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Special Analysis for the Disposal of the Idaho National Laboratory Unirradiated Light Water Breeder Reactor Rods and Pellets Waste Stream at the Area 5 Radioactive Waste Management Site, Nevada National Security Site, Nye County, Nevada

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Table of Contents

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1.0 Introduction

The purpose of this special analysis (SA) is to determine if the Idaho National Laboratory (INL) Unirradiated Light Water Breeder Reactor (LWBR) Rods and Pellets waste stream (INEL103597TR2, Revision 2) is suitable for disposal by shallow land burial (SLB) at the Area 5 Radioactive Waste Management Site (RWMS). The INL Unirradiated LWBR Rods and Pellets waste stream consists of 24 containers with unirradiated fabricated rods and pellets composed of uranium oxide (UO_2) and thorium oxide (ThO_2) fuel in zirconium cladding (INL 2014a). The INL Unirradiated LWBR Rods and Pellets waste stream requires an SA because the ^{229}Th, ^{230}Th, ^{232}U, ^{233}U, and ^{234}U activity concentrations exceed the Nevada National Security Site (NNSS) Waste Acceptance Criteria (WAC) Action Levels (U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office [NNSA/NFO] 2013).

2.0 Methods

The SA is performed by adding the inventory of the proposed new or revised waste to the current baseline performance assessment (PA) model and determining if there is a reasonable expectation of meeting the U.S. Department of Energy (DOE) Manual DOE M 435.1-1, "Radioactive Waste Management Manual," Chapter IV, Section P performance objectives (DOE 1999).

2.1 Waste Description

The INL Unirradiated LWBR Rods and Pellets waste stream is an unirradiated nuclear fuel that is no longer needed. It is legally classified as a low-level radioactive waste. The fuel is a high fired ceramic material composed of 3% UO_2 and 97% ThO_2. The long-lived man-made nuclide, ^{233}U, comprises 97% of the uranium. Other radionuclides are present as contaminants (e.g., ^{232}U) and decay products (e.g., ^{229}Th).

The INL Unirradiated LWBR Rods and Pellets waste stream radionuclide inventories are assumed to be lognormally distributed. The geometric mean of the distribution is assumed to be the representative waste stream inventory reported by the generator (INL 2014b) (Table 1).

Table 1. INL Unirradiated LWBR Rods and Pellets waste stream geometric mean inventory and geometric standard deviation (from INEL 2014b)

Nuclide	Upper Limit Inventory (Bq)	Representative Inventory (Bq)	Geometric Standard Deviation
^{239}Pu	1.00E+07	9.82E+06	1.01
^{226}Ra	4.01E+03	3.92E+03	1.01
^{229}Th	3.59E+08	3.51E+08	1.01
^{230}Th	4.63E+05	4.53E+05	1.01
^{232}Th	1.15E+06	1.13E+06	1.01
^{232}U	3.87E+09	3.78E+09	1.01
^{233}U	1.01E+11	9.92E+10	1.01
^{234}U	1.26E+09	1.23E+09	1.01

The generator reported 95th percentile of the inventory is assumed to be the 95th percentile of the assumed lognormal distribution. The geometric standard deviation of the waste stream lognormal distribution was 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 waste stream volume is assumed to be the 10 cubic meters remaining volume reported on the waste profile in Section B.6.

The INL Unirradiated LWBR Rods and Pellets waste stream inventory represents a small fraction of the ^{229}Th, ^{230}Th, ^{232}U, ^{233}U, and ^{234}U inventory already disposed at the Area 5 RWMS (Table 2). The INL Unirradiated LWBR Rods and Pellets ^{233}U inventory represents a 0.08% increase in inventory.

Table 2. Comparison of INL Unirradiated LWBR Rods and Pellets waste stream (INEL103597TR1_2) inventory and the disposed inventory of radionuclides exceeding the action levels

Nuclide	FY 2013 Disposed Post-1988 SLB Geometric Mean Disposed Inventory (Bq)	INL Unirradiated LWBR Rods and Pellets Geometric Mean Inventory (Bq)	% Change
^{229}Th	6.2E+11	3.51E+08	5.7E-02
^{230}Th	3.1E+11	4.53E+05	1.5E-04
^{232}Th	7.6E+11	1.13E+06	1.5E-04
^{232}U	1.9E+12	3.78E+09	2.0E-01
^{233}U	1.3E+14	9.92E+10	7.6E-02
^{234}U	1.6E+14	1.23E+09	7.7E-04

2.2 Model Description

The SA is performed using the baseline PA model that was approved at the time the waste profile was submitted for review. This version, referred to as the A5 RWMS v4.115 GoldSim model, uses the radionuclide inventory disposed through fiscal year (FY) 2013 (National Security Technologies, LLC, 2014). The A5 RWMS v4.115 GoldSim model is the result of multiple cycles of internal and external peer review (Shott et al. 1998; Bechtel Nevada [BN] 2006). The model is subject to annual review and updating. Baseline model releases are reviewed and approved by NNSA/NFO prior to use.

The SA is performed by adding the INL Unirradiated LWBR Rods and Pellets waste stream radionuclide inventory to the inventory of post-1988 SLB radionuclides disposed through FY 2013. In addition to the SLB inventory, the SA includes the Pit 6, Pit 13, and post-1988 Greater Confinement Disposal borehole inventories. The model is run with a 2.5-meter (m) (8.2-foot [ft]) 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 has been previously shown to provide stable estimates of the mean and 95th percentile results for earlier version of the PA model (BN 2006). A reasonable expectation of compliance with the performance objectives is assumed if the mean and median are less than the performance objectives. In every case, the mean was greater than the median. Only the mean results are reported in the SA.

For comparison purposes, baseline results are obtained by running the model with FY 2013 disposed inventory and without the INL Unirradiated LWBR Rods and Pellets waste stream.

To assess the long-term performance of the INL Unirradiated LWBR Rods and Pellets waste stream, a deterministic model run with a duration of 60,000 years was prepared.

3.0 Results

3.1 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 (330 ft) site boundary. A complete description of the exposure scenario can be found in PA documentation (BN 2006). The annual TED is calculated for a period of 1,000 years (y) 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 Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the resident air pathway results.

Table 3. Maximum air pathway annual TED for a resident at the Area 5 RWMS 100 m (330 ft) site boundary and the waste inventory disposed through FY 2013

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Resident without INEL103597TR1_2 Waste Stream	1,000 y	1.6E-4	5.6E-4
Resident with INEL103597TR1_2 Waste Stream	1,000 y	1.6E-4	5.6E-4

3.1.1 Alternative Air Pathway Scenarios

Uncertainty contributed by the selected exposure scenario was evaluated by calculating air pathway annual TED for alternative scenarios. The scenarios evaluated are the transient occupancy scenario, the resident farmer scenario, and the open rangeland scenario for a ranch at the nearest NNSS boundary and at Cane Spring. The scenarios and their assumptions have been described previously (BN 2006).

The maximum of the mean and 95th percentile 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 Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the alternative scenarios air pathway results.

Table 4. Maximum air pathway annual TED for alternative scenarios with the FY 2013 inventory

Scenario	Inventory	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Transient Occupancy	FY 2013	1,000 y	8.3E-5	3.0E-4
	FY 2013 with INEL103597TR1_2	1,000 y	8.3E-5	3.0E-4
Resident Farmer	FY 2013	1,000 y	4.5E-4	1.6E-3
	FY 2013 with INEL103597TR1_2	1,000 y	4.5E-4	1.6E-3
Open Rangeland/Cane Spring	FY 2013	1,000 y	4.8E-9	1.3E-8
	FY 2013 with INEL103597TR1_2	1,000 y	4.8E-9	1.3E-8
Open Rangeland/NNSS Boundary	FY 2013	1,000 y	8.1E-8	2.3E-7
	FY 2013 with INEL103597TR1_2	1,000 y	8.1E-8	2.3E-7

3.2 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 5). Addition of the INL Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the resident all-pathway annual TED.

Table 5. Maximum all-pathways annual TED for a resident at the Area 5 RWMS 100-m (330-ft) site boundary and the waste inventory disposed through FY 2013

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Resident without INEL103597TR1_2 Waste Stream	1,000 y	8.3E-4	2.6E-3
Resident with INEL103597TR1_2 Waste Stream	1,000 y	8.3E-4	2.6E-3

There are no significant differences between the resident all-pathways annual TED with and without the INL Unirradiated LWBR Rods and Pellets waste stream. Comparison of the means and 95th percentiles indicates they are equivalent throughout the 1,000-year compliance period (Figure 1). The addition of the INL Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the all-pathways resident annual TED.

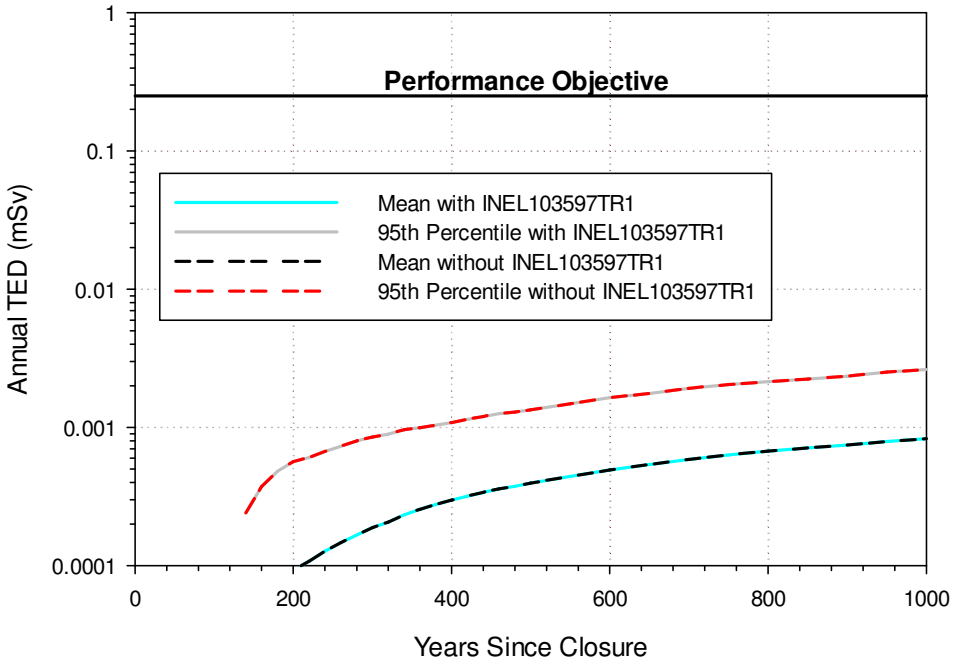

Figure 1. All-pathways annual TED for a resident with and without the INEL103597TR1, Rev. 2, waste stream

3.2.1 All Pathways Uncertainty

Alternative Scenarios

Uncertainty contributed by the selected exposure scenario was evaluated by calculating the all-pathway annual TED for alternative scenarios. The scenarios evaluated are the transient occupancy scenario, the resident farmer scenario, and the open rangeland scenario for a ranch at the nearest NNSS boundary and at Cane Spring. The scenarios and their assumptions have been described previously (BN 2006).

The mean and 95th percentile annual TEDs are all less than the performance objective for all alternative scenarios (Table 6). 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 Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the alternative scenarios all-pathway results.

Table 6. Maximum all-pathway annual TED for alternative scenarios

Scenario	Inventory	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Transient Occupancy	FY 2013	1,000 y	6.5E-3	1.5E-2
	FY 2013 with INEL103597TR1_2	1,000 y	6.5E-3	1.5E-2
Resident Farmer	FY 2013	1,000 y	2.3E-2	7.7E-2
	FY 2013 with INEL103597TR1_2	1,000 y	2.3E-2	7.7E-2
Open Rangeland/Cane Spring	FY 2013	1,000 y	2.3E-3	8.2E-3
	FY 2013 with INEL103597TR1_2	1,000 y	2.3E-3	8.2E-3
Open Rangeland/NNSS Boundary	FY 2013	1,000 y	2.5E-3	9.1E-3
	FY 2013 with INEL103597TR1_2	1,000 y	2.5E-3	9.1E-3

Long-Term Performance

The duration of model simulations was extended beyond 1,000 years to determine the effects of the INL Unirradiated LWBR Rods and Pellets waste stream when the peak dose is expected. The peak dose from ^{233}U is expected to occur after approximately 29,000 years when ^{229}Th reaches secular equilibrium. The peak dose from the ^{233}U decay chain is expected to occur after 29,000 years due to delay caused by environmental transport from buried waste to the accessible environment.

The peak dose was evaluated by increasing the model duration to 60,000 year. The peak dose from ^{233}U is expected when ^{229}Th concentration peaks. The peak ^{229}Th soil concentration occurs at 48,750 years. The resident all-pathways annual TED is below the 0.25 mSv limit throughout the 60,000 year period (Figure 2). Disposal of the INL Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the all-pathways annual TED for 60,000 years.

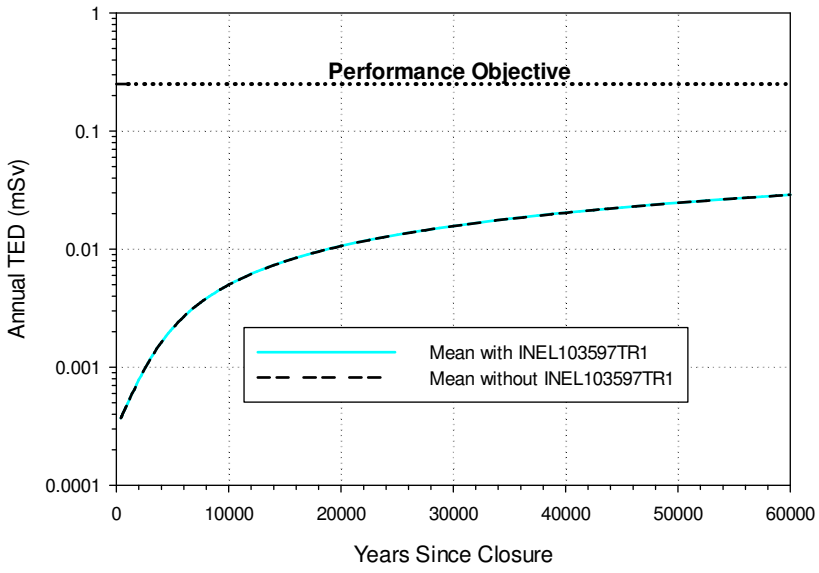

Figure 2. All-pathways annual TED for a resident with and without the INEL103597TR1, Rev. 2, waste stream for 60,000 years

3.3 Intruder Results

Intruder results are evaluated for acute intruder scenarios only. NNSA/NFO institutional control policy is to maintain and enforce use restrictions consistent with the Underground Test Area (UGTA) Federal Facilities Agreement and Consent Order closure strategies (U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office 2008). The Area 5 RWMS is within the Frenchman Flat UGTA (Corrective Action Unit 98) groundwater use restriction area. 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 and 95th percentile acute intruder TEDs occur at 1,000 years and are less than the 5 mSv limit for both the drilling and construction acute intrusion scenarios (Table 7). Addition of the INL Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the acute intruder scenario results.

Table 7. Maximum TED for acute intrusion scenarios at the Area 5 RWMS and the waste inventory disposed through FY 2013

Scenario	Time of Maximum	Mean (mSv)	95th Percentile (mSv)
Drilling Intruder without INEL103597TR1_2	1,000 y	1.6E-3	2.9E-3
Drilling Intruder with INEL103597TR1_2	1,000 y	1.6E-3	2.9E-3
Construction Intruder without INEL103597TR1_2	1,000 y	1.3	2.3
Construction Intruder with INEL103597TR1_2	1,000 y	1.3	2.3

3.4 ^{222}Rn Flux Density Results

The ^{222}Rn flux density is averaged over the area of all post-1988 disposal units. The maximum mean and 95th percentile ^{222}Rn flux density 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 8). Addition of the INL Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the ^{222}Rn flux density. This waste stream does not require an increased depth of burial to attenuate ^{222}Rn flux.

Table 8. Maximum ^{222}Rn flux density at the Area 5 RWMS and the waste inventory disposed through FY 2013

Inventory	Time of Maximum	Mean (Bq m^{-2} s^{-1})	95th Percentile (Bq m^{-2} s^{-1})
FY 2013	1,000 y	0.23	0.50
FY 2013 with INEL103597TR1_2 Waste Stream	1,000 y	0.23	0.50

There are no significant differences in the ^{222}Rn flux density throughout the 1,000-year compliance period (Figure 3). Comparison of the means and 95th percentiles indicates they are

equivalent throughout. The addition of the INL Unirradiated LWBR Rods and Pellets waste stream has no significant effect on the ^{222}Rn flux density.

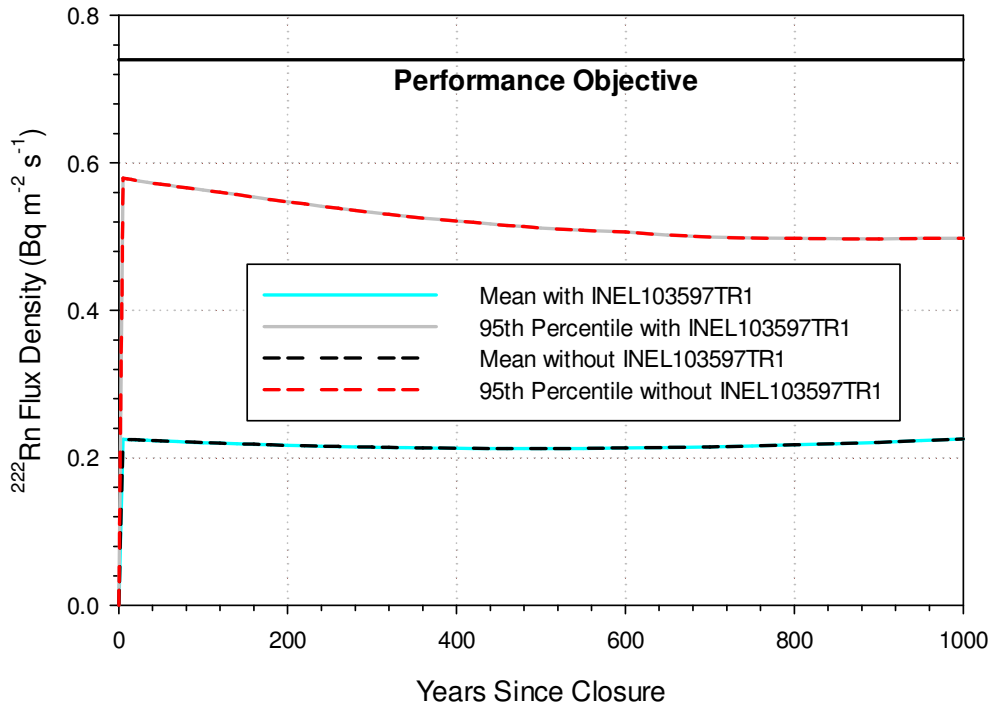

Figure 3. ^{222}Rn flux density with and without the INEL103597TR1, Rev. 2, waste stream

4.0 Conclusions

The results of the SA indicate that there is a reasonable expectation of compliance with all performance objectives with the INL Unirradiated LWBR Rods and Pellets (INEL103597TR1_2) waste stream disposed in the Area 5 RWMS SLB disposal units. The maximum mean and 95th percentile results are all less than the performance objectives for 1,000 years. Uncertainty analysis indicates that there is a high likelihood of compliance with all performance objectives for a period of 1,000 years after closure with addition of the INL Unirradiated LWBR Rods and Pellets waste stream.

The relative impact of the INL Unirradiated LWBR Rods and Pellets waste stream can be evaluated by comparing the SA results with and without the waste stream. Addition of the INL Unirradiated LWBR Rods and Pellets waste stream has no significant effect on any SA result. No increased depth of burial is required for compliance with performance objectives including the ^{222}Rn flux density.

The waste stream is recommended for disposal without conditions.

5.0 References

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