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UNREVIEWED DISPOSAL QUESTION EVALUATION: Disposal of the Idaho National Laboratory Waste Associated with the Unirradiated Light Water Breeder Reactor at the Area 5 Radioactive Waste Management Site, Nevada National Security Site, Nye County, Nevada

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Prepared by

Mission Support and Test Services, LLC
Las Vegas, Nevada

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Prepared by: Dawn N. Reed Digitally signed by Dawn N. Reed Date: 2018.02.07 16:21:11 -08'00' Date: 2/7/2018

Dawn Reed
Senior Scientist

Reviewed by: Gregory J. Shott Digitally signed by Gregory J. Shott Date: 2018.02.07 16:00:53 -08'00' Date: 2/7/2018

Gregory Shott
Principal Scientist

Approved by: Gregory J. Shott Digitally signed by Gregory J. Shott Date: 2018.02.07 16:01:09 -08'00' Date: 2/7/2018

Gregory Shott
Principal Scientist

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Acronyms and Abbreviations

BN	Bechtel Nevada
Bq	becquerel
Bq m^{-3}	becquerel per cubic meter
Bq m^{-2} s^{-1}	becquerel per square meter per second
DOE	U.S. Department of Energy
FY	(Federal) fiscal year
GSD	geometric standard deviation
INL	Idaho National Laboratory
LHS	Latin hypercube sample
LWBR	Light Water Breeder Reactor
m	meter(s)
m^3	cubic meter(s)
mSv	millisievert(s)
NNSA/NFO	U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office
NNSS	Nevada National Security Site
PA	Performance Assessment
Rn	radon
RWMS	Radioactive Waste Management Site
SLB	shallow land burial
SOFs	sum of fractions
TED	total effective dose
Th	thorium
U	uranium
UDQE	unreviewed disposal question evaluation
WAC	Waste Acceptance Criteria
WARP	Waste Acceptance Review Panel
y	years

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1.0 Executive Summary

This Unreviewed Disposal Question Evaluation (UDQE) assesses whether the Idaho National Laboratory (INL) Waste Associated with the Unirradiated Light Water Breeder Reactor (LWBR) waste stream (INL167203QR1, Revision 1 [INL 2017]) is suitable for shallow land burial (SLB) at the Area 5 Radioactive Waste Management Site (RWMS) on the Nevada National Security Site (NNSS). Disposal of the INL Waste Associated with Unirradiated LWBR waste stream meets all U.S. Department of Energy (DOE) Manual DOE M 435.1-1, *Radioactive Waste Management Manual*, Chapter IV, Section P performance objectives (DOE 1999). The INL Waste Associated with Unirradiated LWBR is recommended for acceptance with the condition that the total waste stream ^{233}U activity not exceed 2.6E13 Bq.

2.0 Introduction

This UDQE addresses disposal of the INL Waste Associated with Unirradiated LWBR at the Area 5 RWMS on the NNSS. The waste stream requires a UDQE because the activity concentrations of thorium-229 (^{229}Th), ^{230}Th, ^{232}Th, uranium-232 (^{232}U), ^{233}U and ^{234}U exceed the NNSS Waste Acceptance Criteria (WAC) Action Levels (U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office [NNSA/NFO] 2016).

3.0 Analysis of Performance

The UDQE addresses the long-term performance of the Area 5 RWMS with the INL Waste Associated with the Unirradiated LWBR waste stream disposed in a SLB disposal cell.

3.1 Waste Description

The INL Waste Associated with the Unirradiated LWBR waste stream consists of pellet scrap, pellet powder, solidified pellet-grinding sludge, solidified neutralized laboratory solutions, metallurgical mounts, and miscellaneous debris produced during processing and analysis of unirradiated ^{233}U LWBR fuel pellets (INL 2017). The LWBR fuel pellets were a high-fired ceramic material manufactured from uranium oxide UO_2)/thorium oxide (ThO_2) or UO_2/zirconium oxide (ZrO_2) mixtures.

The INL Waste Associated with Unirradiated LWBR waste stream radionuclide activities are assumed to be lognormally distributed. The geometric mean of the distribution is assumed to be the product of the representative activity concentration and the total remaining volume, 132 cubic meters (m^3), as reported on the waste profile (INL 2017, Section D.5) (Table 1).

Table 1. INL Waste Associated with Unirradiated LWBR Geometric Mean (GM) Inventory and Geometric Standard Deviation (GSD) at Time of Disposal (from INL 2017)

Nuclide	GM Concentration (Bq m^{-3})	95th Percentile Concentration (Bq m^{-3})	GM Activity (Bq)	95th Percentile Activity (Bq)	GSD
^{227}Ac	5.0E+04	2.0E+06	6.6E+06	2.6E+08	9.35
^{210}Pb	4.0E+05	4.0E+06	5.3E+07	5.3E+08	4.04
^{239}Pu	3.0E+09	8.0E+09	4.0E+11	1.1E+12	1.81
^{226}Ra	2.0E+06	1.0E+07	2.6E+08	1.3E+09	2.65
^{229}Th†	7.3E+08	1.5E+09	9.6E+10	2.0E+11	1.56
^{230}Th	2.0E+08	1.0E+09	2.6E+10	1.3E+11	2.65
^{232}Th	2.0E+10	3.5E+10	2.6E+12	4.6E+12	1.40
^{232}U	4.4E+11	1.9E+12	5.8E+13	2.5E+14	2.43
^{233}U†	2.0E+11	4.1E+11	2.6E+13	5.4E+13	1.54
^{234}U	3.0E+11	3.0E+12	4.0E+13	4.0E+14	4.04
^{235}U	1.0E+08	4.0E+09	1.3E+10	5.3E+11	9.35
^{236}U	5.0E+07	5.0E+08	6.6E+09	6.6E+10	4.04
^{238}U	6.0E+08	2.0E+10	7.9E+10	2.6E+12	8.37

† - Based on generator estimate provided in response to comments.

The high activity concentration is assumed to be the 95th percentile of the lognormal distribution. The geometric standard deviation of the lognormal distribution is calculated as:

$$GSD = e^{\frac{\ln(UL) - \ln(GM)}{1.65}}$$

where

GSD	=	geometric standard deviation (dimensionless)
UL	=	95th percentile activity, Bq
GM	=	geometric mean, Bq

The ^{229}Th and ^{233}U geometric mean and 95th percentile activity are based on a response to comments provided by the generator (Gerard 2017).

The INL Waste Associated with Unirradiated LWBR, revision 1, required a UDQE due to ^{229}Th, ^{230}Th, ^{232}Th, ^{232}U, ^{233}U, and ^{234}U exceeding the WAC action levels. Disposal of the total waste stream inventory would cause large relative increases in the ^{232}Th, ^{232}U, ^{233}U, and ^{234}U SLB inventory (Table 2). The Area 5 RWMS SLB SOFs will increase from 0.89 to 0.91 with the addition of the waste stream activity.

Table 2. Expected Increase in the Disposed Inventory of Radionuclides Exceeding their Action Levels and the Area 5 RWMS SOFs at Closure (10/1/2028)

Nuclide	FY 2017 SLB Disposed Geometric Mean Inventory	Geometric Mean INL167203QR1_1 Inventory	Relative Percent Change
^{229}Th	6.5E+11 Bq	9.6E+10 Bq	15
^{230}Th	7.2E+11 Bq	2.6E+10 Bq	3.6
^{232}Th	7.7E+11 Bq	2.6E+12 Bq	3.4E+2
^{232}U	2.5E+12 Bq	5.8E+13 Bq	2.3E+3
^{233}U	1.4E+14 Bq	2.6E+13 Bq	1.9E+1
^{234}U	1.9E+14 Bq	4.0E+13 Bq	2.1E+1
SLB SOFs	0.89	0.91	2.4

The INL Waste Associated with Unirradiated LWBR waste stream maximum activity occurs at closure when ^{232}U and its progeny are present (Figure 1). A second smaller peak in total activity occurs around 110,000 years as the progeny of ^{234}U approach secular equilibrium. The ^{229}Th activity reaches a peak at 35,000 years. The maximum effect of the INL Waste Associated with the Unirradiated LWBR waste stream should occur within 150,000 years of closure.

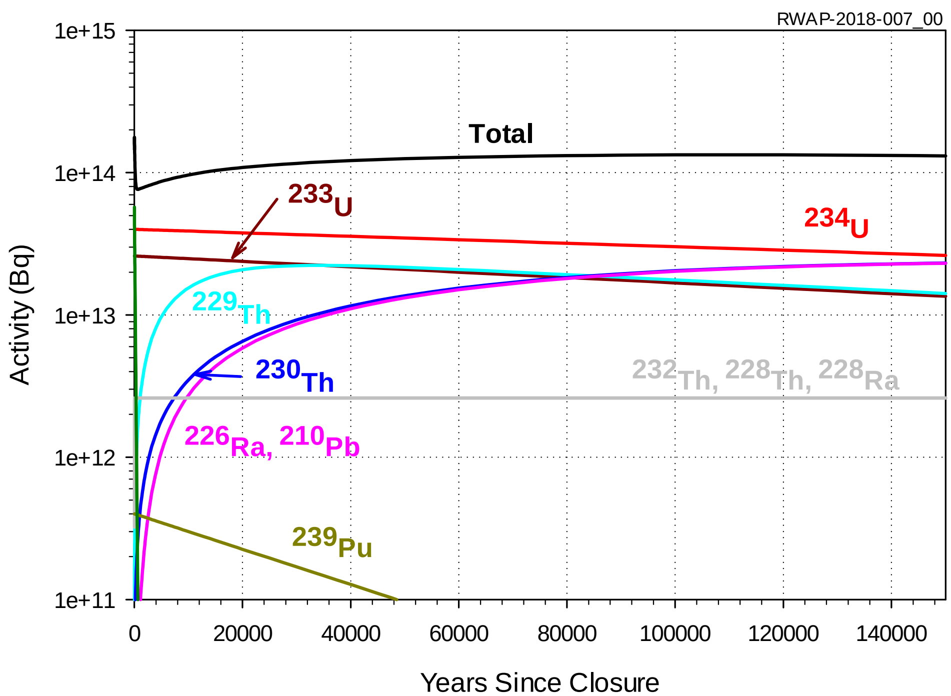

Figure 1. Activity Time Series of the INL Waste Associated with LWBR Waste Stream

3.2 Performance Assessment Modeling

The PA modeling adds the inventory of the INL Waste Associated with the Unirradiated LWBR waste stream to the Area 5 RWMS v4.201 model and determines if there is a reasonable expectation of meeting the DOE Manual DOE M 435.1-1, *Radioactive Waste Management Manual*, Chapter IV, Section P performance objectives (DOE 1999). The PA model evaluates the INL Waste Associated with Unirradiated LWBR waste stream radionuclide activity added to the inventory of post-1988 SLB waste disposed through FY 2017. The UDQE inventory also includes the Pit 6, Pit 13, and post-1988 Greater Confinement Disposal borehole inventories. The model is run with a 2.5-meter (m) closure cover for SLB disposal units.

The mean and median model results are calculated using 5,000 Latin hypercube samples (LHS). A sample size of 5,000 provides stable estimates of the mean and 95th percentile results of the PA model (Bechtel Nevada [BN] 2006). A reasonable expectation of compliance with the performance objectives is assumed if the mean and median are less than the performance objectives for 1,000 years after closure. In every case, the mean was greater than the median. The UDQE only reports the mean results.

For comparison purposes, baseline results are obtained by running the model with the inventory disposed through FY 2017 and without the INL Waste Associated with Unirradiated LWBR waste stream.

4.0 Results and Interpretation

4.1 Performance Assessment Results

4.1.1 Air Pathway Results

The air pathway annual total effective dose (TED) is evaluated for the resident exposure scenario using 5,000 LHS realizations. The resident exposure scenario estimates the dose to an adult residing in a home at the 100-m Area 5 RWMS boundary. A complete description of the exposure scenario can be found in the earlier PA documentation (BN 2006).

The annual TED is calculated for a period of 1,000 years after closure. The maximum mean and 95th percentile annual TED occur at 1,000 years and are both less than the 0.1 millisievert (mSv) limit (Table 3). Addition of the INL Waste Associated with Unirradiated LWBR waste stream increases the air pathway annual TED.

Table 3. Maximum Air Pathway Annual TED for a Resident at the Area 5 RWMS 100-m Site Boundary and the Waste Inventory Disposed through FY 2017

Scenario	Time of Maximum†	Mean (mSv)	95th Percentile (mSv)
Resident without INL167203QR1_1 Waste Stream	1,000 y	1.8E-4	6.1E-4
Resident with INL167203QR1_1 Waste Stream	1,000 y	2.1E-4	7.0E-4

† - years after closure

Addition of the INL Waste Associated with Unirradiated LWBR waste stream increases the air pathways mean annual TED slightly at closure, and it decreases thereafter (Figure 2). The largest relative increase in the mean, 26%, occurs at 160 years.

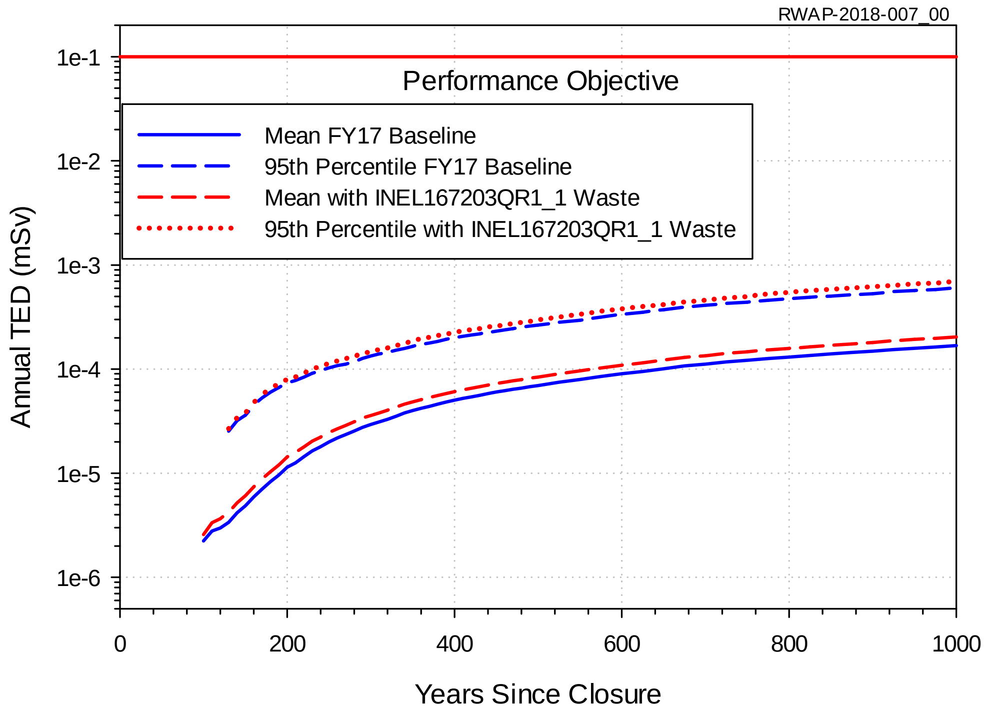

Figure 2. Air Pathway Annual TED Time History for a Resident at the 100-m Boundary with and without the INL167203QR1_1 Waste Stream

4.1.1.1 Alternative Air Pathway Scenarios

Uncertainty contributed by the selected exposure scenario was evaluated by calculating the air pathway annual TED for alternative scenarios. The scenarios evaluated are the transient occupancy scenario, the resident with agriculture scenario, and open rangeland scenarios for a ranch at two plausible locations: one at the NNSS boundary closest to the Area 5 RWMS and another at Cane Spring. The scenarios and their assumptions are described in the PA (BN 2006).

The maximum of the mean and the 95th percentile TEDs are all less than the performance objective for all of the alternative scenarios (Table 4). Although the exposure scenario is a source of uncertainty, there is a high likelihood of compliance for a range of reasonable scenarios. Addition of the INL Waste Associated with Unirradiated LWBR waste stream increases the maximum result for all scenarios.

Table 4. Maximum Air Pathway Annual TEDs for Alternative Scenarios with the FY 2017 Inventory

Scenario	Inventory	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Transient Occupancy	FY 2017 Baseline Inventory	1,000 y	7.2E-5	2.5E-4
	FY 2017 with INL167203QR1_1	1,000 y	8.3E-5	2.8E-4
Resident with Agriculture	FY 2017 Baseline Inventory	1,000 y	3.9E-4	1.3E-3
	FY 2017 with INL167203QR1_1	1,000 y	4.4E-4	1.5E-3
Open Rangeland/ Cane Spring	FY 2017 Baseline Inventory	1,000 y	5.9E-9	1.4E-8
	FY 2017 with INL167203QR1_1	1,000 y	6.7E-9	1.7E-8
Open Rangeland/ NNSS Boundary	FY 2017 Baseline Inventory	1,000 y	1.0E-7	2.4E-7
	FY 2017 with INL167203QR1_1	1,000 y	1.1E-7	2.8E-7

4.1.1.2 Long-Term Air Pathway Performance

The inventory of the INL Waste Associated with Unirradiated LWBR is expected to increase beyond 1,000 years as ^{233}U and ^{234}U progeny are produced by serial radioactive decay. The model duration was increased to 10,000 years to evaluate long-term performance.

Over a 10,000-year period the maximum air pathway annual TED occurs at 10,000 years (Table 5). Addition of the INL Waste Associated with Unirradiated LWBR increases the maximum annual TED approximately 20%, but the mean and 95th percentile remain less than the performance objective.

Table 5. Maximum Air Pathway Annual TED over 10,000 years for a Resident at the Area 5 RWMS 100 m Site Boundary with the Waste Inventory Disposed through FY 2017

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Resident without INL167203QR1_1 Waste Stream	10,000 y	2.3E-3	8.1E-3
Resident with INL167203QR1_1 Waste Stream	10,000 y	2.8E-3	9.7E-3

The INL Waste Associated with Unirradiated LWBR increases the air pathway annual TED throughout the 10,000 year period (Figure 3). The maximum relative increase of approximately 20% occurs at 10,000 years.

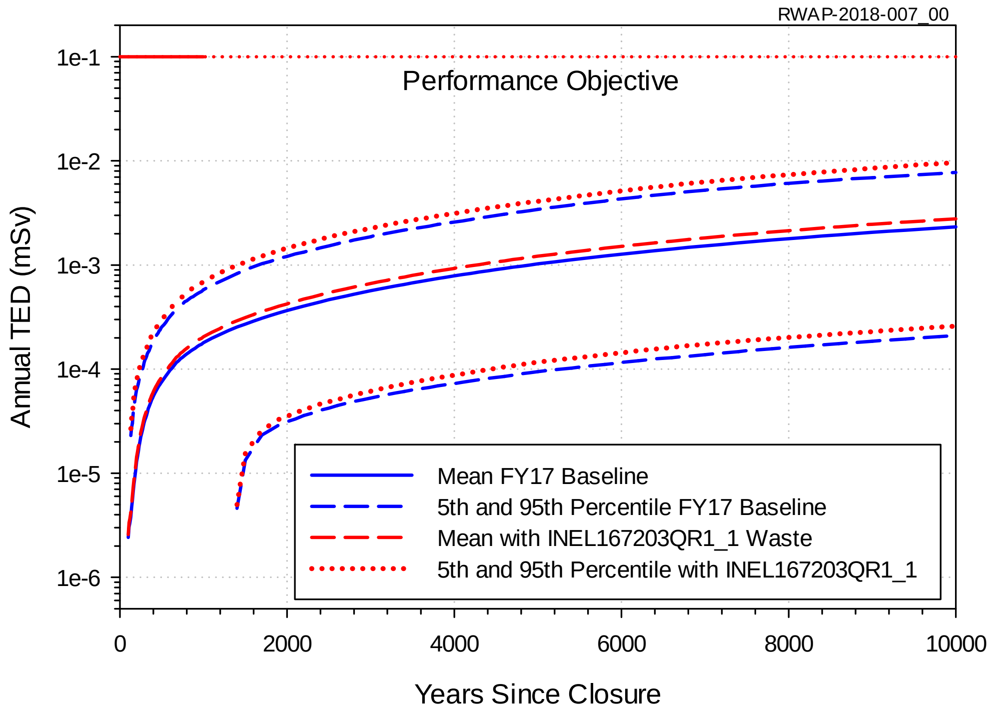

Figure 3. Air Pathway Annual TED 10,000 Year Time History for a Resident at the 100-m Boundary with and without the INL167203QR1_1 Waste Stream

4.1.2 All-Pathways Results

The all-pathways annual TED is also calculated for the resident exposure scenario. The maximum mean and 95th percentile resident all-pathways annual TEDs are less than the 0.25 mSv limit (Table 6). Addition of the INL Waste Associated with Unirradiated LWBR waste stream increases the maximum resident all-pathways annual TED.

Table 6. Maximum All-Pathways Annual TED for a Resident at the Area 5 RWMS 100-m Site Boundary and the Waste Inventory Disposed through FY 2017

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Resident without INL167203QR1_1 Waste Stream	1,000 y	1.1E-3	2.8E-3
Resident with INL167203QR1_1Waste Stream	1,000 y	1.3E-3	3.6E-3

Addition of the INL Waste Associated with Unirradiated LWBR waste stream increases the all-pathways TED throughout the compliance period. The maximum increase in the all-pathways annual TED, 20%, occurs at 1,000 years (Figure 4).

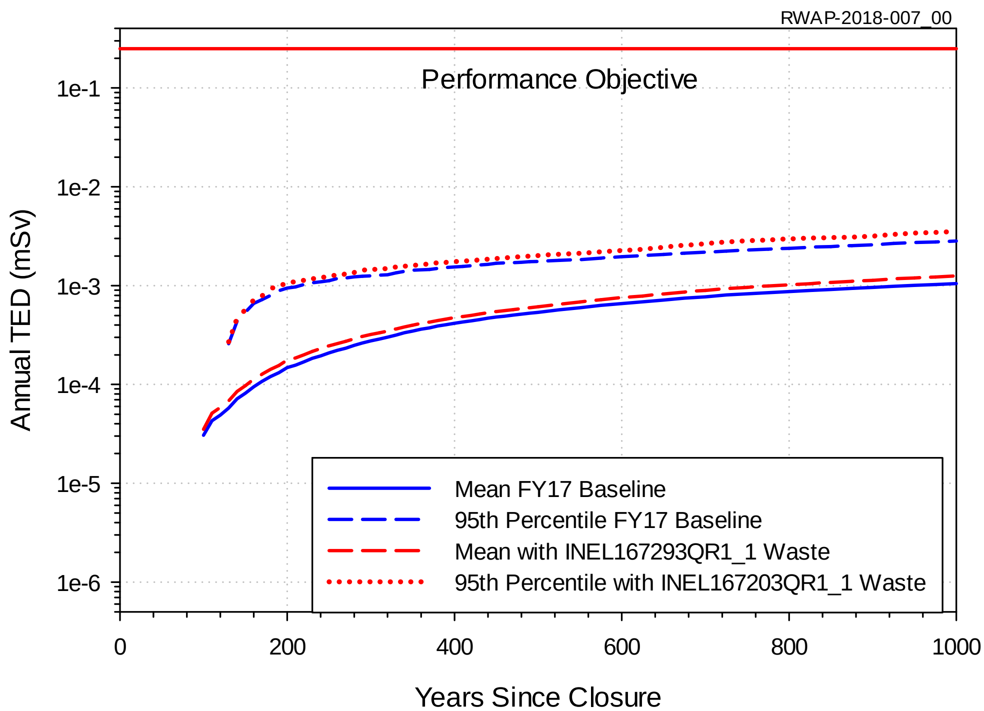

Figure 4. All-Pathways Annual TED Time History for a Resident at the 100-m Boundary with and without INL167203QR1_1 Waste Stream

4.1.2.1 Alternative All-Pathways Scenarios

Uncertainty contributed by the selected exposure scenarios was evaluated by calculating the all-pathways annual TED for alternative scenarios. The scenarios evaluated are the transient occupancy scenario, the resident with agriculture scenario, and open rangeland scenarios for a ranch with two plausible exposure locations: one at the NNSS boundary closest to the Area 5 RWMS and another at Cane Spring. The scenarios and their assumptions are described in the PA (BN 2006).

The mean and 95th percentile all-pathways annual TEDs are all less than the performance objective for all alternative scenarios (Table 7). Although the exposure scenario is a source of uncertainty, there is a high likelihood of compliance for a range of reasonable scenarios. Addition of the INL Waste Associated with Unirradiated LWBR waste stream has no significant effect on the maximum annual TED for all scenarios, except transient occupancy.

Table 7. Maximum All-Pathways Annual TEDs for Alternative Scenarios

Scenario	Inventory	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Transient Occupancy	FY 2017 Baseline Inventory	1,000 y	6.6E-3	1.6E-2
	FY 2017 with INL167203QR1_1	1,000 y	7.4E-3	1.8E-2
Resident with Agriculture	FY 2017 Baseline Inventory	1,000 y	2.6E-2	8.4E-2
	FY 2017 with INL167203QR1_1	1,000 y	2.7E-2	8.5E-2
Open Rangeland/ Cane Spring	FY 2017 Baseline Inventory	1,000 y	4.5E-3	1.5E-2
	FY 2017 with INL167203QR1_1	1,000 y	4.5E-3	1.5E-2
Open Rangeland/ NNSS Boundary	FY 2017 Baseline Inventory	1,000 y	4.7E-3	1.6E-2
	FY 2017 with INL167203QR1_1	1,000 y	4.7E-3	1.6E-2

4.1.2.2 Long-Term All-Pathways Performance

Over a 10,000-year period the maximum all-pathways annual TED occurs at 10,000 years (Table 8). Addition of the INL Waste Associated with Unirradiated LWBR increases the annual TED, but the mean and 95th percentile remain less than the performance objective.

Table 8. Maximum All-Pathways Annual TED over 10,000 years for a Resident at the Area 5 RWMS 100 m Site Boundary with the Waste Inventory Disposed through FY 2017

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Resident without INL167203QR1_1 Waste Stream	10,000 y	1.3E-2	3.7E-2
Resident with INL167203QR1_1 Waste Stream	10,000 y	1.7E-2	5.3E-2

The INL Waste Associated with Unirradiated LWBR increases the all-pathways annual TED throughout the 10,000-year period (Figure 5). The maximum relative increase of approximately 35% occurs at 10,000 years.

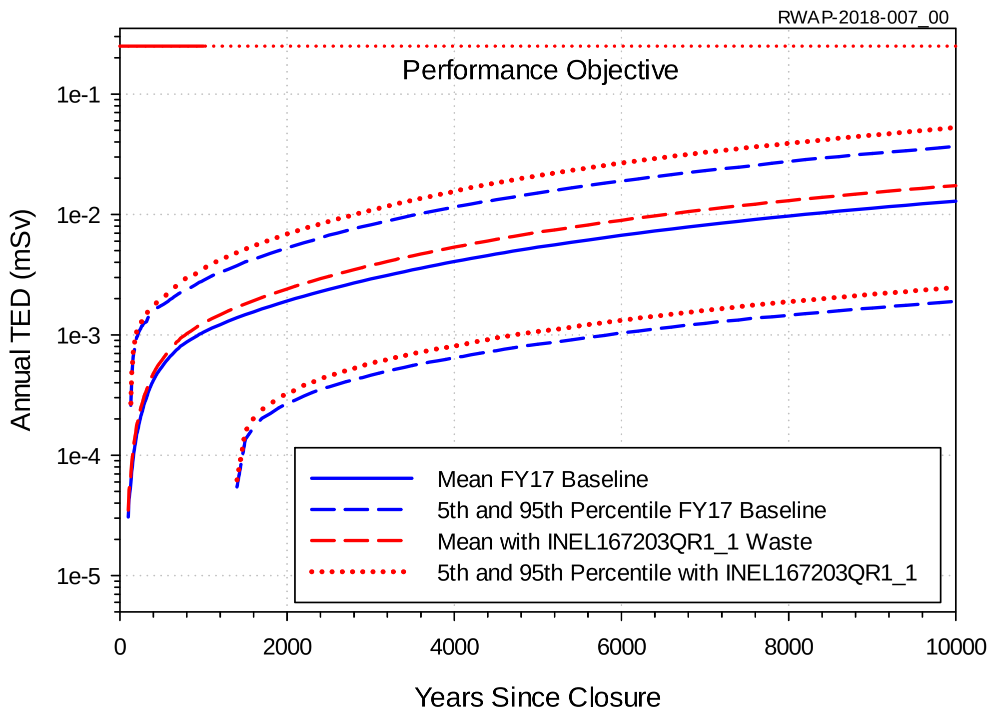

Figure 5. All-Pathways Annual TED 10,000 Year Time History for a Resident at the 100-m Boundary with and without the INL167203QR1_1 Waste Stream

The model duration was increased to 150,000 years to search for peak doses from the INL Waste Associated with Unirradiated LWBR. Model results for such a long time period are considered highly uncertain as many model assumptions likely become invalid as time increases. The model was run deterministically to obtain the 150,000-year results.

The annual all-pathways TED with the INL Waste Associated with Unirradiated LWBR waste stream increases throughout the 150,000 year period with the maximum occurring at 150,000 (Figure 6). The maximum annual TED is less than the 0.25 mSv performance objective throughout the period.

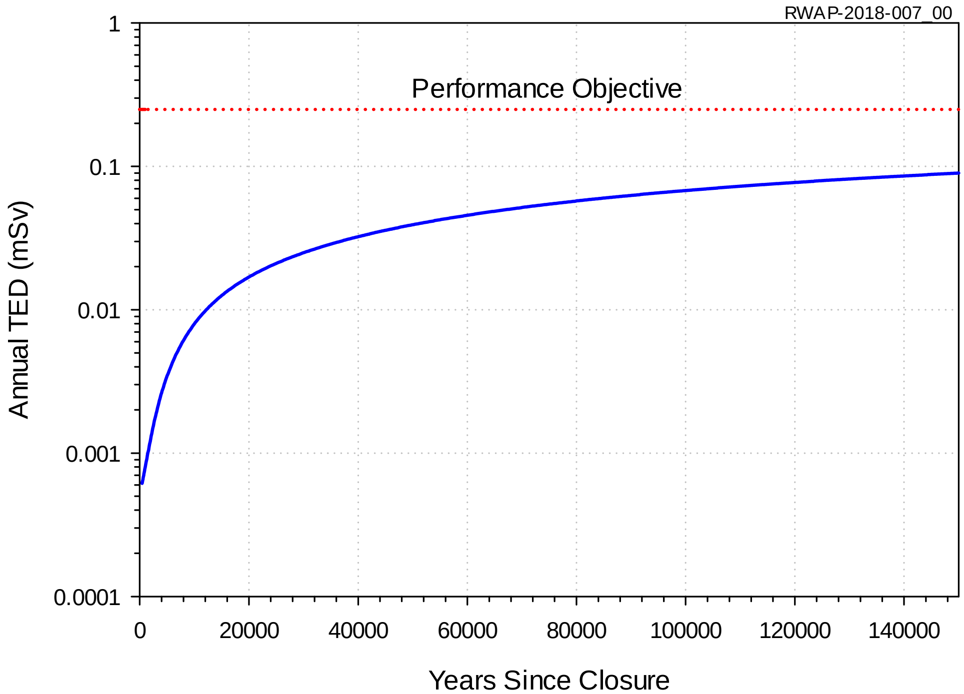

Figure 6. All-Pathways Annual TED 150,000 Year Time History for a Resident at the 100-m Boundary with and without the INL167203QR1_1 Waste Stream

4.1.3 Intruder Results

Intruder results are evaluated for acute intruder scenarios only. NNSA/NFO institutional control policy is to maintain and enforce use restrictions (NNSA/NFO 2015). The proposed land-use restrictions are assumed to eliminate the possibility of chronic intrusion for 1,000 years.

The acute drilling scenario estimates the TED to a drill crew drilling a water well through a disposal unit. Exposure to contaminated drill cuttings occurs while augering a surface casing for the well. The acute construction scenario estimates the dose to construction workers building a residence on a disposal unit. Construction workers are exposed to waste exhumed from the construction excavation.

The maximum mean acute intruder TEDs occur at 1,000 years and are less than the 5 mSv performance measure for both the drilling and construction acute intrusion scenarios (Table 9). Addition of the INL Waste Associated with Unirradiated LWBR waste stream increases the maximum acute construction intruder scenario mean results occurring at 1,000 years.

Table 9. Maximum TED for Acute Intrusion Scenarios at the Area 5 RWMS and the Waste Inventory Disposed through FY 2017

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Drilling Intruder without INL167203QR1_1	1,000 y	1.4E-3	2.5E-3
Drilling Intruder with INL167203QR1_1	1,000 y	1.8E-3	3.0E-3
Construction Intruder without INL167203QR1_1	1,000 y	1.0	1.8
Construction Intruder with INL167203QR1_1	1,000 y	1.3	2.1

Addition of the INL Waste Associated with Unirradiated LWBR waste stream increases the TED a maximum of 45% at 220 years, and it decreases thereafter (Figure 7).

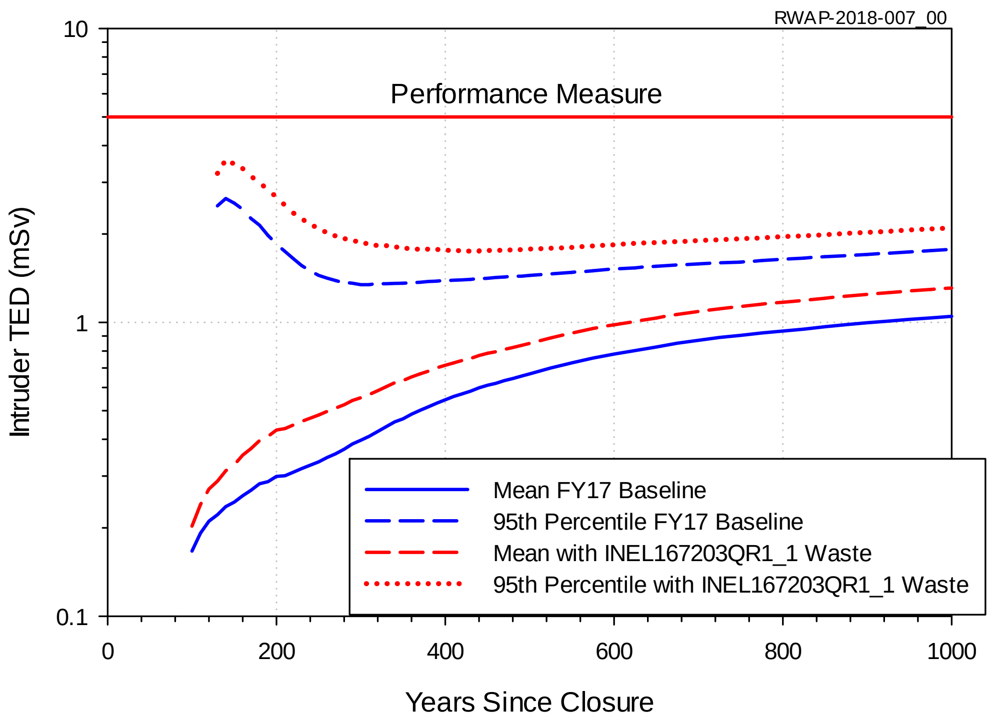

Figure 7. Acute Construction Intrusion Scenario TED Time History with and without the INL167203QR1_1 Waste Stream

4.1.3.1 Long-Term Intruder Results

Over a 10,000-year period the maximum drilling and construction acute intruder TEDs occur at 10,000 years (Table 10). Addition of the INL Waste Associated with Unirradiated LWBR increases the intruder TED, but the mean remains less than the performance measure. The acute construction scenario 95th percentile TED exceeds the performance measure with and without the waste stream.

Table 10. Maximum Intruder TED over 10,000 years at the Area 5 RWMS with the Waste Inventory Disposed through FY 2017

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Drilling Intruder without INL167203QR1_1	10,000 y	7.7E-3	1.4E-2
Drilling Intruder with INL167203QR1_1	10,000 y	1.1E-2	2.2E-2
Construction Intruder without INL167203QR1_1	10,000 y	3.0	5.9
Construction Intruder with INL167203QR1_1	10,000 y	3.6	6.7

4.1.4 ^{222}Rn Flux Density Results

The radon-222 (^{222}Rn) flux density is averaged over the area of all post-1988 disposal units. The maximum mean and 95th percentile ^{222}Rn flux densities occur at 1,000 years and are less than the 0.74 becquerel per square meter per second (Bq m^{-2} s^{-1}) performance objective (Table 11). Addition of the INL Waste Associated with Unirradiated LWBR waste stream slightly increases the maximum ^{222}Rn flux density at 1,000 years. This waste stream does not require an increased depth of burial to attenuate ^{222}Rn flux.

Table 11. Maximum ^{222}Rn Flux Density at the Area 5 RWMS and the Waste Inventory Disposed through FY 2017

Inventory	Time of Maximum	Mean (Bq m^{-2} s^{-1})	95th Percentile (Bq m^{-2} s^{-1})
FY 2017 without INL167203QR1_1	1,000 y	0.23	0.52
FY 2017 with INL167203QR1_1	1,000 y	0.26	0.57

Addition of the INL Waste Associated with Unirradiated LWBR waste stream causes a maximum relative increase of 10% in the ^{222}Rn flux density at 1,000 years, and it decreases thereafter (Figure 8).

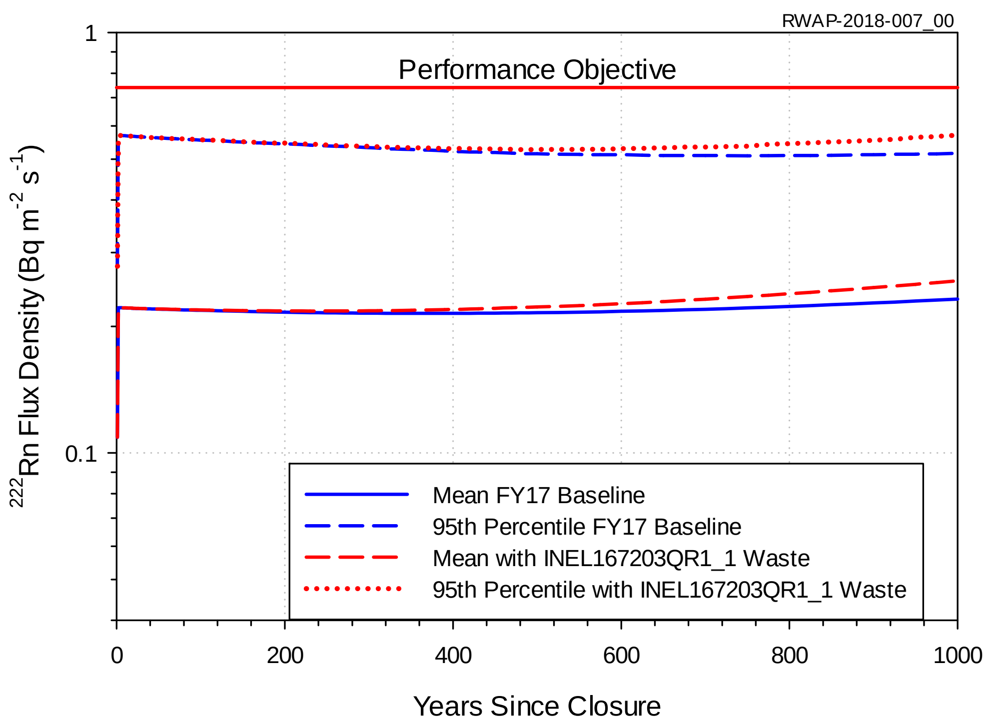

Figure 8. ^{222}Rn Flux Density Time History Averaged Over all Disposal Units with and without the INL167203QR1_1 Waste Stream

4.1.4.1 Long-Term ^{222}Rn Flux Density

Over a 10,000-year period the maximum ^{222}Rn flux density occurs at 10,000 years (Table 12). The mean ^{222}Rn flux density without the INL Waste Associated with Unirradiated LWBR waste stream exceeds the performance objective by 4,700 years. Addition of the INL Waste Associated with Unirradiated LWBR waste stream caused the ^{222}Rn flux density to exceed the performance objective by 3,600 years.

Table 12. Maximum ^{222}Rn Flux Density over 10,000 Years at the Area 5 RWMS with the Waste Inventory Disposed through FY 2017

Scenario	Time of Maximum	Mean (Bq m^{-2} s^{-1})	95th Percentile (Bq m^{-2} s^{-1})
FY 2017 without INL167203QR1_1 Waste Stream	10,000 y	1.8	3.9
FY 2017 with INL167203QR1_1 Waste Stream	10,000 y	2.7	6.5

Addition of the INL Waste Associated with Unirradiated LWBR waste stream increased the ^{222}Rn flux density throughout the 10,000 years (Figure 9). The relative increase increases over time as ^{234}U progeny increase. The maximum increase, approximately 50%, occurs at 10,000 years.

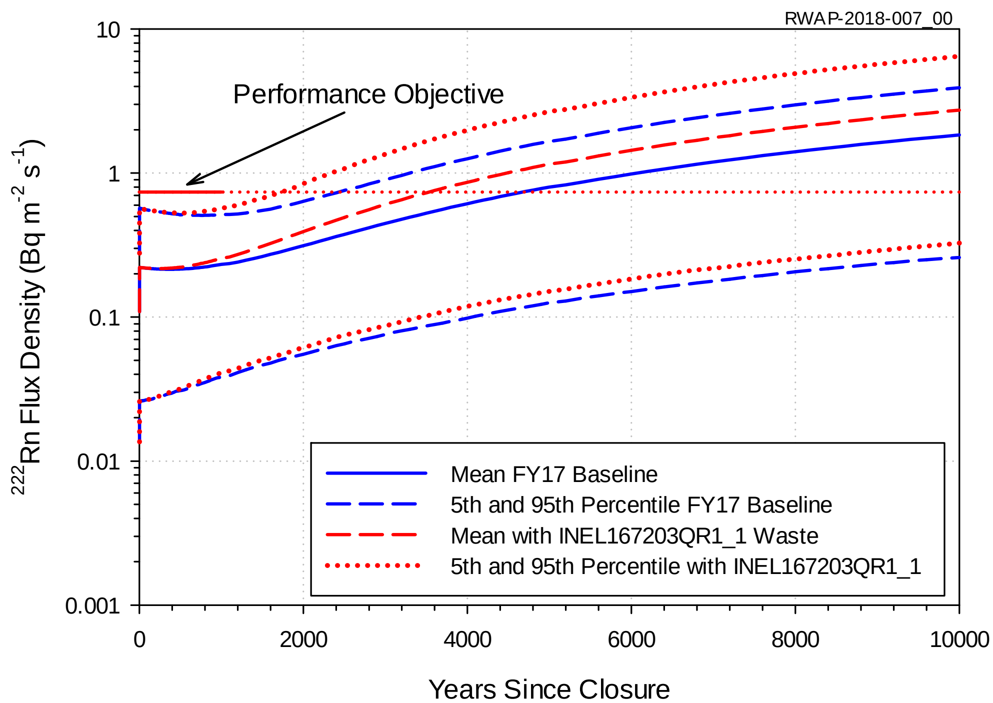

Figure 9. ^{222}Rn Flux Density 10,000 Year Time History Averaged Over all Disposal Units with and without the INL167203QR1_1 Waste Stream

5.0 Conclusions

The effect of adding the INL Waste Associated with Unirradiated LWBR waste stream inventory to the inventory of waste disposed through the end of FY 2017 was evaluated with the Area 5 RWMS v 4.201 PA model. The results indicate that all performance objectives can be met with disposal of the INL Waste Associated with Unirradiated LWBR waste stream in an Area 5 RWMS SLB unit. Addition of the INL Waste Associated with Unirradiated LWBR inventory increases most PA results. All maximum mean and 95th percentile results remain less than their respective performance objectives throughout the 1,000-year compliance period. No result exceeds the Low-Level Radioactive Waste Review Group notification criterion of exceeding 50% of a performance objective. The INL Waste Associated with Unirradiated LWBR waste stream is recommended for acceptance with the condition that the total waste stream ^{233}U activity not exceed 2.6E13 Bq.

6.0 References

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