A Title 40 Code of Federal Regulations Part 191 Evaluation of Buried Transuranic Waste at the Nevada Test Site - 8210

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ABSTRACT

In 1986, 21 m^3 of transuranic (TRU) waste was inadvertently buried in a shallow land burial trench at the Area 5 Radioactive Waste Management Site on the Nevada Test Site (NTS). The U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office is considered five options for management of the buried TRU waste. One option is to leave the waste in-place if the disposal can meet the requirements of Title 40 Code of Federal Regulations (CFR) Part 191, "Environmental Radiation Protection Standard for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes." This paper describes analyses that assess the likelihood that TRU waste in shallow land burial can meet the 40 CFR 191 standards for a geologic repository. The simulated probability of the cumulative release exceeding 1 and 10 times the 40 CFR 191.13 containment requirements is estimated to be 0.009 and less than 0.0001, respectively. The cumulative release is most sensitive to the number of groundwater withdrawal wells drilled through the disposal trench. The mean total effective dose equivalent for a member of the public is estimated to reach a maximum of 0.014 milliSievert (mSv) at 10,000 years, or approximately 10 percent of the 0.15 mSv 40 CFR 191.15 individual protection requirement. The dose is predominantly from inhalation of short-lived Rn-222 progeny in air produced by low-level waste disposed in the same trench. The transuranic radionuclide released in greatest amounts, Pu-239, contributes only 0.4 percent of the dose. The member of public dose is most sensitive to the U-234 inventory and the radon emanation coefficient. Reasonable assurance of compliance with the Subpart C groundwater protection standard is provided by site characterization data and hydrologic processes modeling which support a conclusion of no groundwater pathway within 10,000 years. Limited quantities of transuranic waste in a shallow land burial trench at the NTS can meet the requirements of 40 CFR 191.

INTRODUCTION

The U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Site Office (NNSA/NSO) has operated the Area 5 Radioactive Waste Management Site (RWMS) on the Nevada Test Site (NTS) since 1961. In 1986, three shipments of classified transuranic (TRU) materials, consisting of 21 m^3 of waste in 102 55-gallon barrels, were inadvertently disposed by shallow land burial in Trench 4. A decision on final disposition of the TRU waste in Trench 4 is required before final closure, currently scheduled for 2010. NNSA/NSO is considering five options. One option, recovery of the waste for shipment and disposal at the Waste Isolation Pilot Plant (WIPP), will clearly meet all regulatory requirements, but experience at other sites has shown that the cost of recovery will be high. Other options require regulatory exemptions or decisions that are unlikely to be made before 2010. This paper summarizes the results of an analysis [1] investigating an option to demonstrate that the TRU waste in Trench 4 can meet all the requirements of 40 CFR 191 and close with the TRU waste in-place.

METHODS

Applicable Regulation

U.S. Department of Energy (DOE) TRU waste is regulated under DOE Manual 435.1-1 "Radioactive Waste Management Manual [2]" which requires disposal be in accordance with the requirements of Title 40 Code of Federal Regulations (CFR) Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes" [3]. Written to regulate disposal in geologic repositories, 40 CFR 191 is the applicable regulation for WIPP and the NTS greater confinement disposal (GCD) boreholes. If reasonable assurance can be provided that the TRU waste in Trench 4 meets all the requirements of 40 CFR 191, then closure in-place can be justified as presenting a comparable level of risk as accepted at other disposal facilities.

Two versions of 40 CFR 191 have been promulgated. This analysis uses the 1993 version because Parts 191.15 and Subpart C are more restrictive than the 1985 version. 40 CFR 191 includes four broad regulatory standards: containment requirements (§191.13), assurance requirements (§191.14), individual protection requirements (§191.15), and groundwater protection (Subpart C).

The containment requirements (CRs) in Part 191.13(a) are probabilistic standards that limit the cumulative release to the accessible environment. The accessible environment is defined as (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all of the lithosphere that is beyond the controlled area. The cumulative releases are integrated over 10,000 years and normalized by the 40 CFR 191 Table 1 quantities in Appendix A. The normalized cumulative release is calculated as:

$$R = \sum_{i=1}^{n} \frac{Q_i}{RL_i} \qquad \text{(Eq. 1)}$$

where R is the normalized cumulative release (dimensionless), Q_i the cumulative release over 10,000 years of nuclide i, and RL_i the release limit of nuclide i (Table I). The 40 CFR 191, Appendix A, Table 1 release limits are scaled based on the type and quantity of waste. The applicable waste type for Trench 4 is TRU waste, and the release limits are scaled per 1×10^6 curies (Ci) of TRU waste.

Absolute proof that the CRs can be met is not required because of the uncertainties in estimating the performance of the disposal system over 10,000 years. A reasonable assurance of meeting the CRs is provided by repeatedly simulating the cumulative radionuclide release of the disposal system and determining the frequency of realizations that exceed the release limits.

Table I. Release Limits for the 40 CFR 191.13(a) Containment Requirements

Radionuclide	Release Limit (Ci) per 1 x 10^6 Ci of TRU Waste
Am-241 or Am-243	100
C-14	100
Cs-135, Cs-137	1,000
I-129	100
Np-237	100
Pu-238, Pu-239, Pu-240, or Pu-242	100
Ra-226	100
Sr-90	1,000
Tc-99	10,000
Th-230 or Th-232	10
Sn-126	1,000
U-233, U-234, U-235, U-236, or U-238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 yrs	100
Any other radionuclide with a half-life greater than 20 yrs that does not emit alpha particles	1,000

The purpose of assurance requirements in 40 CFR 191.14 is to provide the confidence needed for long-term compliance with 40 CFR 191.13. Six different types of assurance are required, including active institutional controls, monitoring, passive institutional controls including markers and records, multiple barriers including natural and engineered barriers, selecting a site without significant attractive resources, and a system design that does not preclude waste retrieval. Closure plans can be developed to meet all assurance requirements. Previous assessments have demonstrated that there are no significant attractive resources at the site [4].

The individual protection requirements (IPRs) in 40 CFR 191.15(a) require that the annual committed effective dose to any member of the public be less than 0.15 mSv for 10,000 years. The IPRs apply to the TRU waste and "any associated radioactive material" which is interpreted to include low-level waste disposed in Trench 4, an interpretation consistent with the 40 CFR 191 performance assessment (PA) for the GCD boreholes [5]. The IPRs also apply to undisturbed performance of the site which is interpreted to exclude human intrusion.

Subpart C of 40 CFR 191 includes groundwater protection standards, which require that groundwater resources be protected for 10,000 years to limits contained in 40 CFR 141.

Site Description

The ecologic and hydrogeologic conditions on the NTS [6, 7, 8] and at the Area 5 RWMS [9, 10, 11, 12] have been summarized previously. The Area 5 RWMS is located in Frenchman Flat on the NTS approximately 105 km northwest of Las Vegas, population 1.9 million. Outside of Las Vegas, the region is one of the least populous regions of the U.S. due to the lack of water resources. Frenchman Flat receives an average of 12 cm of precipitation per year, and potential evapotranspiration (ET) is approximately 150 cm yr^{-1}. The floral community surrounding the site is a *Larrea tridentata* (creosote bush) shrubland characteristic of the Mojave Desert. Aboveground net primary productivity is comparatively low (~300 kg ha^{-1} yr^{-1}), and plant roots are rare below the depth of infiltrating precipitation, which is approximately 2.5 m.

Frenchman Flat is a closed basin typical of the Basin and Range Province, filled with 360 to 460 m of alluvial sediments. Permanent surface waters do not occur within the basin. The uppermost aquifer is found in the alluvial sediments at approximately 236 m below the surface.

Multiple results from site characterization studies indicate that precipitation does not infiltrate below the depth of the plant root zone and recharge of the aquifer is negligible under current climatic conditions. A large accumulation of chloride is observed at approximately 2.5 m in the alluviual sediments, indicating the depth of infiltrating precipitation. The amount of accumulated chloride indicates that recharge to the aquifer ceased 10,000 to 15,000 years ago [13]. Weighing lysimeters, in operation for 14 years, have not detected any drainage below a depth of 2 m. Water potential measurements indicate that vadose zone pore water flows upwards in the upper 35 m of the vadose zone. Similar conclusions of negligible recharge have been made by researchers investigating arid intermountain valleys of the desert southwest [14, 15, 16].

Waste Inventory

The inventory of TRU waste in Trench 4 decayed to the final site closure date is summarized in Table II. The TRU waste is a minor component of the Pu-239 disposed at the Area 5 RWMS. The Trench 4 Pu-239 inventory represents approximately 16 percent of the Pu-239 expected to be disposed by shallow land burial at the Area 5 RWMS by closure and 19 percent of the TRU inventory disposed in GCD boreholes. The TRU waste inventory is used for the CR analysis.

Table II. Inventory of TRU Waste Buried in Trench 4 on 1 October 2028

Nuclide	Geometric Mean Activity (Bq)	Geometric Standard Deviation	Nuclide	Geometric Mean Activity (Bq)	Geometric Standard Deviation
Pb-210	1.3E+02	2.68	U-235	5.3E+06	2.77
Ra-226	4.1E+02	2.65	U-236	1.3E+06	2.28
Ra-228	1.2E-03	2.10	U-238	4.4E+03	2.85
Ac-227	2.1E+03	2.85	Np-237	1.3E+07	2.35
Th-228	1.1E-03	2.09	Pu-236	9.3E+10	2.89
Th-229	1.5E+00	2.44	Pu-239	3.1E+12	2.93
Th-230	4.6E+04	2.58	Pu-240	7.5E+11	2.85
Th-232	1.7E-03	2.13	Pu-241	8.3E+11	2.89
Pa-2312	4.6E+03	2.83	Pu-242	4.5E+07	2.81
U-233	1.1E+03	2.40	Am-241	1.0E+12	2.27
U-234	1.3E+08	2.45	Total	5.7E+12	

The dose assessment for the IPRs includes the dose from the TRU waste in Table II and the low-level waste disposed in Trench 4. This waste, referred to as the co-located low-level waste, is summarized by Shott et al. [1]. Trench 4 is a 6.1-m deep unlined shallow land burial trench containing approximately 4,800 m^3 of waste. The disposal unit is expected to be closed with a 4-m vegetated monolayer-ET cover.

Model Development

Previous PAs for the Area 5 RWMS have produced a conceptual model of site performance which is used for this analysis [7, 17]. The Area 5 RWMS is well suited for waste disposal and amenable to relatively simple models. An important simplifying feature is that a groundwater pathway is extremely unlikely. In addition, the site is located within laterally extensive alluvial deposits that are relatively homogenous in the horizontal plane. This allows one-dimensional model implementation in the vertical plane.

Screening of a comprehensive list of features, events, and processes (FEPs) has produced a relatively short list of processes and events that may potentially transport radionuclides. All transport pathways are assumed to be upwards to the land surface. Natural FEPs in the model that influence radionuclide release and transport are the following:

- Upward liquid advection
- Liquid-phase diffusion
- Precipitation/dissolution of solutes
- Adsorption on solid surfaces
- Existence of a no liquid flux boundary (NLFB) above which no upward liquid phase transport occurs due to the disconnected liquid phase at low water contents
- Gas-phase diffusion
- Animal burrow excavation and collapse
- Plant uptake, translocation, and senescence
- Radioactive decay and ingrowth
- Climate change
- Changing soil moisture contents in response to climate change
- Changing water potential gradients in response to climate change
- Changing primary productivity in response to climate change
- Changing flora and fauna composition and characteristics (i.e., root allometry, burrow excavation rates, and depth distributions) in response to climate change

Once radionuclides are released to surface soil and the atmosphere, the cumulative release to the accessible environment and the total effective dose equivalent (TEDE) is estimated for a resident at the 100-m site boundary. The accessible environment for the cumulative release is defined as the atmosphere and surface soils. The resident is exposed though external irradiation from soil and by immersion in air, inhalation of gases and resuspended soil, dermal adsorption of H-3, and inadvertent soil ingestion. Ingestion of agricultural products is not included as this is not expected at a site without water resources.

The conceptual model of site performance is implemented in GoldSim, a probabilistic simulation platform developed originally for PA [18]. The model was developed from the existing Area 5 RWMS PA GoldSim model by including additional calculations for the 40 CFR 191 CRs. The normalized cumulative release is calculated as the integrated release to surface soils and the atmosphere over 10,000 years. The release mechanisms include the natural FEPs listed above and human intrusion. Human intrusion is simulated as a discrete event occurring randomly in time (i.e., a Poisson process). The selected intrusion scenario, water well drilling, and its probability of occurrence were estimated by a panel of subject matter experts [19].

The effects of climate change are implemented by selecting different parameter values over time as the climate regime changes. Future climate regimes are based on the climate forecast developed for the Yucca Mountain Project [20], scaled for conditions in Frenchman Flat. Present-day conditions are assumed to persist for 400 to 600 years. A monsoon period with increased summer precipitation and mean annual temperature is assumed to follow for 900 to

1,400 years. The remainder of the assessment period is assumed to be a glacial-transition period with colder temperatures and increased precipitation. These changes are assumed to occur instantaneously, but the timing is assumed to be uncertain.

Current hydrologic conditions with negligible infiltration below the plant root zone are assumed to persist as long as the present-day climate continues. During the monsoon climate regime, precipitation is assumed to increase 1.6 times and mean annual temperatures 0.6 ºC. Most of the precipitation increase is expected in the summer when potential evapotranspiration (PET) is high. The increasing temperatures expected for the monsoon climate regime, high summer temperatures, and increased plant growth in response to increased precipitation are all assumed to work together to maintain high ET during the monsoon climate. Similar climatic conditions currently occur in the Sonoran and Chihuahuan Deserts where recharge in intermountain valleys is believed to be negligible. Therefore, recharge below the plant root zone is assumed to be negligible during the monsoon climate regime.

With the onset of the glacial-transition period, mean annual temperature is expected to decrease 5.3 ºC and precipitation to increase 1.7 times. The hydrologic response to these colder, wetter conditions was evaluated using the hydrologic process model, UNSAT-H v3.01 [21]. Ninety-year simulations were run using daily precipitation time series from Fortymile Canyon, a colder, higher elevation site on NTS with a mean annual precipitation near that expected for the glacial-transition period. Daily PET time series were simulated using 13 years of meteorological data recorded at the Area 5 RWMS. Daily air temperatures were reduced by 5.3 ºC to simulate glacial-transition conditions.

The UNSAT-H simulations indicate that alluvium moisture contents may increase slightly (e.g., the expected value of the volumetric water content increases from 0.079 to 0.083) during the glacial-transition climate regime and that infiltration below the plant root zone may begin. This infiltrating water is not expected to reach the uppermost aquifer within 10,000 years due to low water content, low hydraulic conductivity (~1E-10 cm s^{-1}), and thickness of the vadose zone.

Floral communities are assumed to change in response to climatic conditions. Changes are based on assemblages observed at analog sites in the Sonoran and Chihuahuan Deserts for the monsoon climate regime and on the eastern slope of the Cascade Mountains for the glacial-transition regime. During the monsoon climate regime, the current plant community persists, but increased precipitation causes increased primary productivity. An *Artemisia spp*. (sage brush) shrubland or arid grassland is assumed to be established during the glacial-transition climate regime. Primary productivity and its uncertainty are assumed to increase for future climate regimes.

Increased primary productivity and water availability are assumed to increase fauna population densities. Changing climate and floral communities are also expected to change species composition. The fauna present, their population densities, and burrow characteristics are estimated for *Artemisia spp*.-dominated analog sites in the Pacific Northwest. The most significant change is expected to be an increase in the population of large fossorial mammals such as badgers and rabbits.

Uncertainty and Sensitivity Analysis

The model addresses epistemic parameter uncertainty by assigning probability density functions (pdfs) to important input parameters and propagating this uncertainty through the model by Monte Carlo simulation. Variability is addressed by assigning pdfs that describe the lack of knowledge about the mean parameter value averaged over the population, region, and/or time period simulated. Monte Carlo simulations were performed with 10,000 realizations generated by Latin hypercube sampling (LHS) for the CRs and 5,000 LHS realizations for the IPRs.

The sensitivity analysis uses multiple methods to confirm the sensitivity ranking as recommended by Frey and Patil [22]. The methods used are the correlation coefficient, standardized regression coefficient (SRC), partial correlation coefficient, GoldSim importance, and the generalized boosted model (gbm) package available through the R-Project [23, 24]. These are all global model dependent sensitivity analysis methods except for the GoldSim importance, which is model independent.

The gbm package fits a generalized additive model to the data using the methods of Freidman [25, 26]. The package returns a plot of the residual sum of squares versus iteration, the relative influence, and marginal dependence of the explanatory variables. The relative influence is a sensitivity index calculated as the Type III sum of squares error normalized to 100. The Type III sum of squares error measures the reduction in the residual sum of squares due to adding the parameter to the model with all other parameters included. The marginal dependence graphically represents the relationship between an input variable and the gbm model prediction integrated over all other parameters. The gbm package was run with a data set of 30,000 model realizations using the residual square error loss function. The number of regression trees and the gradient step were selected to optimize the coefficient of determination.

RESULTS

Cumulative Release

The containment requirements are given as a likelihood of the cumulative normalized release, R, exceeding limits scaled to total inventory. The probability of R exceeding one must be less than 1 in 10 (i.e., P[R>1] < 0.1), and the probability of R exceeding 10 must be less than 1 in 1,000 (i.e., P[R>10] < 0.001).

Ten thousand realizations of R for a 4-m monolayer-ET cover over 10,000 years were generated using LHS. The probability of R exceeding one was estimated to be 0.0093, an order of magnitude less than the 0.1 limit. The largest value of R in 10,000 realizations was 4.9. Because there was no realization greater than 10, it is concluded that the P(R>10) is less than 0.0001. The PA results provide a reasonable assurance of meeting the 40 CFR 191.13(a) CRs.

Comparison of the disposal system performance with the CRs can also be visualized by the complementary cumulative distribution function (CCDF) (Fig. 1). The CCDF expresses the P(X>x). The red-hatched area shows the region that constitutes a violation of the CRs. The curve does not intersect the probabilistic release limits, indicating that the disposal system meets the CRs. The markedly different slopes of the CCDF indicate the pdf of R is at least bimodal.

The lowest mode, which includes most of the probability, is composed of realizations where Trench 4 is not disturbed by human intrusion. The realizations with the higher mode include intrusion events.

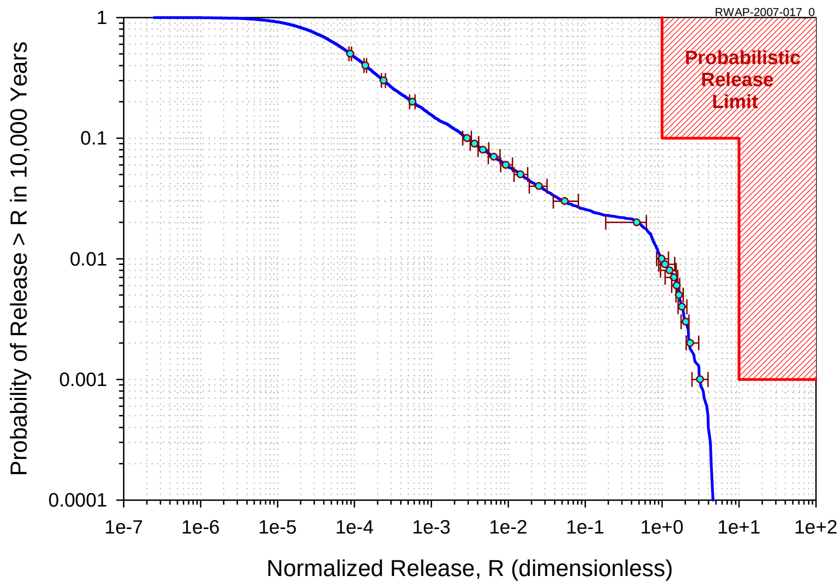

Fig. 1. CCDF of the cumulative normalized release, R, over 10,000 years for the TRU waste buried in Trench 4 with error bars. Error bars show the 95 percent central interval of 1,000 samples generated by resampling with replacement.

The precision of the CCDF can be evaluated by estimating the 95 percent centered confidence intervals about the CCDF. The confidence intervals were estimated using the percentile bootstrap method [27]. The confidence intervals indicate that the precision of the CCDF is sufficient to make a determination that the CRs are met.

Individual Protection Requirements

The TEDE received by a resident is a function of the radionuclide concentration in soil and air. The IPR analysis does not include releases by intrusion. The concentration in soil of most radionuclides is increasing throughout the 10,000-year compliance period (Fig. 2). The highest activity concentration radionuclides released to surface soil are not from the regulated TRU waste, but are from LLW disposed in Trench 4.

Radionuclides transported by gaseous diffusion, H-3, Rn-222, and its progeny Pb-210, have the highest initial concentrations in surface soil. Tritium decays to negligible levels within a few hundred years. Rn-222 and Pb-210 concentrations change gradually reflecting the changing Rn-222 production rate in the waste. The remaining radionuclides show a gradual buildup of concentration over time as they are transported to the surface by liquid diffusion, liquid advection, and bioturbation. By 1,200 years, Tc-99 becomes the highest concentration radionuclide. Technetium is preferentially released because its high solubility and poor adsorption on soil allows faster upward transport by liquid advection and diffusion. Once Tc-99 is transported to cover soil below the NLFB by liquid diffusion and advection, plant uptake and animal burrowing transport it to surface soil.

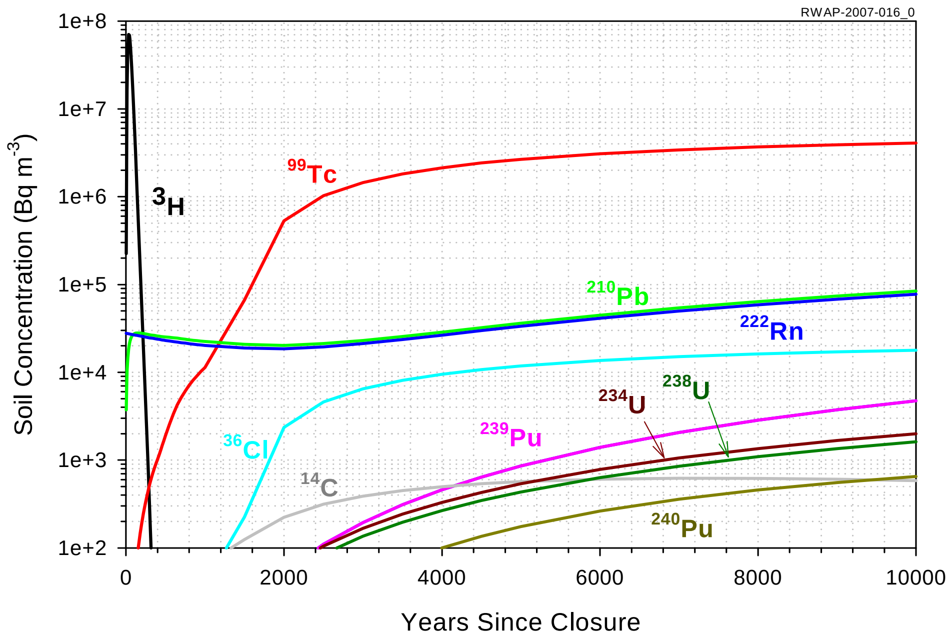

Fig. 2. Mean radionuclide activity concentration in surface soil for the undisturbed performance case.

The trends in air activity concentration closely follow that observed in soil. The activity concentration of gaseous species, H-3 and Rn-222, are significantly enhanced relative to particulate radionuclides. Overall, air concentrations are many orders of magnitude less than soil concentrations.

Resident Total Effective Dose Equivalent

The IRPs are assessed for a resident at the 100-m Area 5 RWMS site boundary. Five thousand LHS realizations of the TEDE were calculated for a period of 10,000 years after closure of the Area 5 RWMS. The mean TEDE reaches a maximum at 10,000 years (Fig. 3). The mean, median, and 95th percentile TEDEs are less than the 0.15 mSv IPR throughout the 10,000-year compliance period. The simulated resident TEDE results provide a reasonable assurance of meeting the 40 CFR 191 IPRs.

The TEDE to a resident is mostly from radionuclides released from the LLW disposed in Trench 4. Eighty-eight percent of the TEDE at 10,000 years is from inhalation of Rn-222 and its short-lived progeny in air. Another 10 percent is contributed by Pb-210 and its short-lived progeny deposited in the cover by diffusing Rn-222. By 9,000 years, the TRU waste component in Trench 4 becomes the next most important contributor to dose after Rn-222. The contribution is minor, amounting to only 0.5 percent of the resident's TEDE. At earlier times, Tc-99 from LLW is the second most important source of dose.

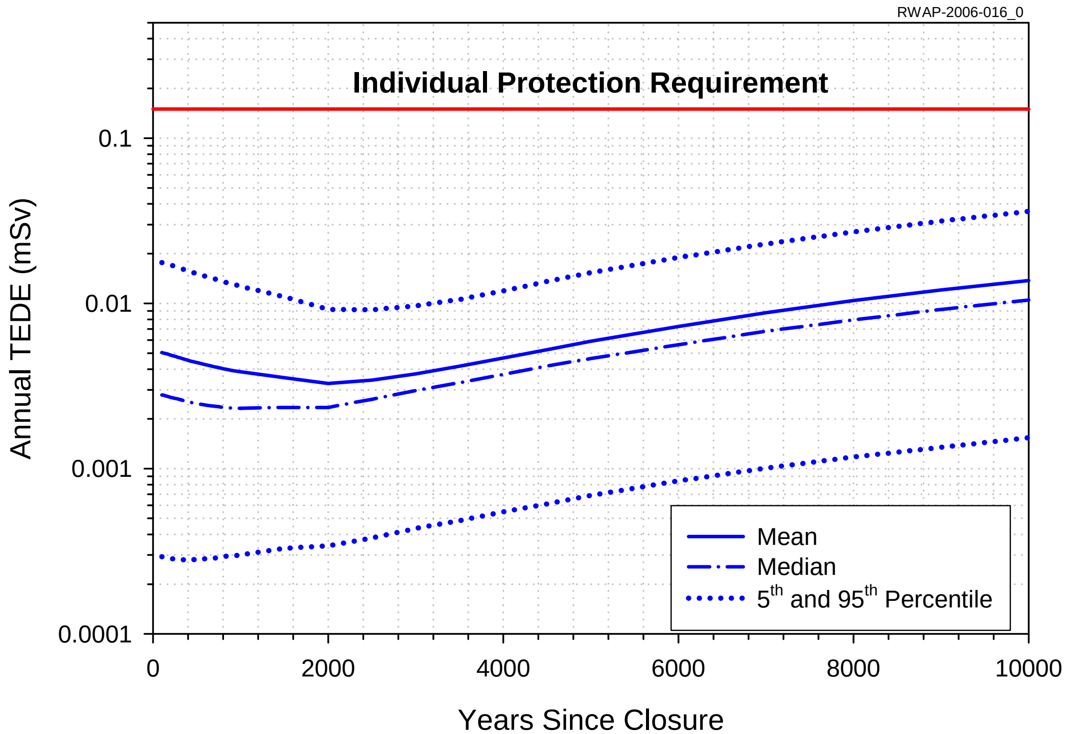

Fig. 3. TEDE for a resident at the 100-m boundary from waste disposed in Trench 4.

Local maxima of the resident TEDE occur at 100 and 10,000 years after closure. The probability of exceeding the 0.15 mSv IPR was evaluated at these two times. A majority of the TEDE probability distribution at both times lies below the IPR. At 100 years, a single realization in a sample of 5,000 exceeds the IPR. All realizations at 10,000 years were less than the IPR. The probability distributions of the resident's TEDE provide strong evidence that there is a very high probability of meeting the IPRs.

Sensitivity Analysis

The sensitivity analysis relies on multiple divergent methods to corroborate results. Model dependent sensitivity indexes reliably describe sensitivity to the extent that the model fits the data. The coefficients of determination indicate that the models for the cumulative release and resident TEDE fit the data reasonably well and should provide accurate, but qualitative, ranking of input parameter sensitivity (Table IV). The gbm model provides a better fit than the normal regression model.

Table IV. Sensitivity Analysis Regression Model Coefficient of Determination

Model Output	Normal Linear Regression	Generalized Boosted Regression
Normalized Cumulative Release	0.915	0.949
Resident TEDE at 100 years	0.858	0.960
Resident TEDE at 10,000 years	0.845	0.997

All of the sensitivity analysis methods indicate that the normalized cumulative release is strongly sensitive to the total number of intruder boreholes, except the GoldSim importance (Table V). The reason for the poor performance of the GoldSim importance measure is not determined. Moderate sensitivity to the number of boreholes per intrusion and the TRU Pu-239 inventory was observed. The gbm method identified slight sensitivity to the TRU Am-241 inventory, depth of the NLFB, and the liquid phase diffusion coefficient.

Table V. Summary of Sensitivity Analysis Results for the Normalized Cumulative Release

Parameter	Correlation Coefficient	SRC	Partial Correlation Coefficient	GoldSim Importance	GBM Relative Influence
Number of Boreholes	0.954	0.957	0.955	0	82.1
Number of Well Hits per Intrusion Event	-0.005	-0.001	-0.004	0.02	3.43
TRU Pu-239 Inventory	0.018	0.017	0.058	0.07	2.47
TRU Am-241 Inventory	0.007	0.009	0.027	0.006	1.20

The gbm marginal dependencies indicate that the cumulative release is an approximately linearly increasing function of the total number of intruder boreholes and the number of boreholes per intrusion event. The Pu-239 TRU inventory shows a non-linear rapidly increasing relationship with the cumulative release. The marginal dependence of the Am-241 TRU inventory decreases with increasing inventory, suggesting a spurious relationship.

All of the sensitivity analysis methods indicate the resident TEDE at 100 years is strongly sensitive to the co-located Ra-226 inventory and radon emanation coefficient (Table VI). The model shows moderate sensitivity to the Rn-222 sievert per working-level month (Sv/WLM) conversion factor. The gbm regression model shows slight sensitivity to parameters related to inhalation of Rn-222 and its short-lived progeny in air. In this case, the GoldSim importance measure produces similar results and suggests that approximately 69 percent of the TEDE variance is explained by uncertainty in the Ra-226 inventory and the emanation coefficient.

The gbm marginal dependence shows a strong positively increasing relationship between the TEDE and the Ra-226 inventory, radon emanation coefficient, and the Rn-222 Sv/WLM conversion factor. The time spent in sedentary activity shows a negative linear relationship with dose less time spent in sedentary activity increases the complementary time spent outdoors in light activity when ventilation is higher. Therefore, time spent in sedentary activity is expected to be negatively correlated with the dose from inhalation of Rn-222 and its short-lived progeny.

Table VI. Summary of Sensitivity Analysis Results for Resident TEDE at 100 years

Parameter	Correlation Coefficient	SRC	Partial Correlation Coefficient	GoldSim Importance	GBM Relative Influence
Co-Located Ra-226 Inventory	0.787	0.835	0.907	0.552	66.6
Radon Emanation Coefficient	0.361	0.354	0.680	0.135	19.4
Rn-222 Sv/WLM Factor	0.100	0.057	0.145	0.012	2.07
Light Activity Ventilation Rate	0.046	0.014	0.036	0.003	0.194
Time Spent in Sedentary Activity	-0.036	-0.016	-0.041	0.006	0.216

The resident TEDE at 10,000 years is strongly sensitive to the co-located U-234 inventory and radon emanation coefficient (Table VII). The model shows moderate sensitivity to the Rn-222 Sv/WLM conversion factor. Slight sensitivity was observed for parameters related to inhalation of Rn-222 progeny. Approximately 79 percent of the TEDE variance is explained by the U-234 inventory and radon emanation coefficient.

Table VII. Summary of Sensitivity Analysis Results for the Resident TEDE at 10,000 Years

Parameter	Correlation Coefficient	SRC	Partial Correlation Coefficient	GoldSim Importance	GBM Relative Influence
Co-Located U-234 Inventory	0.641	0.644	0.851	0.414	50.2
Radon Emanation Coefficient	0.612	0.613	0.838	0.378	39.4
Rn-222 Sv/WLM Factor	0.172	0.179	0.403	0.033	5.44
Light Activity Ventilation Rate	0.075	0.071	0.174	0.014	0.772
Time Spent in Sedentary Activity	-0.064	-0.069	-0.169	0.006	0.669

The gbm marginal dependence show strong linear relationships for the U-234 inventory, radon emanation coefficient, Rn-222 Sv/WLM conversion factor, time spent in sedentary activities, and light activity ventilation rate (Fig. 4). The time spent in sedentary activities and the light activity ventilation rate affect the quantity of air inhaled and hence the Rn-222 inhalation dose.

CONCLUSIONS

A probabilistic assessment of 21 m^3 of TRU waste disposed in a shallow land burial trench indicates that there is reasonable assurance that the requirements of 40 CFR 191 can be met. The CCDF of the normalized cumulative release indicates that the probabilities of exceeding the CRs are less than the limits. The cumulative release was most sensitive to the number of intruder boreholes. Review of the site closure plans and an evaluation of attractive resources indicate that all assurance requirements can be met. The maximum TEDE to a resident over 10,000 years is estimated to be 0.014 mSv, less than the 0.15 mSv IPR. The resident TEDE was most sensitive to the U-234 inventory and the Rn-222 emanation coefficient. A groundwater pathway is considered unlikely under current climatic conditions, and climate change over the next 10,000 years is not expected to initiate a groundwater pathway, thus ensuring that all groundwater protection requirements can be met. Closure in-place of the TRU waste buried in Trench 4 at the Area 5 RWMS can meet all the requirements of 40 CFR 191 and, therefore, represents an acceptable risk.

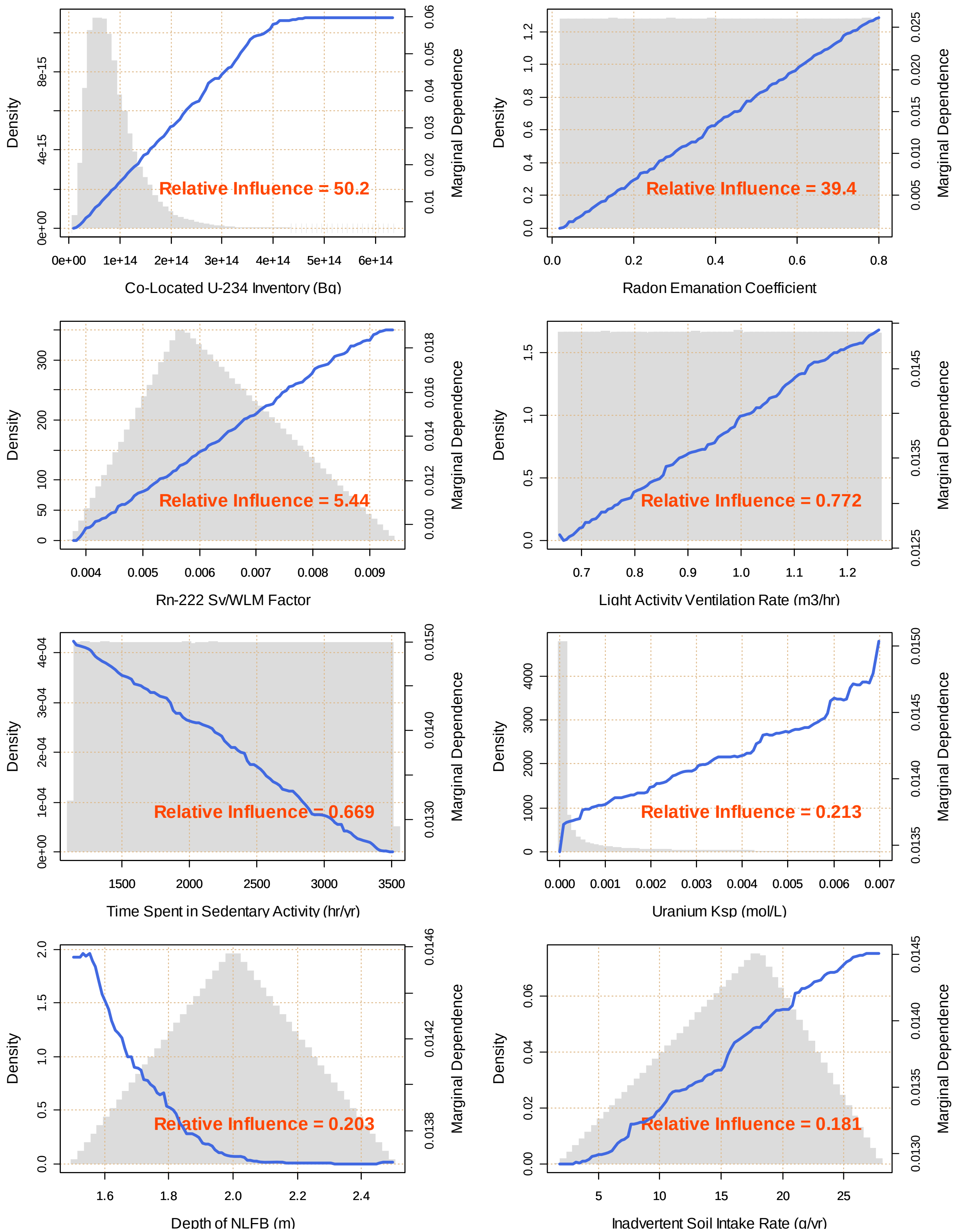

Fig. 4. Histogram (grey) and marginal dependence (blue) of most sensitive input parameters for resident TEDE at 10,000 years as measured by the gbm relative influence.

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