.16E-04	2.42E-05	1.01E-06	6.06E-07	1.77E-06	3.83E-06	1.02E-02
Am-241	8.60E+00	2.94E+00	2.38E+00	4.32E+00	1.41E+01	3.14E+01	6.46E+00	4.63E-01	1.89E-01	3.01E-02	3.78E+00	9.87E+00
Am-243	5.70E-04	1.17E-03	3.55E-05	5.03E-03	6.45E-04	2.92E-03	1.29E-03	9.38E-05	3.75E-05	5.31E-06	4.07E-05	1.49E-04
Cm-242	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-243	1.43E-10	2.91E-10	1.42E-11	6.75E-08	1.69E-10	1.03E-06	3.26E-10	2.78E-11	9.43E-12	1.34E-12	1.03E-11	3.74E-11
Cm-244	4.93E-12	1.00E-11	5.43E-13	2.39E-09	5.58E-12	2.64E-08	1.12E-11	1.06E-12	3.25E-13	4.61E-14	3.53E-13	1.29E-12
Ni-63	2.48E+00	2.53E+01	8.36E-01	4.47E+00	1.62E+00	2.94E+00	1.35E+01	1.26E-01	3.95E-02	1.83E-02	1.55E-01	1.57E+00
Sr-90	1.76E-01	9.57E-03	1.31E-01	9.42E-02	5.56E-01	8.67E-01	1.61E-01	2.41E-02	4.49E-02	5.05E-02	7.84E-01	1.24E+00
Cs-137	6.67E-02	1.94E-02	2.06E-02	2.11E-02	1.72E-01	3.39E-02	7.35E-03	2.90E-03	1.46E-03	6.84E-04	4.91E-03	1.93E-02

a. Inventories based on the WMA C PA (RPP-ENV-58782), Table 4-3.
b. Post-retrieval inventories based on the Draft WIR Evaluation (DOE/ORP-2018-01), Table 2-6.

Table 18. Residual inventory (Ci) decayed to 2468 for the 200-series tanks and C-301.

Nuclide	C-201[a]	C-202[a]	C-203[a]	C-204[a]	C-301[a]
C-14	7.24E-04	1.92E-04	1.57E-04	1.78E-04	1.93E-03
Ni-59	4.05E-03	4.14E-03	3.39E-03	3.17E-03	4.12E-01
Nb-94	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc-99	2.63E-03	2.50E-03	2.32E-03	3.18E-03	3.63E-02
I-129	4.57E-07	7.35E-06	1.47E-05	3.57E-07	2.06E-04
Np-237	3.70E-03	3.05E-03	3.11E-05	2.16E-02	2.88E-02
Pu-238	1.28E-02	1.16E-02	3.95E-04	8.02E-06	2.15E-02
Pu-239	1.56E+01	1.41E+01	4.80E-01	9.71E-03	2.10E+01
Pu-240	3.24E+00	2.94E+00	1.00E-01	2.02E-03	4.39E+00
Pu-241	3.61E-09	3.24E-09	1.11E-10	2.25E-12	5.22E-09
Pu-242	1.60E-04	1.45E-04	4.94E-06	9.97E-08	1.30E-03
Am-241	1.34E+00	7.16E-01	1.97E-02	1.63E-03	2.90E+00
Am-243	9.36E-04	4.52E-04	1.17E-05	1.17E-06	1.31E-03
Cm-242	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-243	5.75E-08	2.78E-08	7.19E-10	7.17E-11	9.88E-08
Cm-244	1.98E-09	9.58E-10	2.48E-11	2.48E-12	3.07E-09
Ni-63	3.74E-02	8.99E-03	2.49E-03	6.56E-04	4.29E-01
Sr-90	3.29E-03	6.37E-03	3.00E-03	1.98E-03	5.89E-02
Cs-137	2.38E-04	2.09E-04	3.08E-04	1.40E-04	4.10E-03

a. Inventories based on the WMA C PA (RPP-ENV-58782), Table 4-3.

Table 19. Residual inventory (Ci) decayed to 2468 for the CR-Vault tanks.

Nuclide	CR-001[a]	CR-002[a]	CR-003[a]	CR-011[a]
C-14	2.54E-04	1.40E-04	3.98E-04	7.39E-04
Ni-59	5.42E-02	2.99E-02	8.51E-02	1.58E-01
Nb-94	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc-99	4.80E-03	2.65E-03	7.52E-03	1.40E-02
I-129	2.72E-05	1.50E-05	4.26E-05	7.91E-05
Np-237	3.80E-03	2.10E-03	5.95E-03	1.11E-02
Pu-238	2.83E-03	1.56E-03	4.44E-03	8.24E-03
Pu-239	2.77E+00	1.53E+00	4.34E+00	8.07E+00
Pu240	5.77E-01	3.19E-01	9.06E-01	1.68E+00
Pu-241	6.87E-10	3.79E-10	1.08E-09	2.00E-09
Pu-242	1.70E-04	9.41E-05	2.67E-04	4.97E-04
Am-241	3.82E-01	2.11E-01	6.00E-01	1.11E+00
Am-243	1.73E-04	9.56E-05	2.72E-04	5.05E-04
Cm-242	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-243	1.30E-08	7.18E-09	2.04E-08	3.79E-08
Cm244	4.05E-10	2.23E-10	6.35E-10	1.18E-09
Ni-63	5.64E-02	3.11E-02	8.85E-02	1.64E-01
Sr-90	7.74E-03	4.27E-03	1.21E-02	2.25E-02
Cs-137	5.40E-04	2.98E-04	8.46E-04	1.57E-03

[a] Inventories based on the WMA C PA (RPP-ENV-58782), Table 3-15a for the CR-Vault and adjusted according to the waste volumes provided in Table Att-6 for each tank in the CR-Vault.

Table 20. Residual inventory (Ci) at closure (i.e., 2068) for the ancillary equipment.

Nuclide	Pipelines[a]	Valve Pits	Diversion Boxes[a]
C-14	3.12E-03	6.24E-05	1.21E-04
Ni-59	6.37E-01	1.27E-02	2.47E-02
Nb-94	0.00E+00	0.00E+00	0.00E+00
Tc-99	5.61E-02	1.12E-03	2.17E-03
I-129	3.17E-04	6.34E-06	1.23E-05
Np-237	4.35E-02	8.87E-04	1.72E-03
Pu-238	7.80E-01	1.56E-02	3.02E-02
Pu-239	3.28E+01	6.56E-01	1.27E+00
Pu-240	7.04E+00	1.41E-01	2.73E-01
Pu-241	1.85E+00	1.60E-10	3.10E-10
Pu-242	2.00E-03	3.99E-05	7.74E-05
Am-241	8.42E+00	8.91E-02	1.73E-01
Am-243	2.10E-03	4.19E-05	8.12E-05
Cm-242	0.00E+00	2.23E-03	4.31E-03
Cm-243	2.55E-03	5.10E-05	9.86E-05
Cm-244	2.10E-02	4.22E-04	8.17E-04
Ni-63	1.05E+01	2.10E-01	4.08E-01
Sr-90	1.47E+03	2.94E+01	5.69E+01
Cs-137	6.21E+01	1.24E+00	2.40E+00

[a] Inventories based on the WMA C PA (RPP-ENV-58782), Table 4-3.

Table 21. Additional alternative Class C calculation input parameter values.

Equipment	Waste Volume (m^3)	Waste Mass[i] (g)	Waste Thickness (m)	Waste Volume from Drilling (m^3)
C-101	14.47[a]	2.97E+07	3.53E-02[j]	7.54E-04[q]
C-102	44.51[b]	9.12E+07	1.08E-01[j]	2.32E-03[q]
C-103	9.57[c]	1.96E+07	2.33E-02[j]	4.99E-04[q]
C-104	7.20[c]	1.48E+07	1.75E-02[j]	3.75E-04[q]
C-105	2.24[d]	4.59E+06	5.46E-03[j]	1.17E-04[q]
C-106	10.49[c]	2.15E+07	2.56E-02[j]	5.47E-04[q]
C-107	23.36[e]	4.79E+07	5.69E-02[j]	1.22E-03[q]
C-108	12.90[c]	2.64E+07	3.14E-02[j]	6.72E-04[q]
C-109	7.60[c]	1.56E+07	1.85E-02[j]	3.96E-04[q]
C-110	8.00[c]	1.64E+07	1.95E-02[j]	4.17E-04[q]
C-111	15.16[f]	3.11E+07	3.69E-02[j]	7.90E-04[q]
C-112	32.22[g]	6.61E+07	7.85E-02[j]	1.68E-03[q]
C-201	0.60[c]	1.23E+06	2.05E-02[k]	4.39E-04[q]
C-202	0.60[c]	1.23E+06	2.05E-02[k]	4.39E-04[q]
C-203	0.50[c]	1.03E+06	1.71E-02[k]	3.66E-04[q]
C-204	0.50[c]	1.03E+06	1.71E-02[k]	3.66E-04[q]
C-301	4.00[c]	8.20E+06	1.41E-01[l]	3.03E-03[q]
CR-001	0.52[c]	1.06E+06	1.65E-01[m]	3.53E-03[q]
CR-002	0.29[c]	5.86E+06	1.46E-01[m]	3.12E-03[q]
CR-003	0.81[c]	1.67E+06	2.48E-01[m]	5.30E-03[q]
CR-011	1.51[c]	3.09E+06	2.86E-01[m]	6.11E-03[q]
Pits	0.10[c]	2.05E+05	4.00E-04[n]	8.55E-06[q]
Boxes	0.20[c]	4.10E+05	4.00E-04[n]	8.55E-06[q]
Pipelines	6.10[c]	1.25E+07	1.09E-03[o]	2.33E-05[r]
Plugged Pipelines	6.10[h]	1.25E+07[h]	2.18E-02[p]	4.66E-04[r]

[a] RPP-RPT-58386, "Retrieval Data Report for Single-Shell Tank 241-C-101."
[b] RPP-RPT-59631, "Retrieval Data Report for Single-Shell Tank 241-C-102."
[c] RPP-ENV-58782, "Performance Assessment of Waste Management Area C, Hanford Site, Washington."
[d] RPP-RPT-61449, "Retrieval Data Report for Single-Shell Tank 241-C-105."
[e] RPP-RPT-58295, "Retrieval Data Report for Single-Shell Tank 241-C-107."
[f] RPP-RPT-60173, "Retrieval Data Report for Single-Shell Tank 241-C-111."
[g] RPP-RPT-58490, "Retrieval Data Report for Single-Shell Tank 241-C-112."
[h] The plugged pipelines use the same volume/mass and inventory as the pipeline analysis since the waste concentrations are the same regardless of the volume of waste contained in the pipe.
[i] A waste density of 2.05E+06 g/m^3 was assumed
[j] Waste thickness based on the waste volume divided by an area of 410.42 m^3 (i.e., tank radius of 11.43 m)
[k] Waste thickness based on the waste volume divided by an area of 29.22 m^3 (i.e., tank radius of 3.05 m)
[l] Waste thickness based on the waste volume divided by an area of 29.22 m^3 (i.e., tank radius of 3.05 m)
[m] Waste thickness determined by assuming 10% of the waste volumes presented in Figure 3-48 in the WMA C PA (RPP-ENV-58782) and the waste thickness correlation presented in RPP-RPT-58156.
[n] assumed to be 0.04 cm (0.0157 in.) based on RPP-15043, "Single-Shell Tank System Description."
[o] Waste thickness based on a well diameter of 26.67 cm (10.5 in.) (i.e., rural pasture scenario) intersecting 5% of the 3 inch pipe volume presented in the WMA C PA ((RPP-ENV-58782)
[p] Waste thickness based on a well diameter of 26.67 cm (10.5 in.) (i.e., rural pasture scenario) intersecting 100% of the 3 inch pipe volume presented in the WMA C PA (RPP-ENV-58782)
[q] Based on the area of a 0.165 m (6.5 in.) well (i.e., suburban garden scenario) times the waste thickness
[r] Based on the area of a 0.267 m (10.5 in.) well (i.e., rural pasture scenario) times the waste thickness

Table 22. 10 CFR 61.55 Class A concentration limits.

Table 1 Radionuclides	Class A Table Value	
C-14	0.8	Ci/m^3
Ni-59	22	Ci/m^3
Nb-94	0.02	Ci/m^3
Tc-99	0.30	Ci/m^3
I-129	0.008	Ci/m^3
Np-237	10	nCi/g
Pu-238	10	nCi/g
Pu-239	10	nCi/g
Pu-240	10	nCi/g
Pu-241	350	nCi/g
Pu-242	10	nCi/g
Am-241	10	nCi/g
Am-243	10	nCi/g
Cm-242	2000	nCi/g
Cm-243	10	nCi/g
Cm-244	10	nCi/g
Table 2 Radionuclides	**Class A Table Value**	
Ni-63	3.5	Ci/m^3
Sr-90	0.04	Ci/m^3
Cs-137	1	Ci/m^3

Summary of Residual Waste Class C Results:
A summary of the SOF averaging expression results of the Class C waste comparisons for the large tanks, C-301, CR-Vault tanks and cells, and ancillary equipment (i.e., pipelines, valve pits and diversion boxes) are provided in Table 23. Detailed Class C calculation results are also provided below (Table 25 through Table 30) for the acute and chronic equations, respectively.

Table 23. Summary of the Class C SOF results.

	Acute Class C Equation		Chronic Class C Equation	
Equipment	**Table 1 SOF**	**Table 2 SOF**	**Table 1 SOF**	**Table 2 SOF**
C-101	2.8E-02	1.0E-04	6.3E-03	2.3E-05
C-102	7.4E-02	1.5E-04	1.7E-02	3.3E-05
C-103	7.9E-03	6.8E-05	1.8E-03	1.5E-05
C-104	1.0E-02	7.1E-05	2.4E-03	1.6E-05
C-105	7.3E-02	2.8E-04	1.6E-02	6.4E-05
C-106	4.9E-02	4.4E-04	1.1E-02	9.9E-05
C-107	2.3E-02	1.5E-04	5.1E-03	3.5E-05
C-108	1.1E-03	1.2E-05	2.6E-04	2.8E-06
C-109	6.0E-04	2.2E-05	1.3E-04	5.0E-06
C-110	1.2E-03	2.5E-05	2.8E-04	5.5E-06
C-111	6.2E-03	3.8E-04	1.4E-03	8.6E-05
C-112	1.6E-02	6.1E-04	3.6E-03	1.4E-04
C-201	2.7E-01	2.5E-05	6.1E-02	5.7E-06
C-202	2.4E-01	4.4E-05	5.3E-02	1.0E-05
C-203	8.0E-03	2.1E-05	1.8E-03	4.7E-06
C-204	4.7E-04	1.4E-05	1.1E-04	3.1E-06
C-301	3.8E-01	4.4E-04	8.5E-02	9.8E-05
CR-001	4.6E-01	5.3E-04	1.0E-01	1.2E-04
CR-002	4.1E-01	4.7E-04	9.2E-02	1.1E-04
CR-003	6.9E-01	8.0E-04	1.6E-01	1.8E-04
CR-011	8.0E-01	9.2E-04	1.8E-01	2.1E-04
Pits	1.5E-03	2.3E-02	3.4E-04	5.3E-03
Boxes	1.5E-03	2.3E-02	3.3E-04	5.1E-03
Pipelines	3.4E-03	5.2E-02	7.7E-04	1.2E-02
Plugged Pipelines	6.8E-02	1.0E+00	1.5E-02	2.4E-01

The results in Table 23 show that the residual wastes meet the Class C limits for all tanks, vaults, pits, boxes and pipelines and plugged pipelines. The largest SOF was calculated for the plugged pipeline under the acute averaging expression, which resulted in a SOF of 1.0. Therefore, DOE has shown that the WMA C residual wastes are suitable for near surface disposal using the averaging expressions for comparison to the NRC Class C limits.

As a test of the averaging expressions, a comparison of the WMA C PA intruder drilling doses with the revised averaging expressions for the Class C calculations were conducted. The comparison was conducted by multiplying the SOF value for each radionuclide by 500 mrem, which provided a dose for each radionuclide from the Class C calculation SOFs for comparison to the WMA C PA doses. The dose from the averaging equations were then divided by the WMA C PA doses, resulting in a factor showing how the averaging expression doses over-predicts (i.e., a factor greater than 1.0) or under-predicts (i.e., a factor less than 1.0) in comparison to the WMA C PA doses. Table 24 provides the results of the dose comparison for the 100- and 200- series tanks, for the largest dose contributing radionuclides including Pu-239, Pu-240 and Am-241.

Table 24. Ratio of the averaging expression dose to the WMA PA dose.

Table 1 Radionuclides	Acute Scenario Comparison	Chronic Scenario Comparison
Pu-239	9	8
Pu-240	9	8
Am-241	11	10

As shown in Table 24, the averaging expressions over-predict the doses (i.e., and the Class C SOFs) for Pu-239, Pu-240 and Am-241 by a factor of 8 to 11 times in comparison to the WMA C PA doses. The differences may be due to the differences in the dosimetry used the calculations in 10 CFR 61.55 versus the newer dosimetry used in the WMA C PA. Regardless, the comparisons of the WMA C residual waste concentrations to the Class C limits result in conservative SOFs for the radionuclides that are approximately 10 times greater than the limits that would be derived using the WMA C PA dose results in accordance with 10 CFR 61.58.

Table 25. Class C SOF results for the 100-series tanks based on the acute equation.

Table 1 Radionuclides	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112
C-14	8.0E-08	1.9E-07	1.6E-07	7.1E-08	1.1E-06	1.9E-07	7.2E-07	1.9E-07	1.8E-08	3.5E-08	9.0E-08	4.0E-07
Ni-59	8.1E-10	2.3E-09	9.8E-08	7.6E-08	3.9E-07	9.2E-06	1.5E-09	8.2E-10	5.7E-10	1.6E-10	3.3E-10	1.2E-09
Nb-94	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tc-99	5.1E-05	2.6E-04	2.9E-06	2.0E-05	5.1E-04	1.1E-05	5.7E-06	3.1E-06	5.7E-07	2.9E-06	3.2E-06	1.8E-05
I-129	6.6E-06	6.3E-03	7.3E-06	1.2E-06	2.2E-05	1.5E-06	7.2E-06	9.2E-08	6.4E-08	6.4E-07	3.8E-08	1.4E-07
Np-237	5.5E-06	2.4E-05	1.3E-05	7.6E-05	3.0E-06	5.8E-05	2.4E-05	1.1E-07	6.5E-07	1.0E-06	2.0E-06	2.2E-05
Pu-238	8.3E-06	1.5E-05	3.6E-05	1.6E-05	2.1E-05	6.5E-05	2.7E-06	1.2E-07	4.3E-07	4.3E-07	2.3E-06	1.0E-05
Pu-239	1.8E-02	5.9E-02	4.7E-03	4.8E-03	4.9E-02	1.6E-02	1.5E-02	6.2E-04	3.7E-04	1.1E-03	2.4E-03	5.9E-03
Pu-240	1.9E-03	5.3E-03	9.4E-04	1.4E-03	9.4E-03	3.2E-03	1.6E-03	6.6E-05	3.9E-05	1.1E-04	2.5E-04	6.2E-04
Pu-241	2.5E-13	9.9E-14	2.1E-14	1.3E-13	2.0E-13	2.1E-13	1.6E-14	9.2E-16	5.9E-15	4.2E-15	2.5E-15	1.2E-13
Pu-242	2.7E-08	1.9E-09	3.1E-08	1.9E-05	3.0E-07	3.9E-07	2.3E-08	9.6E-10	5.7E-10	1.7E-09	3.6E-09	9.7E-06
Am-241	8.1E-03	2.8E-03	2.3E-03	4.1E-03	1.3E-02	3.0E-02	6.1E-03	4.4E-04	1.8E-04	2.9E-05	3.6E-03	9.4E-03
Am-243	5.4E-07	1.1E-06	3.4E-08	4.8E-06	6.1E-07	2.8E-06	1.2E-06	8.9E-08	3.6E-08	5.0E-09	3.9E-08	1.4E-07
Cm-242	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cm-243	1.4E-13	2.8E-13	1.3E-14	6.4E-11	1.6E-13	9.7E-10	3.1E-13	2.6E-14	8.9E-15	1.3E-15	9.7E-15	3.5E-14
Cm-244	4.7E-15	9.5E-15	5.1E-16	2.3E-12	5.3E-15	2.5E-11	1.1E-14	1.0E-15	3.1E-16	4.4E-17	3.3E-16	1.2E-15
SOF	***2.8E-02***	***7.4E-02***	***7.9E-03***	***1.0E-02***	***7.3E-02***	***4.9E-02***	***2.3E-02***	***1.1E-03***	***6.0E-04***	***1.2E-03***	***6.2E-03***	***1.6E-02***
Table 2 Radionuclides	C-101	**C-102**	**C-103**	**C-104**	**C-105**	**C-106**	**C-107**	**C-108**	**C-109**	**C-110**	**C-111**	**C-112**
Ni-63	1.4E-05	1.4E-04	4.6E-06	2.5E-05	9.0E-06	1.6E-05	7.5E-05	7.0E-07	2.2E-07	1.0E-07	8.6E-07	8.7E-06
Sr-90	8.5E-05	4.6E-06	6.3E-05	4.6E-05	2.7E-04	4.2E-04	7.8E-05	1.2E-05	2.2E-05	2.4E-05	3.8E-04	6.0E-04
Cs-137	1.3E-06	3.8E-07	4.0E-07	4.1E-07	3.3E-06	6.6E-07	1.4E-07	5.6E-08	2.8E-08	1.3E-08	9.5E-08	3.8E-07
SOF	***1.0E-04***	***1.5E-04***	***6.8E-05***	***7.1E-05***	***2.8E-04***	***4.4E-04***	***1.5E-04***	***1.2E-05***	***2.2E-05***	***2.5E-05***	***3.8E-04***	***6.1E-04***

Table 26. Class C SOF results for the 200-series tank, pits, boxes and pipelines, based on the acute equation.

Table 1 Radionuclides	C-201	C-202	C-203	C-204	C-301	Valve Pits	Diversion Boxes	Pipelines	Plugged Pipeline
C-14	2.5E-07	6.6E-08	5.4E-08	6.1E-08	6.6E-07	2.5E-09	2.4E-09	5.5E-09	1.1E-07
Ni-59	5.0E-08	5.1E-08	4.2E-08	3.9E-08	5.1E-06	1.8E-08	1.8E-08	4.1E-08	8.2E-07
Nb-94	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
Tc-99	2.4E-06	2.3E-06	2.1E-06	2.9E-06	3.3E-05	1.2E-07	1.2E-07	2.7E-07	5.3E-06
I-129	1.6E-08	2.5E-07	5.0E-07	1.2E-08	7.0E-06	2.5E-08	2.5E-08	5.6E-08	1.1E-06
Np-237	4.9E-05	4.1E-05	4.1E-07	2.9E-04	3.8E-04	1.4E-06	1.3E-06	3.0E-06	6.0E-05
Pu-238	1.7E-04	1.5E-04	5.3E-06	1.1E-07	2.9E-04	2.4E-05	2.3E-05	5.4E-05	1.1E-03
Pu-239	2.1E-01	1.9E-01	6.4E-03	1.3E-04	2.8E-01	1.0E-03	9.9E-04	2.3E-03	4.5E-02
Pu-240	4.3E-02	3.9E-02	1.3E-03	2.7E-05	5.8E-02	2.2E-04	2.1E-04	4.9E-04	9.8E-03
Pu-241	1.4E-12	1.2E-12	4.2E-14	8.5E-16	2.0E-12	1.6E-06	1.6E-06	3.7E-06	7.3E-05
Pu-242	2.1E-06	1.9E-06	6.6E-08	1.3E-09	1.7E-05	6.2E-08	6.0E-08	1.4E-07	2.8E-06
Am-241	1.8E-02	9.5E-03	2.6E-04	2.2E-05	3.9E-02	2.6E-04	2.5E-04	5.8E-04	1.2E-02
Am-243	1.2E-05	6.0E-06	1.6E-07	1.6E-08	1.7E-05	6.5E-08	6.3E-08	1.5E-07	2.9E-06
Cm-243	7.6E-10	3.7E-10	9.6E-12	9.5E-13	1.3E-09	7.9E-08	7.7E-08	1.8E-07	3.5E-06
Cm-244	2.6E-11	1.3E-11	3.3E-13	3.3E-14	4.1E-11	6.6E-07	6.4E-07	1.5E-06	2.9E-05
SOF	***2.7E-01***	***2.4E-01***	***8.0E-03***	***4.7E-04***	***3.8E-01***	***1.5E-03***	***1.5E-03***	***3.4E-03***	***6.8E-02***
Table 2 Radionuclides	C-201	C-202	C-203	C-204	C-301	Valve Pits	Diversion Boxes	Pipelines	Plugged Pipeline
Ni-63	2.9E-06	7.0E-07	1.9E-07	5.1E-08	3.3E-05	1.9E-06	1.9E-06	4.3E-06	8.6E-05
Sr-90	2.2E-05	4.3E-05	2.0E-05	1.4E-05	4.0E-04	2.3E-02	2.3E-02	5.2E-02	1.0E+00
Cs-137	6.5E-08	5.7E-08	8.4E-08	3.8E-08	1.1E-06	4.0E-05	3.8E-05	8.8E-05	1.8E-03
SOF	***2.5E-05***	***4.4E-05***	***2.1E-05***	***1.4E-05***	***4.4E-04***	***2.3E-02***	***2.3E-02***	***5.2E-02***	***1.0E+00***

Table 27. Class C SOF results for the CR-Vault tanks based on the acute equation.

Table 1 Radionuclides	CR-001	CR-002	CR-003	CR-011
C-14	8.1E-07	7.1E-07	1.2E-06	1.4E-06
Ni-59	6.3E-06	5.5E-06	9.4E-06	1.1E-05
Nb-94	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tc-99	4.1E-05	3.6E-05	6.1E-05	7.0E-05
I-129	8.6E-06	7.6E-06	1.3E-05	1.5E-05
Np-237	4.7E-04	4.2E-04	7.1E-04	8.1E-04
Pu-238	3.5E-04	3.1E-04	5.3E-04	6.1E-04
Pu-239	3.4E-01	3.0E-01	5.1E-01	5.94E-01
Pu-240	7.2E-02	6.3E-02	1.1E-01	1.2E-01
Pu-241	2.4E-12	2.1E-12	3.6E-12	4.2E-12
Pu-242	2.1E-05	1.9E-05	3.2E-05	3.7E-05
Am-241	4.7E-02	4.2E-02	7.1E-02	8.2E-02
Am-243	2.1E-05	1.9E-05	3.2E-05	3.7E-05
Cm-243	1.6E-09	1.4E-09	2.4E-09	2.8E-09
Cm-244	5.0E-11	4.4E-11	7.5E-11	8.7E-11
SOF	***4.6E-01***	***4.1E-01***	***6.9E-01***	***8.0E-01***
Table 2 Radionuclides	**CR-001**	**CR-002**	**CR-003**	**CR-011**
Ni-63	4.1E-05	3.6E-05	6.1E-05	7.1E-05
Sr-90	4.9E-04	4.3E-04	7.4E-04	8.5E-04
Cs-137	1.4E-06	1.2E-06	2.1E-06	2.4E-06
SOF	***5.3E-04***	***4.7E-04***	***8.0E-04***	***9.2E-04***

Table 28. Class C SOF results for the 100-series tanks based on the chronic equation.

Table 1 Radionuclides	**C-101**	**C-102**	**C-103**	**C-104**	**C-105**	**C-106**	**C-107**	**C-108**	**C-109**	**C-110**	**C-111**	**C-112**
C-14	1.8E-08	4.3E-08	3.6E-08	1.6E-08	2.5E-07	4.3E-08	1.6E-07	4.2E-08	4.0E-09	7.8E-09	2.0E-08	9.0E-08
Ni-59	1.8E-10	5.1E-10	2.2E-08	1.7E-08	8.7E-08	2.1E-06	3.4E-10	1.8E-10	1.3E-10	3.6E-11	7.5E-11	2.8E-10
Nb-94	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tc-99	1.1E-05	5.8E-05	6.5E-07	4.4E-06	1.1E-04	2.4E-06	1.3E-06	7.1E-07	1.3E-07	6.5E-07	7.2E-07	4.1E-06
I-129	1.5E-06	1.4E-03	1.6E-06	2.6E-07	4.9E-06	3.4E-07	7.9E-13	2.1E-08	1.4E-08	1.4E-07	8.5E-09	3.1E-08
Np-237	1.2E-06	5.4E-06	3.0E-06	1.7E-05	6.8E-07	1.3E-05	5.4E-06	2.6E-08	1.5E-07	2.3E-07	4.5E-07	5.1E-06
Pu-238	1.9E-06	3.3E-06	8.1E-06	3.7E-06	4.6E-06	1.5E-05	6.1E-07	2.7E-08	9.7E-08	9.7E-08	5.2E-07	2.3E-06
Pu-239	4.0E-03	1.3E-02	1.1E-03	1.1E-03	1.1E-02	3.5E-03	3.4E-03	1.4E-04	8.4E-05	2.5E-04	5.3E-04	1.3E-03
Pu-240	4.2E-04	1.2E-03	2.1E-04	3.2E-04	2.1E-03	7.3E-04	3.5E-04	1.5E-05	8.9E-06	2.6E-05	5.6E-05	1.4E-04
Pu-241	5.7E-14	2.2E-14	4.7E-15	3.0E-14	4.6E-14	4.8E-14	3.5E-15	2.1E-16	1.3E-15	9.4E-16	5.7E-16	2.7E-14
Pu-242	6.0E-09	4.3E-10	6.9E-09	4.2E-06	6.7E-08	8.9E-08	5.2E-09	2.2E-10	1.3E-10	3.8E-10	8.2E-10	2.2E-06
Am-241	1.8E-03	6.3E-04	5.1E-04	9.2E-04	3.0E-03	6.7E-03	1.4E-03	9.9E-05	4.0E-05	6.4E-06	8.1E-04	2.1E-03
Am-243	1.2E-07	2.5E-07	7.6E-09	1.1E-06	1.4E-07	6.2E-07	2.8E-07	2.0E-08	8.0E-09	1.1E-09	8.7E-09	3.2E-08
Cm-242	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.6E-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cm-243	3.1E-14	6.2E-14	3.0E-15	1.4E-11	3.6E-14	2.2E-10	7.0E-14	5.9E-15	2.0E-15	2.9E-16	2.2E-15	8.0E-15
Cm-244	1.1E-15	2.1E-15	1.2E-16	5.1E-13	1.2E-15	5.6E-12	2.4E-15	2.3E-16	6.9E-17	9.8E-18	7.5E-17	2.8E-16
SOF	***6.3E-03***	***1.7E-02***	***1.8E-03***	***2.4E-03***	***1.6E-02***	***1.1E-02***	***5.1E-03***	***2.6E-04***	***1.3E-04***	***2.8E-04***	***1.4E-03***	***3.6E-03***
Table 2 Radionuclides	**C-101**	**C-102**	**C-103**	**C-104**	**C-105**	**C-106**	**C-107**	**C-108**	**C-109**	**C-110**	**C-111**	**C-112**
Ni-63	3.1E-06	3.2E-05	1.0E-06	5.6E-06	2.0E-06	3.7E-06	1.7E-05	1.6E-07	4.9E-08	2.3E-08	1.9E-07	2.0E-06
Sr-90	1.9E-05	1.0E-06	1.4E-05	1.0E-05	6.1E-05	9.5E-05	1.8E-05	2.6E-06	4.9E-06	5.5E-06	8.6E-05	1.4E-04
Cs-137	2.9E-07	8.5E-08	9.0E-08	9.2E-08	7.5E-07	1.5E-07	3.2E-08	1.3E-08	6.4E-09	3.0E-09	2.1E-08	8.4E-08
SOF	***2.3E-05***	***3.3E-05***	***1.5E-05***	***1.6E-05***	***6.4E-05***	***9.9E-05***	***3.5E-05***	***2.8E-06***	***5.0E-06***	***5.5E-06***	***8.6E-05***	***1.4E-04***

Table 29. Class C SOF results for the 200-series tank, pits, boxes and pipelines, based on the chronic equation.

Table 1 Radionuclides	C-201	C-202	C-203	C-204	C-301	Valve Pits	Diversion Boxes	Pipelines	Plugged Pipeline
C-14	5.6E-08	1.5E-08	1.2E-08	1.4E-08	1.5E-07	5.6E-10	5.4E-10	1.2E-09	2.5E-08
Ni-59	1.1E-08	1.2E-08	9.5E-09	8.8E-09	1.2E-06	4.1E-09	4.0E-09	9.3E-09	1.9E-07
Nb-94	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
Tc-99	5.4E-07	5.1E-07	4.7E-07	6.5E-07	7.4E-06	2.7E-08	2.6E-08	6.0E-08	1.2E-06
I-129	3.5E-09	5.6E-08	1.1E-07	2.7E-09	1.6E-06	5.7E-09	5.5E-09	1.3E-08	2.5E-07
Np-237	1.1E-05	9.1E-06	9.3E-08	6.5E-05	8.6E-05	3.0E-07	3.0E-07	6.8E-07	1.4E-05
Pu-238	3.8E-05	3.5E-05	1.2E-06	2.4E-08	6.4E-05	5.5E-06	5.3E-06	1.2E-05	2.4E-04
Pu-239	4.7E-02	4.2E-02	1.4E-03	2.9E-05	6.3E-02	2.3E-04	2.2E-04	5.1E-04	1.0E-02
Pu-240	9.7E-03	8.8E-03	3.0E-04	6.1E-06	1.3E-02	4.9E-05	4.8E-05	1.1E-04	2.2E-03
Pu-241	3.1E-13	2.8E-13	9.5E-15	1.9E-16	4.5E-13	3.7E-07	3.6E-07	8.2E-07	1.6E-05
Pu-242	4.8E-07	4.3E-07	1.5E-08	3.0E-10	3.9E-06	1.4E-08	1.4E-08	3.1E-08	6.2E-07
Am-241	4.0E-03	2.1E-03	5.9E-05	4.9E-06	8.7E-03	5.9E-05	5.7E-05	1.3E-04	2.6E-03
Am-243	2.8E-06	1.4E-06	3.5E-08	3.5E-09	3.9E-06	1.5E-08	1.4E-08	3.3E-08	6.6E-07
Cm-242	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
Cm-243	1.7E-10	8.3E-11	2.2E-12	2.1E-13	3.0E-10	1.8E-08	1.7E-08	4.0E-08	8.0E-07
Cm-244	5.9E-12	2.9E-12	7.4E-14	7.4E-15	9.2E-12	1.5E-07	1.4E-07	3.3E-07	6.6E-06
SOF	***6.1E-02***	***5.3E-02***	***1.8E-03***	***1.1E-04***	***8.5E-02***	***3.4E-04***	***3.3E-04***	***7.7E-04***	***1.5E-02***
Table 2 Radionuclides	C-201	C-202	C-203	C-204	C-301	Valve Pits	Diversion Boxes	Pipelines	Plugged Pipeline
Ni-63	6.6E-07	1.6E-07	4.4E-08	1.2E-08	7.5E-06	4.3E-07	4.2E-07	9.6E-07	1.9E-05
Sr-90	5.1E-06	9.8E-06	4.6E-06	3.0E-06	9.0E-05	5.3E-03	5.1E-03	1.2E-02	2.4E-01
Cs-137	1.5E-08	1.3E-08	1.9E-08	8.6E-09	2.5E-07	8.9E-06	8.6E-06	2.0E-05	4.0E-04
SOF	***5.7E-06***	***1.0E-05***	***4.7E-06***	***3.1E-06***	***9.8E-05***	***5.3E-03***	***5.1E-03***	***1.2E-02***	***2.4E-01***

Table 30. Class C SOF results for the CR-Vault tanks based on the chronic equation.

Table 1 Radionuclides	CR-001	CR-002	CR-003	CR-011
C-14	1.8E-07	1.6E-07	2.7E-07	3.1E-07
Ni-59	1.4E-06	1.2E-06	2.1E-06	2.4E-06
Tc-99	9.1E-06	8.1E-06	1.4E-05	1.6E-05
I-129	1.9E-06	1.7E-06	2.9E-06	3.4E-06
Np-237	1.1E-04	9.4E-05	1.6E-13	1.8E-04
Pu-238	7.9E-05	7.0E-05	1.2E-04	1.4E-04
Pu-239	7.7E-02	6.8E-02	1.2E-01	1.3E-01
Pu-240	1.6E-02	1.4E-02	2.4E-02	2.8E-02
Pu-241	5.5E-13	4.8E-13	8.2E-13	9.5E-13
Pu-242	4.8E-06	4.2E-06	7.1E-06	8.2E-06
Am-241	1.1E-02	9.4E-03	1.6E-02	1.8E-02
Am-243	4.8E-06	4.3E-06	7.3E-06	8.4E-06
Cm-243	3.6E-10	3.2E-10	5.4E-10	6.3E-10
Cm-244	1.1E-11	1.0E-11	1.7E-11	2.0E-11
SOF	***1.0E-01***	***9.2E-02***	***1.6E-01***	***1.8E-01***
Table 2 Radionuclides	**CR-001**	**CR-002**	**CR-003**	**CR-011**
Ni-63	9.2E-06	8.2E-06	1.4E-05	1.6E-05
Sr-90	1.1E-04	9.8E-05	1.7E-04	1.9E-04
Cs-137	3.1E-07	2.7E-07	4.6E-07	5.3E-07
SOF	***1.2E-04***	***1.1E-04***	***1.8E-04***	***2.1E-04***

5.0 REFERENCES

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ATTACHMENT A – COR-1800255

Radiological Survey Report for 200E / 241C / C101-C112, C201-204, and CR Vaults
(13 pages, numbered separately)

WASHINGTON RIVER PROTECTION SOLUTIONS, LLC RADIOLOGICAL SURVEY REPORT(Submitted for Approval)			**RSR No.** COR-1800255	Page 1 of 13
Date 02/01/2018	Start/Stop Time 0800/1000	Area/Location 200E / 241C / C101-C112, C201-204, and CR Vaults		RWP/Rev. CO-109/023

Purpose of Survey:	Description of Work:
☐ Material Clearance Number: N/A Cleared to: N/A ☐ Ram Shipment: N/A X Required Task: COO-W040 ☐ Job Coverage: N/A ☐ Other: N/A	COO-W040: Weekly radiation survey of C Farm and CR Vault. Comments: Performed weekly radiation survey of C Farm and CR Vault as per task description COO-W040. Routine was located in a posted RA/HRA/CA. Tank C-109 R5 Blank - sleeving containment deteriorated (marked on map). Tank C-105 Mars box and "A" pit not accessible at this time due to "Construction" roped off areas. Tank C-111 Slurry Pump Pit- did not access VCZ (mercury monitoring needed), dose rate taken at VCZ boundary.

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Dose Rate Measurements

Note[1]: F = Field (>=30 cm) C = Contact (<=1 cm) H = HEBE

No.	Description	Dist. (cm) Note[1]	WO mR/hr	WC mR/hr	CF Non-Penetrating	CF Penetrating	Neutron Dose mrem/hr	Shallow Dose mrem/hr	Deep Dose mrem/hr
D1	C-101 Sluice Pit 'C '	30	<.5	<.5	2	1	N/A	<0.5	<.5
D2	C-101 12" Riser with Breather Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D3	C-101 Sluice Box #2	30	<.5	<.5	2	1	N/A	<0.5	<.5
D4	C-101 Riser #1 4" ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D5	C-101 Heel Pit 'B'	30	<.5	<.5	2	1	N/A	<0.5	<.5
D6	C-101 Riser #8, 4" Blank	30	45	5	2	1	N/A	85	5
D7	C-101 12" Blank	30	1.5	1.5	2	1	N/A	1.5	1.5
D8	C-101 Pump Pit 'A'	30	<.5	<.5	2	1	N/A	<0.5	<.5
D9	C-101 Condenser Pit	30	9	9	2	1	N/A	9	9
D10	POR-138	30	1	1	2	1	N/A	1	1
D11	POR-314	30	<.5	<.5	2	1	N/A	<0.5	<.5
D12	C-102 Sluice Pit "C" Contact of Hot Spot (see comments)	C	110	110	2	1	N/A	110	110
D13	C-102 Sluice Pit "C"	30	30	25	2	1	N/A	35	25
D14	C-102 12" Riser #3 Breather Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D15	C-102 Sluice Box #2	30	<.5	<.5	2	1	N/A	<0.5	<.5
D16	C-102 Riser #1, 4" Blank	30	<.5	<.5	2	1	N/A	<0.5	<.5
D17	C-102 Heel Pit "B"	30	<.5	<.5	2	1	N/A	<0.5	<.5
D18	C-102 Riser #8, 12" ENRAF	30	1.5	1.5	2	1	N/A	1.5	1.5
D19	C-102 Sluicer Box#1	30	12	12	2	1	N/A	12	12
D20	C-102 Pump Pit "A"	30	8	8	2	1	N/A	8	8
D21	C-102 Condenser Pit	30	10	10	2	1	N/A	10	10
D22	241-C Valve Pit "By POR-08 Exhauster"	30	6	6	2	1	N/A	6	6
D23	POR-104 Valve Pit	30	1.5	1.5	2	1	N/A	1.5	1.5
D24	C-103 Sluice Pit "C" Green Spot	30	8	8	2	1	N/A	8	8
D25	C-103 Riser #2 12" Breather Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D26	C-103 Riser #1 4" Temp Probe	30	<.5	<.5	2	1	N/A	<0.5	<.5
D27	C-103 Heel Pit "B" Pit	30	1.5	1.5	2	1	N/A	1.5	1.5
D28	C-103 Riser #8 4" Blank	30	1	1	2	1	N/A	1	1
D29	C-103 Riser #7 12" Exhaust Duct	30	4	4	2	1	N/A	4	4
D30	C-103 Riser #5 4" ENRAF	30	2	2	2	1	N/A	2	2
D31	C-103 Pump Pit "A"	30	5	5	2	1	N/A	5	5
D32	C-103 Condenser Pit	30	2.5	2.5	2	1	N/A	2.5	2.5
D33	C-104 Sluice Pit "C"	C	45	37	2	1	N/A	53	37
D34	C-104 Sluice Pit "C"	30	30	25	2	1	N/A	35	25
D35	C-104 Riser #2, 10" Riser with Breather Filter	30	2	2	2	1	N/A	2	2
D36	C-104 Heel Pit "B"	30	<.5	<.5	2	1	N/A	<0.5	<.5

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D37	C-104 Riser #14, 4" Blank	30	<.5	<.5	2	1	N/A	<0.5	<.5
D38	C-104 AMS Box "Saltwell Pump Pit"	30	<.5	<.5	2	1	N/A	<0.5	<.5
D39	C-104 Riser #8, 4" with ENRAF	30	4	4	2	1	N/A	4	4
D40	C-104 Riser #7, 12" "covered in Lead Blankets"	C	30	30	2	1	N/A	30	30
D41	C-104 Riser #7, 12" "covered in Lead Blankets"	30	20	20	2	1	N/A	20	20
D42	C-104 Pump Pit "A"	C	60	55	2	1	N/A	65	55
D43	C-104 Pump Pit "A"	30	45	42	2	1	N/A	48	42
D44	C-104 Exhauster Duct at Condenser Pit	30	1	1	2	1	N/A	1	1
D45	C-104 Condenser Pit	30	30	4	2	1	N/A	56	4
D46	POR 134	30	<.5	<.5	2	1	N/A	<0.5	<.5
D47	C-105 Sluice Pit "C"	30	<.5	<.5	2	1	N/A	<0.5	<.5
D48	C-105 Riser #2 Breather Filter	30	12	12	2	1	N/A	12	12
D49	C-105 Riser #1, 4" with Temp Probe	30	2.5	2.5	2	1	N/A	2.5	2.5
D50	C-105 Mars Box	30	<.5	<.5	2	1	N/A	<0.5	<.5
D51	C-105 Riser #8 blank	30	<.5	<.5	2	1	N/A	<0.5	<.5
D52	C-105 Riser #7, 12" Blank "covered in Foam"F	30	<.5	<.5	2	1	N/A	<0.5	<.5
D53	C-105 Pump Pit "A"	30	5	5	2	1	N/A	5	5
D54	C-105 Exhauster Duct on Condenser Pit	30	17	17	2	1	N/A	17	17
D55	C-105 Condenser Pit	30	17	17	2	1	N/A	17	17
D56	Plenum Between C-105, & 106	C	90	90	2	1	N/A	90	90
D57	Plenum Between C-105, & 106	30	50	40	2	1	N/A	60	40
D58	C-106 Sluice Pit "C"	30	1	1	2	1	N/A	1	1
D59	C-106 Riser #2 12" with Exhaust Duct	30	5	5	2	1	N/A	5	5
D60	C-106 Riser #1 with ENRAF	30	3	3	2	1	N/A	3	3
D61	C-106 Heel Pit "B"	30	<.5	<.5	2	1	N/A	<0.5	<.5
D62	C-106 Riser #14, 4" with blank	30	<.5	<.5	2	1	N/A	<0.5	<.5
D63	C-106 Riser #8 with Temp Probe	30	1.5	1.5	2	1	N/A	1.5	1.5
D64	C-106 Riser #7, 12" with Sluicer Assembly	30	6	6	2	1	N/A	6	6
D65	C-106 Pump Pit "A"	C	120	60	2	1	N/A	180	60
D66	C-106 Pump Pit "A"	30	35	30	2	1	N/A	40	30
D67	C-106 Riser #15, 12" with Breather Filter	30	1	1	2	1	N/A	1	1
D68	C-106 Condenser Pit	30	3.5	3.5	2	1	N/A	3.5	3.5
D69	241-C-91 at C-106	30	2.5	2.5	2	1	N/A	2.5	2.5
D70	C-107 Riser #4, 4" with condensate line	30	6	6	2	1	N/A	6	6
D71	C-107 Riser #3 with Exhaust Duct	30	12	12	2	1	N/A	12	12
D72	C-107 Riser #2, 12" Blank	30	14	1	2	1	N/A	27	1
D73	C-107 Riser #1 " Covered in Foam"	30	1	1	2	1	N/A	1	1
D74	C-107 Mars Box POR-240/237	30	.5	.5	2	1	N/A	0.5	0.5
D75	C-107 Riser #8, 4" with ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D76	C-107 Riser #7, 12" with Breather Filter	30	1.5	<.5	2	1	N/A	3	<.5

D77	C-107 Riser #6 12" "Covered in Foam"	30	<.5	<.5	2	1	N/A	<0.5	<.5
D78	C-107 Riser #5, 4" with TBX	30	<.5	<.5	2	1	N/A	<0.5	<.5
D79	C-108 Riser #4, 4" with Breather Filter	30	12	<.5	2	1	N/A	24	<.5
D80	C-108 Riser #3, 12" with Inlet Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D81	C-108 Sluice Box #2	30	<.5	<.5	2	1	N/A	<0.5	<.5
D82	C-108 Riser #1, 4" with TBX	30	<.5	<.5	2	1	N/A	<0.5	<.5
D83	C-108 Slurry Pump Pit	30	<.5	<.5	2	1	N/A	<0.5	<.5
D84	C-108 Riser #8, 4" with ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D85	C-108 Sluice Box #1	30	.8	.8	2	1	N/A	0.8	0.8
D86	C-108 Riser #6, 12" with Exhaust Duct	30	8	1.5	2	1	N/A	14.5	1.5
D87	C-108 Riser #5, 4" with TBX	30	1	1	2	1	N/A	1	1
D88	POR-117	30	<.5	<.5	2	1	N/A	<0.5	<.5
D89	POR-209	30	4.5	4.5	2	1	N/A	4.5	4.5
D90	C-109 Riser #4, 4" with Breather Filter	30	4.5	4.5	2	1	N/A	4.5	4.5
D91	C-109 Riser #3, 12" with Exhaust Duct	30	12	12	2	1	N/A	12	12
D92	C-109 Sluice Box #2	30	1.5	1.5	2	1	N/A	1.5	1.5
D93	C-109 Riser #1, 4" with ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D94	C-109 Slurry Pump Pit	30	<.5	<.5	2	1	N/A	<0.5	<.5
D95	C-109 Riser #8 4" with Thermo Couple	30	<.5	<.5	2	1	N/A	<0.5	<.5
D96	C-109 Sluice Box #1	30	<.5	<.5	2	1	N/A	<0.5	<.5
D97	C-109 Riser #6, 12" with Inlet Filter	30	.5	.5	2	1	N/A	0.5	0.5
D98	C-109 Riser #5, 4" Blank	30	.5	.5	2	1	N/A	0.5	0.5
D99	C-110 Riser #4, 4" with ENRAF	30	2	2	2	1	N/A	2	2
D100	C-110 Riser #3, 12" with Exhaust Duct	30	3.5	3.5	2	1	N/A	3.5	3.5
D101	C-110 Sluice Box #2	30	.5	.5	2	1	N/A	0.5	0.5
D102	C-110 Riser #1, 4" with Condenstaion Drain	30	<.5	<.5	2	1	N/A	<0.5	<.5
D103	C-110 Foam Covered Pit	30	5	5	2	1	N/A	5	5
D104	C-110 Slurry Pump Pit	30	<.5	<.5	2	1	N/A	<0.5	<.5
D105	C-110 Riser #8, 4" with Temp Probe	30	<.5	<.5	2	1	N/A	<0.5	<.5
D106	C-110 Sluice Box #1	30	<.5	<.5	2	1	N/A	<0.5	<.5
D107	C-110 Riser #6, 12" with Breather Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D108	C-110 Riser #5, 4" with Blank	30	<.5	<.5	2	1	N/A	<0.5	<.5
D109	C-111 Riser #4, 4" with Blank	30	<.5	<.5	2	1	N/A	<0.5	<.5
D110	C-111 Sluice Box #2	30	<.5	<.5	2	1	N/A	<0.5	<.5
D111	C-111 Riser #2, 12" with Breather Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D112	C-111 Riser #1, 4" with Camera	30	<.5	<.5	2	1	N/A	<0.5	<.5
D113	C-111 Slurry Pump Pit	30	<.5	<.5	2	1	N/A	<0.5	<.5
D114	C-111 Riser #8, 4" with ENRAF	30	1.5	1.5	2	1	N/A	1.5	1.5
D115	C-111 Riser #7, 12" with Exhaust Duct	30	2.5	2.5	2	1	N/A	2.5	2.5
D116	C-111 Sluice Box #1	30	1.5	1.5	2	1	N/A	1.5	1.5

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D117	C-111 Riser #5, 4" with Temp Probe	30	<.5	<.5	2	1	N/A	<0.5	<.5
D118	C-112 Riser #4, 4" Blank	30	3.5	3.5	2	1	N/A	3.5	3.5
D119	C-112 Riser #3, 12" with Exhaust Duct	30	15	15	2	1	N/A	15	15
D120	C-112 Sluice Box #2	30	1	1	2	1	N/A	1	1
D121	C-112 Riser #1, 4" with Thermocouple	30	<.5	<.5	2	1	N/A	<0.5	<.5
D122	C-112 Foam Covered Pit	30	<.5	<.5	2	1	N/A	<0.5	<.5
D123	C-112 Slurry Pump Pit	30	<.5	<.5	2	1	N/A	<0.5	<.5
D124	C-112 Riser #8, camera	30	<.5	<.5	2	1	N/A	<0.5	<.5
D125	C-112 Sluice Box #1	30	<.5	<.5	2	1	N/A	<0.5	<.5
D126	C-112 Riser #7, 12" with Breather Filter\MPR	30	<.5	<.5	2	1	N/A	<0.5	<.5
D127	C-112 4" R5 ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D128	POR-303	30	1	1	2	1	N/A	1	1
D129	C-801	30	<.5	<.5	2	1	N/A	<0.5	<.5
D130	C-201 Riser #5, 4" with Breather Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D131	C-201 Riser #6, 12" with Multi Port	30	<.5	<.5	2	1	N/A	<0.5	<.5
D132	C-201 AMS Box	30	<.5	<.5	2	1	N/A	<0.5	<.5
D133	C-201 Riser #8, 4" with ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D134	C-201 12" Exhaust Duct	30	<.5	<.5	2	1	N/A	<0.5	<.5
D135	C-201 Cover Blocks	30	2.5	2.5	2	1	N/A	2.5	2.5
D136	C-202 Riser #5, 4" with Breather Filter	30	.8	.8	2	1	N/A	0.8	0.8
D137	C-202 Riser #6, 12" Blank	30	.8	.8	2	1	N/A	0.8	0.8
D138	C-202 Riser #7, 12" with AMS Box	30	15	<.5	2	1	N/A	30	<.5
D139	C-202 Riser #8, 4" with ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D140	C-202 12" with Exhaust Duct	30	<.5	<.5	2	1	N/A	<0.5	<.5
D141	C-202 Cover Blocks	30	2	2	2	1	N/A	2	2
D142	C-203 Riser #5, 4" with Breather Filter	30	1	1	2	1	N/A	1	1
D143	C-203 12" R6 MPR	30	10	10	2	1	N/A	10	10
D144	C-203 12" R7 AMS Box	30	<.5	<.5	2	1	N/A	<0.5	<.5
D145	C-203 4" R8 ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D146	C-203 12" Exh. Duct	30	<.5	<.5	2	1	N/A	<0.5	<.5
D147	C-203 Cover Blocks	30	<.5	<.5	2	1	N/A	<0.5	<.5
D148	C-204 Riser #5, 4" with Breather Filter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D149	C-204 Riser #6, 12' with Multi Port	30	<.5	<.5	2	1	N/A	<0.5	<.5
D150	C-204 Riser #7, 12" with AMS Box	30	<.5	<.5	2	1	N/A	<0.5	<.5
D151	C-204 Riser #8, 4" with ENRAF	30	<.5	<.5	2	1	N/A	<0.5	<.5
D152	C-204 12" Exh. Duct	30	<.5	<.5	2	1	N/A	<0.5	<.5
D153	C-204 Cover Blocks	30	<.5	<.5	2	1	N/A	<0.5	<.5
D154	C-252 Foamed Cover blocks by construction laydown C-204 12" with Exhauster Duct	30	<.5	<.5	2	1	N/A	<0.5	<.5
D155	241-C-301 Restricted Access "around area chain"	30	<.5	<.5	2	1	N/A	<0.5	<.5

D156	241-C-153 Near vehicle exit from farm	30	<.5	<.5	2	1	N/A	<0.5	<.5
D157	241-C-152 North west of Cesium spill	30	<.5	<.5	2	1	N/A	<0.5	<.5
D158	241-C-151 South west of Cesium spill	30	<.5	<.5	2	1	N/A	<0.5	<.5
D159	241-CR-153	30	6	6	2	1	N/A	6	6
D160	241-CR-152	30	3.5	3.5	2	1	N/A	3.5	3.5
D161	241-CR-151	30	<.5	<.5	2	1	N/A	<0.5	<.5
D162	CR-011 Multi Port	30	2.5	2.5	2	1	N/A	2.5	2.5
D163	CR-011 Ball Valve	30	3	3	2	1	N/A	3	3
D164	CR-001 Multi Port	30	6	6	2	1	N/A	6	6
D165	CR-001 Ball Valve	30	7	7	2	1	N/A	7	7
D166	CR-002 Multi Port	30	2	2	2	1	N/A	2	2
D167	CR-002 Ball Valve	30	2.5	2.5	2	1	N/A	2.5	2.5
D168	CR-003 Multi Port	30	1.5	1.5	2	1	N/A	1.5	1.5
D169	CR-003 Ball Valve	30	16	16	2	1	N/A	16	16
D170	4" Blank in VCZ	30	<.5	<.5	2	1	N/A	<0.5	<.5
D171	244-CR	30	<.5	<.5	2	1	N/A	<0.5	<.5
D172	4" Blank in VCZ	30	<.5	<.5	2	1	N/A	<0.5	<.5
D173	12" Breather Filter in VCZ	30	<.5	<.5	2	1	N/A	<0.5	<.5
D174	12" Stainless Cap next to VCZ	30	<.5	<.5	2	1	N/A	<0.5	<.5
D175	4" Blank in VCZ	30	<.5	<.5	2	1	N/A	<0.5	<.5
D176	244-CR Filter Bank	30	<.5	<.5	2	1	N/A	<0.5	<.5
D177	C-Farm RA perimeter	30	<.5	<.5	2	1	N/A	<0.5	<.5
D178	POR-003	30	5	5	2	1	N/A	5	5
D179	POR-295	30	<.5	<.5	2	1	N/A	<0.5	<.5

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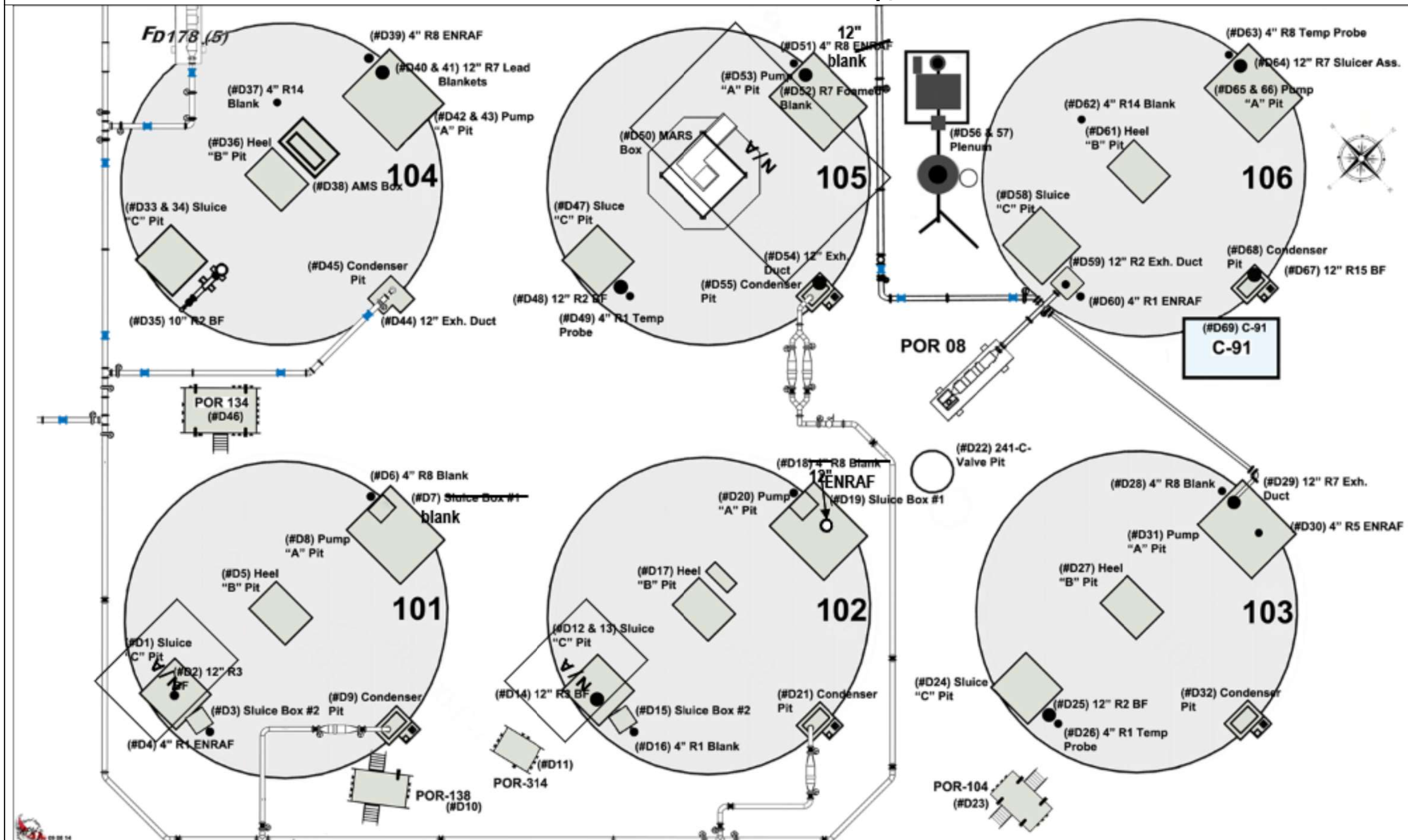
Map/Sketch



Map Name: 40	Map Description: Tanks 1-6

Legend	Direct Measurement	Air Sample	Smear	LAW	Neutron Dose Rate	Transferability	Field	Contact	Other Distance	Other Measurement
	#	#	#	#	#	T#	F#	C#	D#	O#

- - - - - - - - - - (designation inside) - - - - - - - - - - Radiological Area Boundary

Note: Dose Rates in mrem/hr unless otherwise noted.

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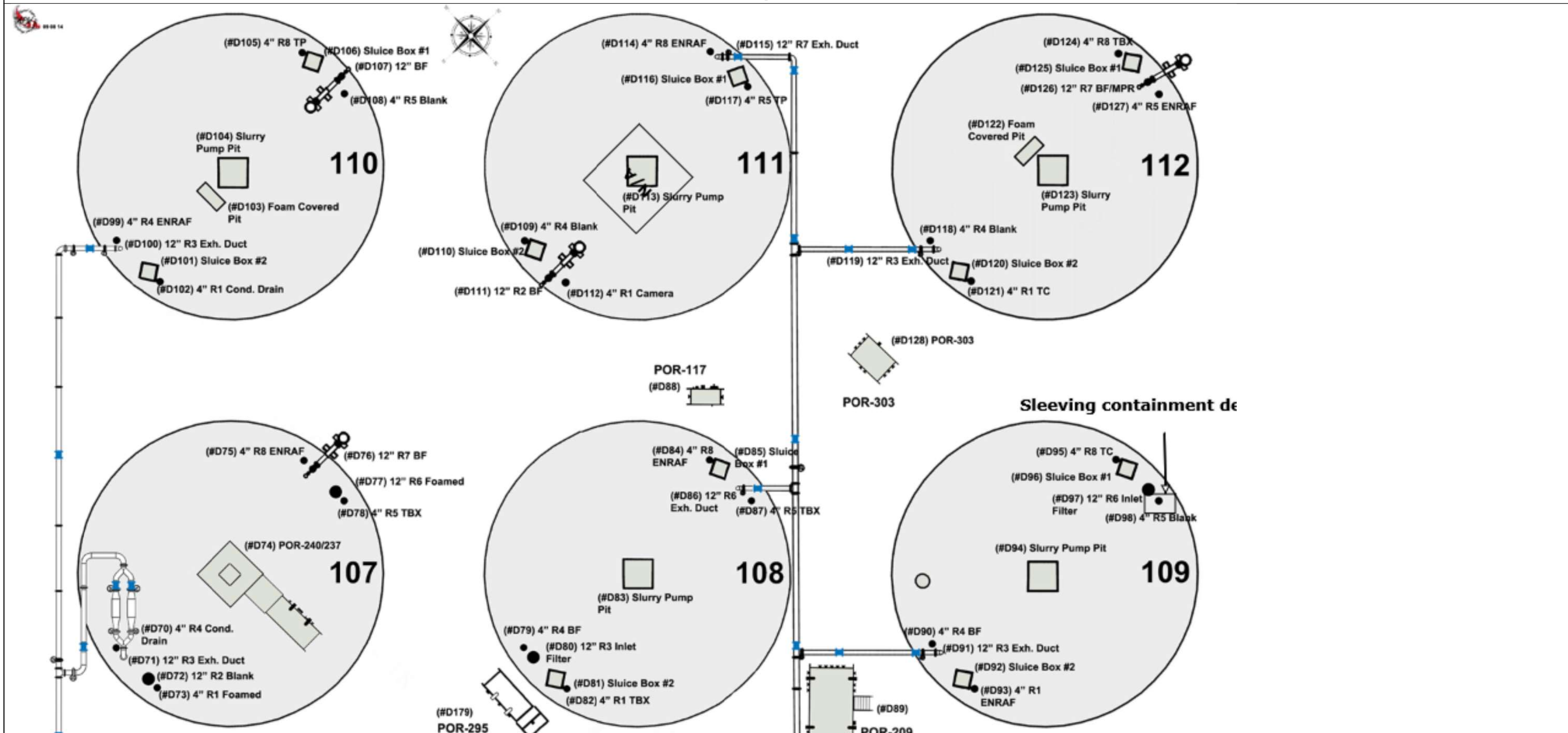
Map/Sketch



Map Name: W-040	Map Description: Tanks 7-12									
Legend	Direct Measurement [#]	Air Sample (triangle #)	Smear (circle #)	LAW L#	Neutron Dose Rate (diamond #)	Transferability T#	Field F#	Contact C#	Other Distance D#	Other Measurement O#
	- - - - - - - - - - (designation inside) - - - - - - - - - - Radiological Area Boundary							Note: Dose Rates in mrem/hr unless otherwise noted.		

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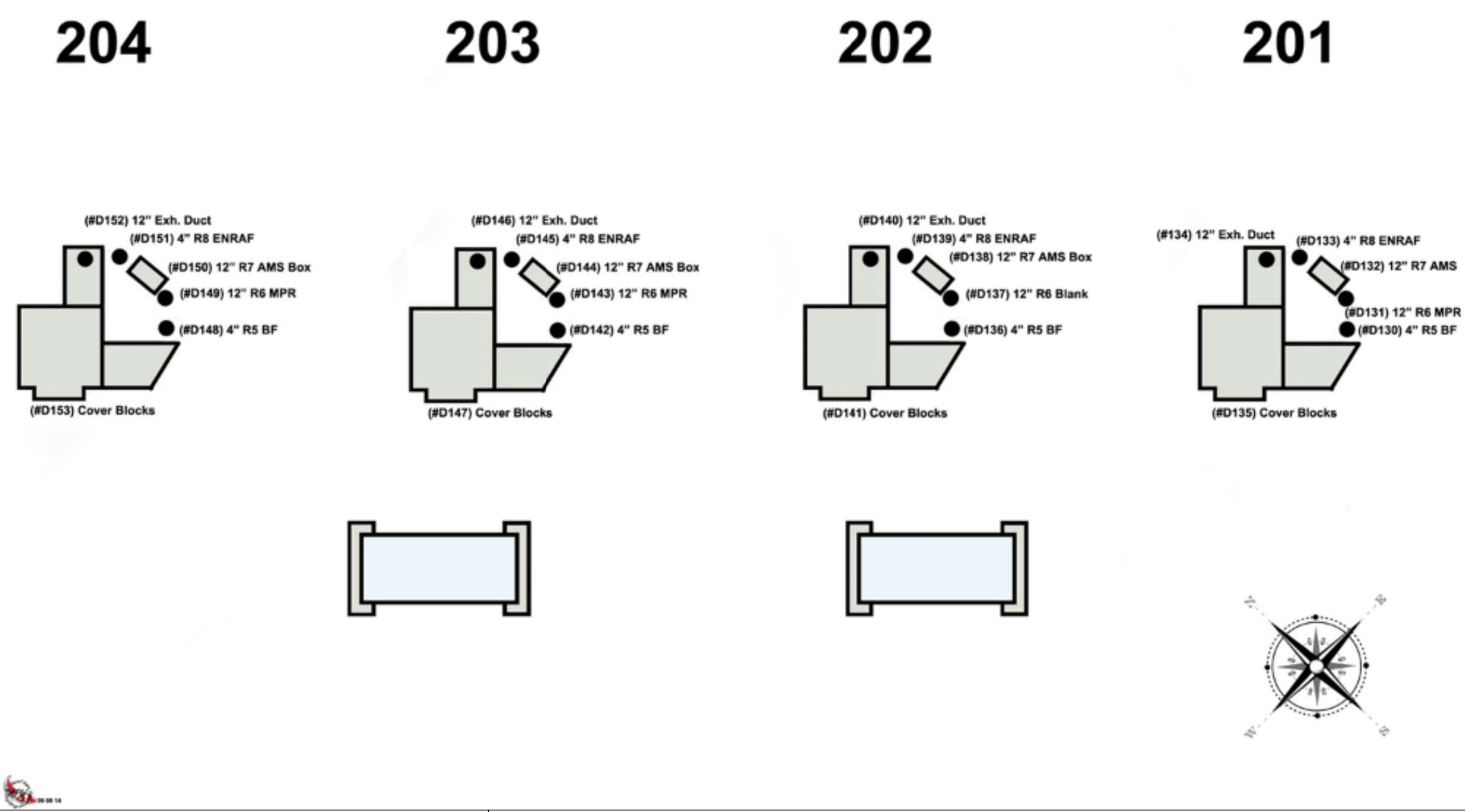
Map/Sketch



Map Name: 200 Series		Map Description: 201-204								
Legend	Direct Measurement #	Air Sample #	Smear #	LAW #	Neutron Dose Rate #	Transferability T#	Field F#	Contact C#	Other Distance D#	Other Measurement O#
	- - - - - - - - - - (designation inside) - - - - - - - - - - Radiological Area Boundary							Note: Dose Rates in mrem/hr unless otherwise noted.		

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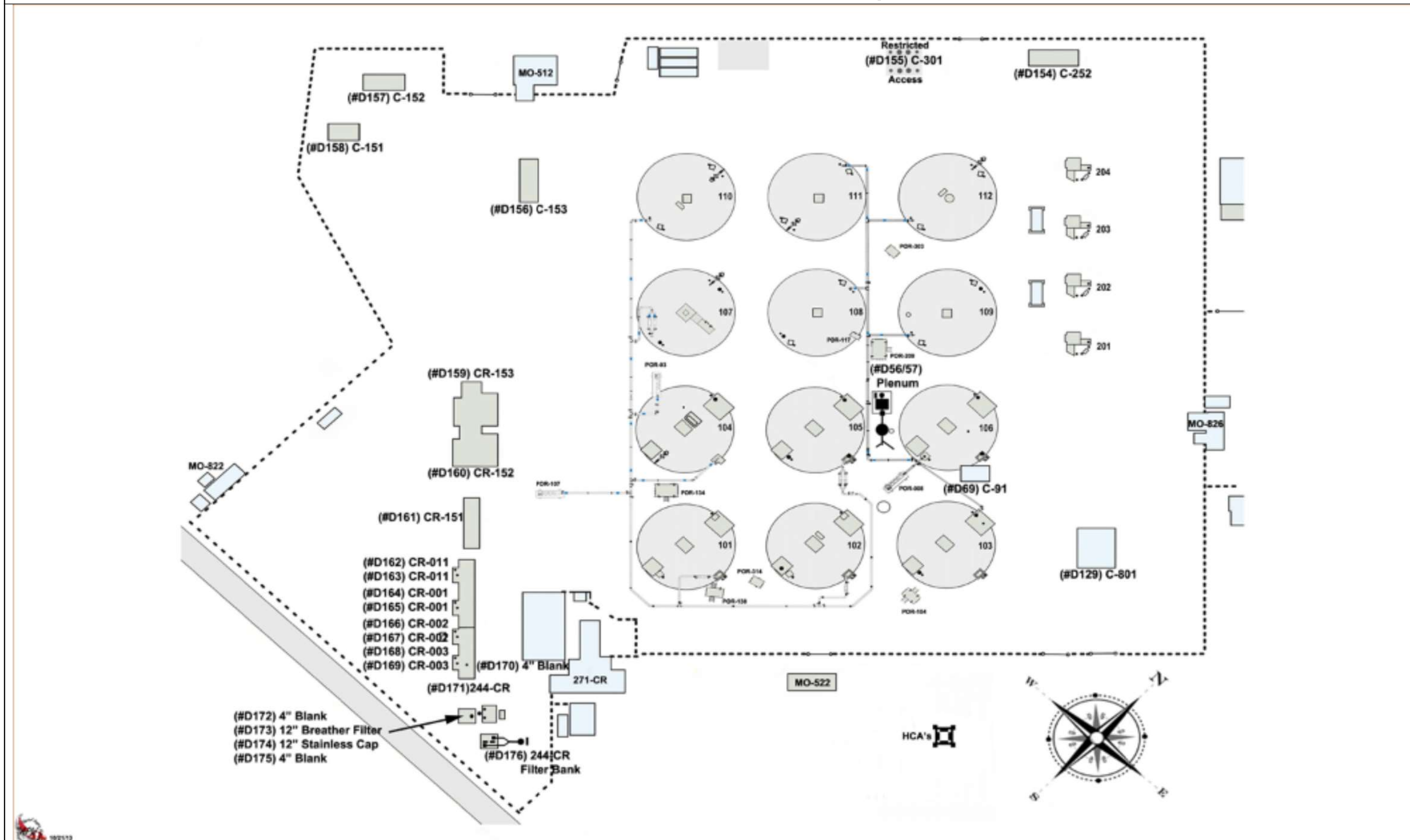
Map/Sketch



Map Name: 241-C			Map Description: Overview							
Legend	Direct Measurement #	Air Sample #	Smear #	LAW #	Neutron Dose Rate #	Transferability T#	Field F#	Contact C#	Other Distance D#	Other Measurement O#
	- - - - - - - - - - (designation inside) - - - - - - - - - - Radiological Area Boundary							Note: Dose Rates in mrem/hr unless otherwise noted.		

Instruments

Instrument Type	Bar Code No.	Probe Bar Code No.	Efficiency (Used)	Due Date
RO-20	ICEB9-0175	N/A	N/A	N/A
RO-20	ICEB9-0189	N/A	N/A	N/A

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History
2/1/2018 2:14:33 PM - Name Redacted - Submitted: 2/6/2018 1:14:16 PM - Name Redacted - Final Approval:

User:
Title: Owner
Date: Thursday, February 01, 2018, 2:14 PM Pacific Standard Time
==
User:
Title: Contributor
Date: Tuesday, February 06, 2018, 11:30 AM Pacific Standard Time
==
User:
Title: Contributor
Date: Monday, February 05, 2018, 6:28 AM Pacific Standard Time
==

User:
Title: Contributor
Date: Thursday, February 01, 2018, 2:48 PM Pacific Standard Time
==

User:
Title: Reviewer
Date: 2/6/2018 1:14:16 PM Pacific Standard Time
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