SENES Consultants
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SOIL DECOMMISSIONING CRITERIA

SWEETWATER URANIUM PROJECT

SOURCE MATERIALS LICENSE SUA-1350

SWEETWATER COUNTY, WYOMING

Prepared for:

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1. INTRODUCTION

The Sweetwater Uranium Mill operated between 1981 and 1983 and has since been on standby. In August 1999 the facility obtained a performance-based operating license from the U.S. Nuclear Regulatory Commission (NRC). Soil cleanup criteria for the site were based on the numeric radium standards specified in 10 CFR 40 (Appendix A). In November 2004, the license was renewed and in 2005 it was amended with a license condition regarding remediation of subsurface soils in the vicinity of the former Catchment Basin (NRC, 2005). Proposed cleanup criteria were based on previously established numeric standards and these criteria were approved for this objective by the NRC (NRC, 2005).

After submittal of the Catchment Basin Excavation Completion Report (Kennecott, 2008), the NRC requested verification that the soil criteria used for the Catchment Basin remediation were also consistent with dose-based criteria indicated in Criterion 6(6) of 10 CFR 40 Appendix A. In response, Kennecott submitted a radiological assessment verifying that doses from the soil criteria applied were in compliance with a scenario-specific Radium Benchmark Dose standard for the remediated Catchment Basin as required for decommissioning plans approved after June 11, 1999 (Kennecott, 2009).

Because the performance-based license for the Sweetwater Uranium Project was issued after June 11, 1999 and the approval included a decommissioning and reclamation plan, future soil cleanup criteria for the site must be based on Criterion 6(6) requirements. Although the 2009 dose assessment for the Catchment Basin cleanup standards verified consistency with the Radium Benchmark Dose Approach, it did not establish future soil decommissioning criteria for the entire mill site, only for the area related to the Catchment Basin. This report establishes future soil cleanup criteria for the entire Sweetwater Uranium Project based on the Radium Benchmark Dose Approach in accordance with Criterion 6(6).

2. REGULATORY SPECIFICATIONS

As indicated in Criterion 6(6) of 10 CFR 40 Appendix A, the criteria for Ra-226 in soil at uranium mills are prescriptive numeric limits, defined as an average above-background Ra-226 concentration of 5 pCi/g across any 100 m^2 area to a depth of 15 cm, and 15 pCi/g for any underlying 15-cm depth increment. These soil radium standards, known as the "5/15 rule", are specific to 11e.(2) byproduct material from mill operations and do not apply to naturally occurring radioactive materials (NORM) associated with unprocessed uranium ores, mine waste rock, or natural in-situ uranium mineralization. Unrefined or unprocessed materials are not licensed or regulated by the NRC per 10 CFR Part 40.13(b) which states:

> *"(b) Any person is exempt from the regulations in this part and from the requirements for a license set forth in section 62 of the act to the extent that such person receives, possesses, uses, or transfers unrefined and unprocessed ore containing source material; provided, that, except as authorized in a specific license, such person shall not refine or process such ore..."*

For byproduct radionuclides other than Ra-226, Criterion 6(6) indicates that soil cleanup criteria are to be derived using a dose-based benchmarking approach. This involves determining the maximum annual

total effective dose equivalent (TEDE) to a critical receptor within 1,000 years due to Ra-226 and its progeny, Pb-210 (NRC, 2003), given respective soil concentrations equivalent to the above-background numeric 5/15 criteria for byproduct Ra-226 in soils. This dose rate is termed the Radium Benchmark Dose (RBD). For the Sweetwater Uranium Project site, the RBD approach applies only to byproduct uranium and thorium (Th-230) as geologic deposits of elevated natural thorium (Th-232) are not associated with the Great Divide Basin region of Wyoming (USGS, 2009).

Once the RBD is determined, dose-based soil standards known as Derived Concentration Guideline Levels (DCGLs) are individually determined for residual byproduct uranium and Th-230. Each DCGL is determined by calculating a soil concentration that would result in a dose equivalent to the RBD under the same critical receptor scenario. Calculated DCGLs represent the basis for soil cleanup levels for byproduct uranium and Th-230, pending application ALARA (As Low As Reasonably Achievable) principles (NRC, 2003). If more than one residual byproduct radionuclide is present in the same 100 m^2 area, the sum of the ratios for each measured radionuclide concentration to its respective DCGL must not exceed "1" (this “unity rule” is defined in Section 6).

For Th-230, there is an additional regulatory requirement. The amount of residual byproduct Th-230 that can remain in soils at the site must not exceed a concentration that would result in the buildup of Ra-226 to levels exceeding 5 pCi/g within 1,000 years. This requirement has specific numeric limits of 14 pCi/g in the top 15 cm of the soil profile, and 43 pCi/g for any underlying 15-cm thick subsurface layer, assuming that the initial Ra-226 concentrations are near background levels (NRC, 2003).

3. RADIUM BENCHMARK DOSE MODELING

3.1 Receptor Scenario Selection

A number of potential land uses and corresponding critical receptor scenarios were considered for RBD modeling. These included ranching, mining, home-based business, light industry and resident farmer scenarios in accordance with the guidance provided in Appendix H of NUREG-1620 (NRC, 2003). A resident rancher scenario was selected as the most plausible land use within the foreseeable future (within 200 years) for reasons described below.

Upon license termination and site decommissioning, the DOE will assume long-term stewardship of the tailings impoundment and any surrounding area necessary for environmental monitoring. Legal access and land use will be restricted under this direct institutional control. However, former mill facilities areas are expected to be released for unrestricted use, and it is appropriate to consider potential failures of institutional control over 1,000 years. With ready access via local roadways, a rancher could conceivably reside at or near the former site and perform livestock ranching operations in the area. This scenario would be consistent with historic land uses in the Great Divide Basin. The lack of precipitation (less than 6 inches annually), along with a short growing season (less than three months) (Shepherd Miller, 1994), reasonably preclude a resident farmer scenario. Much of the land in the region is Federal

land managed by the BLM. Section 16, Township 24 North, Range 93 West that adjoins the site to the west is State owned land.

A home-based business is possible, but is less likely due to the remote location and relative lack of community resources favorable to such endeavors. Uranium mining via conventional methods would require a conventional mill or heap leach facility. This scenario, along with uranium extraction via in-situ recovery (ISR) methods, would require a new NRC license.

3.2 Modeling Code and Parameter Selections

The RBD for the Sweetwater Uranium Project site was developed using the RESRAD-OFFSITE computer code, Version 3.1 (NRC, 2013). Version 3.1 adds new source term modeling capabilities, though respective attributes were not necessary for this assessment and standard features of Version 2.5 (ANL, 2009) were used. RESRAD-OFFSITE can be used to model doses to a receptor living within a zone of contamination, or at a location removed from the contamination. In this case, the assumed receptor scenario was a resident rancher living within a hypothetical zone of residual 11e.(2) byproduct material in soils after site decommissioning. RESRAD-OFFSITE has a number of advantageous features versus RESRAD (onsite), including more sophisticated groundwater modeling capabilities, air dispersion modeling, visual mapping tools, and ability to model greater complexity in the receptor scenario.

Aside from RESRAD-OFFSITE advantages, both RESRAD codes have limitations with respect to the areal dimensions of the contaminated zone (this is restricted to rectangular shapes, though a gamma "shape factor" can be used for different exposure geometries). The true dimensions of the contaminated zone are likely to have a different shape and be discontinuous in some areas (e.g. where institutional controls over the impoundment will restrict access). Also, the location of a receptor dwelling may differ from that conventionally used in RESRAD modeling (at the center of the contamination zone). Unless the dwelling is near the edge of the contaminated zone, these factors have little impact on the RBD.

The dose pathways included for the resident rancher scenario included external gamma, inhalation, plant and meat ingestion, drinking water, and incidental soil ingestion. Plant and meat ingestion pathways were limited based on the climate, growing season, and livestock range requirements (well beyond the zone of contamination). The radon pathway was excluded per Criterion 6(6) specifications. The aquatic foods pathway was excluded as an unrealistic source of potential exposure at the site. The milk pathway was also excluded per guidance provided in Appendix H, NUREG-1620 (NRC, 2003).

The contaminated zone was assumed partially based on gamma survey data collected in 1997 along transects radiating outwards from the tailings impoundment to characterize the limits of windblown byproduct Ra-226 in excess of 5 pCi/g above background (Figure 1). It was further assumed that some degree of residual byproduct Ra-226 is present in surface soils across areas physically disturbed by historic milling operations (official gamma surveys have not been conducted across these areas).

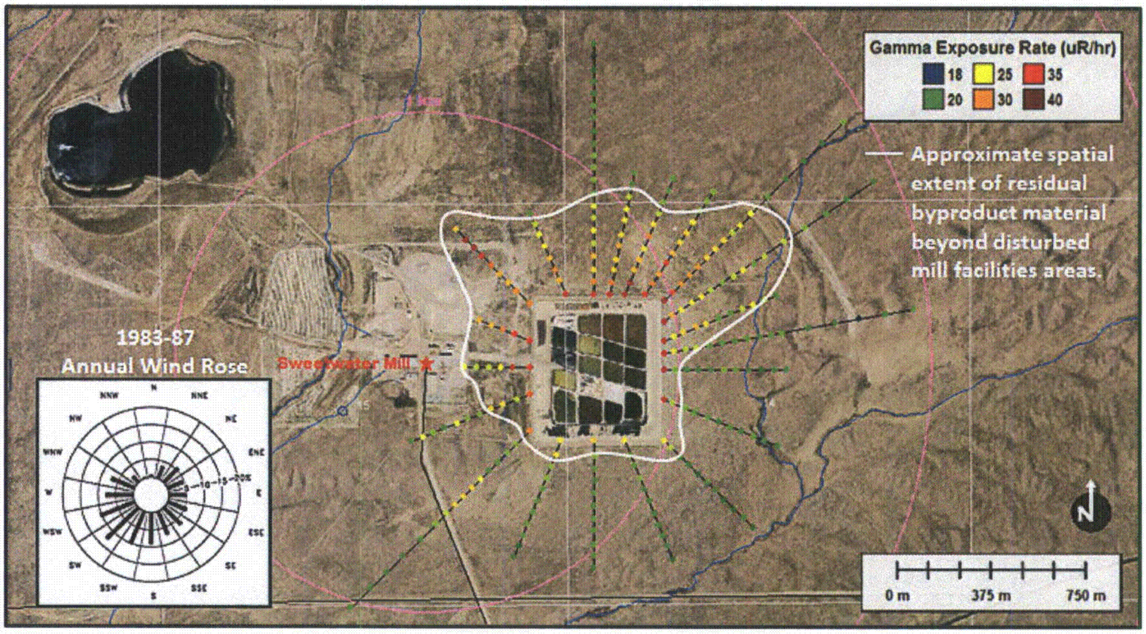

Figure 1: 1997 radiological gamma survey results showing the spatial extent of windblown tailings in the vicinity of the impoundment. Gamma values are represented by interpolated color blends based on the range of discrete color assignments shown in the legend.

The hypothetical site layout used for the resident rancher dose modeling scenario is shown in Figure 2. The rancher dwelling and two small gardens are located at the center of a zone of homogeneous soil Ra-226 contamination. Per NUREG-1620 guidance (NRC, 2003), Ra-226 and Pb-210 concentrations surface soils in the contaminated zone were set at 5 pCi/g above background to a depth of 15 cm. The areal extent of the modeled contamination zone was approximately 297 acres, roughly centered between mill facilities and the tailings impoundment.

A much larger agricultural area, modeled as livestock rangeland, encompasses the entire contamination zone but extends well beyond this zone on all sides (about 1500 acres in total). Although meteorological data and a site-specific wind rose for the mill has been established (Figure 1), joint wind frequency data in a STAR file format as used by RESRAD-OFFSITE were not available. Instead, a STAR file for Rawlins Wyoming from the RESRAD-OFFSITE program library was used for the atmospheric modeling. Prevailing wind directions for Rawlins (Figure 2) are reasonably similar to those found at the site.

The same site layout and model input parameters were used to model doses for subsurface soils (15-30 cm depth), but Ra-226 and Pb-210 concentrations were set at 15 pCi/g each, and 15 cm of clean cover soil was assumed. Model input parameters were based on site-specific information wherever possible. Guidance from Appendix H of NUREG-1620 and/or RESRAD user manuals was used for other parameter selections as applicable to a rancher scenario. RESRAD-OFFSITE defaults, considered "broadly applicable" across the U.S., were used for all other parameter inputs. Key parameter values and those that were modified from code defaults, along with rationale and references are provided in Table 1.

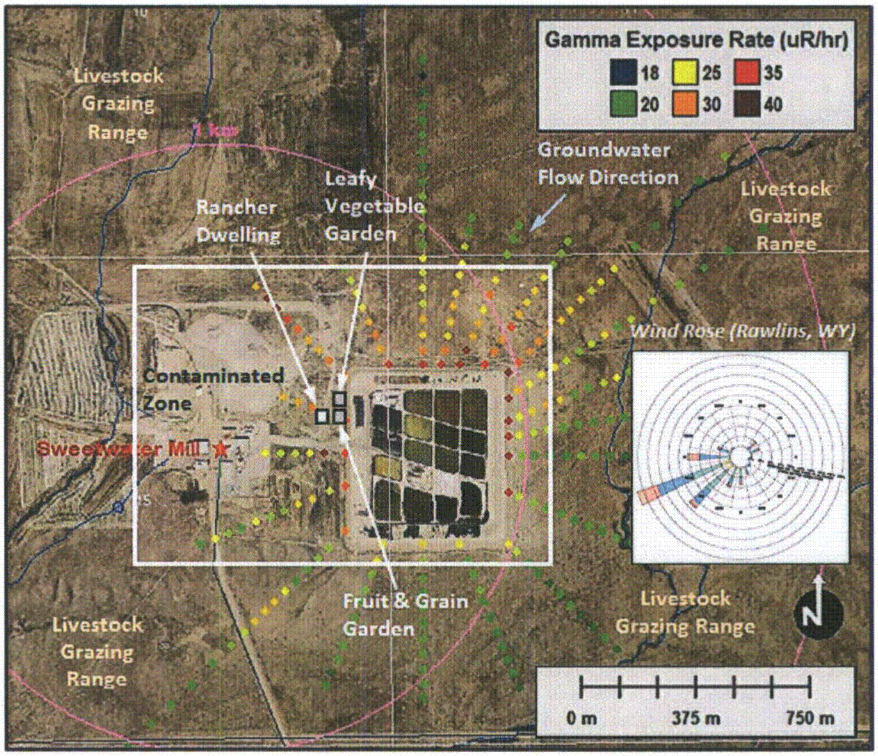

Figure 2: Site layout scenario for RESRAD modeling of the RBD.

Table 1: Site-specific RESRAD-OFFSITE modeling parameters for a resident rancher receptor scenario.

MODEL PARAMETER	PARAMETER VALUE	RATIONALE / COMMENTS	SOURCE / REFERENCE
Occupancy / Gamma			
Fraction onsite indoor occupancy	0.5	Assumes rancher occupancy similar to resident farmer	Table 2.3, RESRAD Version 6 User's Manual
Fraction onsite outdoor occupancy	0.25	Assumes rancher occupancy similar to resident farmer (about 42 hr/wk working outdoors onsite)	Table 2.3, RESRAD Version 6 User's Manual
Fraction per agricultural area	0.01 or 0.2	Assumes 1.7 hr/wk per garden, 38.6 hr/wk in livestock grazing areas (included in onsite outdoor occupancy)	RESRAD-OFFSITE Version 2.5 User's Manual
Gamma penetration factor	0.45	Lower end of range in guidance (assumes more shielding due to thicker dwelling slab)	Appendix H, NUREG-1620
Contamination Zone			
Area (acres)	297	Approximate extent of known and assumed impacts associated with mill	1997 gamma survey and assumed additional areas from aerial photos of mill facility disturbances
Thickness (m)	0.15	Defined by regulatory cleanup criteria	10 CFR 40, Appendix A
Soils (General)			
Field Capacity	0.116	Value indicated for sandy loam soil in RESRAD guidance (field capacity assumed = volumetric water content)	Revised Environmental Report (Shepherd Miller, 1994); Appendix B, RESRAD-OFFSITE User's Manual, 2007

Volumetric water content	0.116	Value indicated in RESRAD guidance for sandy loam soil (site-specific soil classification)	Revised Environmental Report (Shepherd Miller, 1994); Appendix B, RESRAD-OFFSITE User's Manual, 2007
Soil Erodibility Factor	0.27	Sandy loam soil (site-specific classification), assumes low 0.5% organic matter content	Revised Environmental Report (Shepherd Miller, 1994); Appendix B, Section 2.4, RESRAD-OFFSITE User's Manual, 2007
Erosion Rate (m/y)	3.36E-04	Calculated by RESRAD-OFFSITE based on USLE and hydrologic/soil input parameters	RESRAD-OFFSITE User's Manual, 2007
Length parallel to aquifer flow (m)	1428	Calculated by RESRAD-OFFSITE based on site layout scenario	RESRAD-OFFSITE User's Manual, 2007
Hydraulic Conductivity (m/yr)	8.9	Site-specific average vertical estimate for unsaturated soils	Groundwater plume interpretation report (Telesto, 2009)
Cover & Management Factor	0.13	Tall weeds/short brush, 50% cover, 20% cover in contact with ground surface	Appendix B, RESRAD-OFFSITE User's Manual, 2007
<u>Unsaturated Zone</u>			
Thickness (m)	31.4	Previous RESRAD analysis	Site-specific estimate from GW monitoring data
<u>Saturated Zone</u>			
Thickness (m)	100	RESRAD default	RESRAD-OFFSITE default value, Version 2.5
Hydraulic Conductivity (m/yr)	890	Site-specific average horizontal estimate	Groundwater plume interpretation report (Telesto, 2009)
<u>Agricultural Areas</u>			
Fraction on Contaminated Zone	1 or 0.2	100% for gardens, 20% for livestock rangeland	10 CFR 40, Appendix A
Root Depth (m)	0.3	For leafy vegetables per NUREG-1620 guidance. Default of 1.2 m for other species (reasonable for many Great Divide species that are palatable to grazing animals).	Appendix H, NUREG-1620
<u>Meteorological Data</u>			
MET wind data	STAR data	From RESRAD-OFFSITE library for Rawlins, WY	RESRAD-OFFSITE Version 2.5 User's Manual
Annual Precipitation (m)	0.15	Area-specific (upper end of 5-6 inch range cited in reference document)	Revised Environmental Report (Shepherd Miller, 1994)
Evapotranspiration Coefficient	0.8	Mean of cited range for semi-arid uranium mill sites	Appendix H, NUREG-1620
<u>Consumption Rates</u>			
Fraction of meat from livestock grazing on or near contaminated zone	0.25	Assumes low rainfall and sparse vegetation requires large ranges to support grazing animals (only a small fraction of time would be spent grazing in contaminated areas)	Appendix H, NUREG-1620
Fraction of fruit, grain, and vegetables grown on contaminated zone	0.1	Assumes irrigation of small gardens from onsite well, but short growing season and limited production potential.	Appendix H, NUREG-1620

3.3 Deterministic Modeling Results

Deterministic RBD modeling results indicate that a resident rancher living within a hypothetical 297-acre contaminated zone at the decommissioned Sweetwater Mill site would receive a maximum TEDE of 34.2 mrem/yr due to Ra-226 and Pb-210 concentrations of 5 pCi/g each residing in the top 15 cm of the soil profile (Figure 3). The maximum dose rate (the RBD) is received at t = 0 years, the majority of which is due to external gamma radiation from soil Ra-226 with very small contributions from plant and meat ingestion (< 2 mrem/yr) (Figure 4). Deterministic dose conversion factors at the RBD for surface soils were 6.7 (mrem/yr)/(pCi/g) for residual Ra-226, and 0.17 (mrem/yr)/(pCi/g) for residual Pb-210.

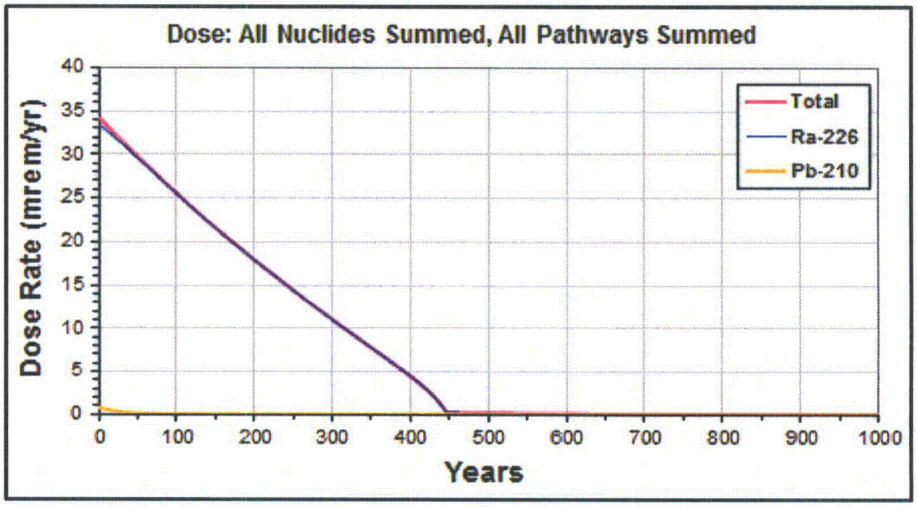

Figure 3: Deterministic RBD modeling results, 0-15 cm soil depth.

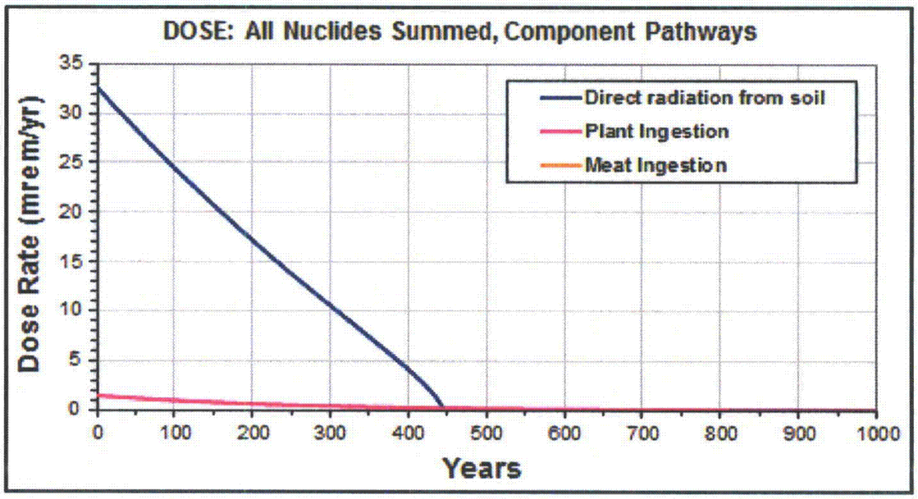

Figure 4: Component dose pathways for the RBD, 0-15 cm soil depth.

For subsurface soils (15-30 cm) with Ra-226 and Pb-210 concentrations of 15 pCi/g each and 15 cm of clean cover soils, deterministic modeling indicates that the rancher would receive a maximum TEDE of 42.2 mrem/yr (Figure 5). This subsurface RBD is received in year 446 after the clean cover has eroded

away. Again, direct radiation is the dominant pathway for all years, though at time zero plant ingestion accounts for close to a third of the total dose due to root uptake of both Ra-226 and Pb-210 (Figure 6). Deterministic dose conversion factors at the RBD for subsurface soils were about 2.75 (mrem/yr)/(pCi/g) for residual Ra-226, and 0 (mrem/yr)/(pCi/g) for residual Pb-210.

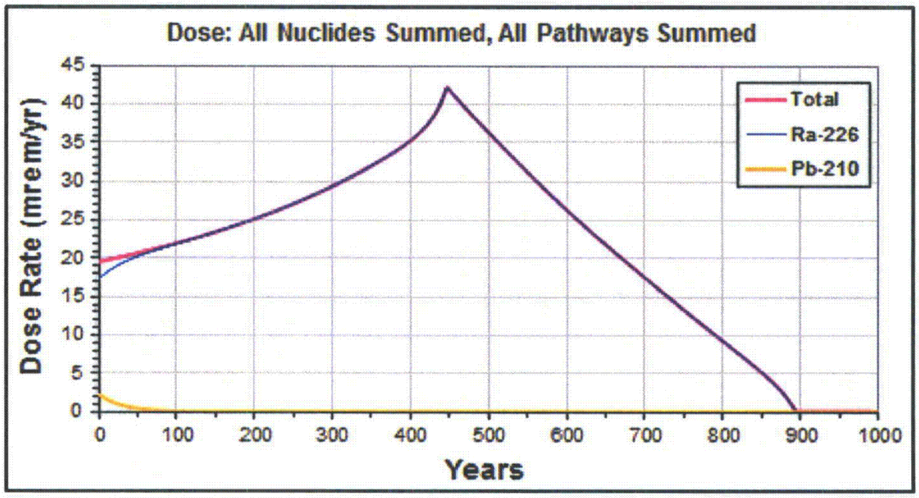

Figure 5: Radium Benchmark Dose modeling results, 15-30 cm soil depth.

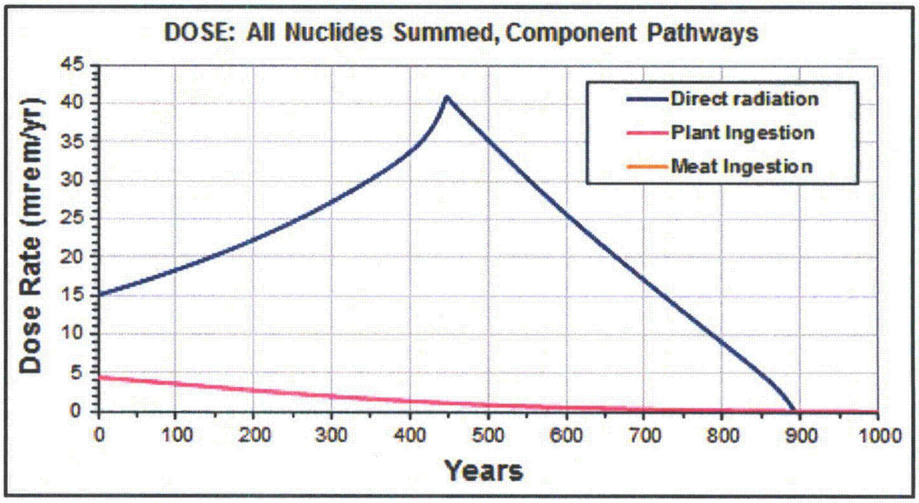

Figure 6: Component dose pathways for the RBD, 15-30 cm soil depth.

3.4 Sensitivity Analysis

A sensitivity analysis was performed for many model input parameters, particularly those with potential to significantly impact the modeled RBD based on assessment of the component pathways shown in Figures 4 and 6. To illustrate the utility of sensitivity analysis, the external gamma penetration factor (degree of gamma exposure rate shielding afforded by the dwelling to an indoor occupant) was allowed to vary by a factor of 1.5 from the base value of 0.45. This essentially covers the range of values indicated in NUREG-1620. Because gamma radiation is the primary component of total dose in this

model (Figures 3 and 5), this parameter is likely to be significant with respect to the modeled RBD. This expectation was confirmed by the sensitivity analysis (Figure 7). For the higher gamma penetration value (0.675), there is greater transmission of photons through the foundation and walls of the building and thus the indoor dose from direct radiation due to Ra-226 in the soil is higher (by 5.3 mrem/yr).

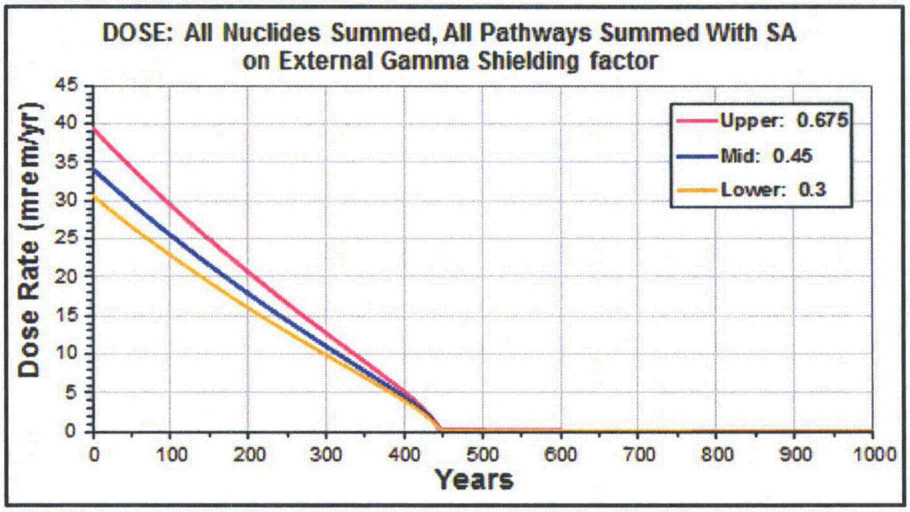

Figure 7: Sensitivity analysis on the external gamma penetration factor.

Using this general assessment approach, and with an emphasis on model parameters where values other than program defaults were used, 19 potentially important model parameters were tested with sensitivity analysis for impacts on the deterministic RBD values for surface soils (0-15 cm) and subsurface soils (15-30 cm). The results are tabulated in Tables 2 and 3 respectively.

Table 2: Sensitivity analysis (1) results: model parameters to which the deterministic RBD for surface soils (0-15 cm) is at least somewhat sensitive.

MODEL PARAMETER TESTED	SENSITIVITY MULTIPLIER	TESTED VALUES (high, base, low)	NOTABLE IMPACT ON MAX DOSE (RBD)?
External Gamma Penetration Factor	1.5	0.675, 0.45, 0.3	Yes, ± 4 to 5 mrem/yr at max dose
Fraction onsite indoor occupancy	1.5	0.53, 0.5, 0.33	Yes, ± 0.5 to 3.5 mrem/yr at max dose
Fraction onsite outdoor occupancy	2	0.28, 0.25, 0.125	Yes, ± 1 to 5 mrem/yr at max dose
Fraction occupancy in grazing areas	2	0.23, 0.2, 0.1	Yes, ± 1 to 5 mrem/yr at max dose
Length of Contaminated Zone (m)	2	2618, 1309, 655	Yes, 11 mrem/yr lower when 1/2 as long (no change if doubled)
Width of contaminated Zone (m)	2	1824, 912, 456	Yes, 10 mrem/yr lower when 1/2 as wide (no change if doubled)

Ra-226 Distribution Coefficient (K_d, cm^3/g)	2	140, 70, 35	Not at RBD, but significant impact on dose in subsequent years due to differences in leaching
Precipitation (cm)	2	30, 15, 7.5	Not at RBD, but significant impact on dose in subsequent years due to differences in erosion rate
Soil Erodibility Factor	1.5	0.405, 0.27, 0.18	Not at RBD, but significant impact on dose in subsequent years due to differences in erosion rate
Non-Leafy Root Depth (m)	2	2.4, 1.2, 0.6	Slight (+1 mrem/yr at 1/2 root depth)
Leafy Vegetable Root Depth (m)	2	0.6, 0.3, 0.15	Negligible, less than ± 0.5 mrem/yr

Table 3: Sensitivity analysis (2) results: model parameters to which the deterministic RBD for subsurface soils (15-30 cm) is at least somewhat sensitive.

MODEL PARAMETER TESTED	SENSITIVITY MULTIPLIER	TESTED VALUES (high, base, low)	NOTABLE IMPACT ON MAX DOSE (RBD)?
External Gamma Penetration Factor	1.5	0.675, 0.45, 0.3	Yes, ± 4.4 to 6.6 mrem/yr at max dose (446 yrs)
Fraction onsite indoor occupancy	1.5	0.53, 0.5, 0.33	Yes, ± 0.8 to 4.4 mrem/yr at max dose (446 yrs)
Fraction onsite outdoor occupancy	2	0.28, 0.25, 0.125	Yes, ± 1.8 to 7.4 mrem/yr at max dose (446 yrs)
Fraction occupancy in grazing areas	2	0.23, 0.2, 0.1	Yes, ± 1.8 to 5.9 mrem/yr at max dose (446 yrs)
Length of Contaminated Zone (m)	2	2618, 1309, 655	Yes, 13 mrem/yr lower when 1/2 as long (no change if doubled)
Width of contaminated Zone (m)	2	1824, 912, 456	Yes, 12 mrem/yr lower when 1/2 as wide (no change if doubled)
Ra-226 Distribution Coefficient (Kd, cm^3/g)	2	140, 70, 35	Yes, ± 17 to 21 mrem/yr at max dose (446 yrs) due to differences in leaching
Precipitation (cm)	2	30, 15, 7.5	Yes, ± 17 to 21 mrem/yr at max dose (446 yrs) due to differences in erosion
Density of Cover (g/cm^3)	2	2.25, 1.5, 1	Yes, ± 13-15 mrem/yr and time of RBD varies by ± 150-220 yrs due to major differences in erosion rate
Soil Erodibility Factor (cover)	1.5	0.405, 0.27, 0.18	Yes, ± 13-15 mrem/yr and time of RBD varies by ± 150-220 yrs due to major differences in erosion rate
Non-Leafy Root Depth (m)	2	2.4, 1.2, 0.6	Slight (+1 mrem/yr if 1/2 root depth)
Leafy Vegetable Root Depth (m)	2	0.6, 0.3, 0.15	Negligible, less than ± 0.5 mrem/yr

There are several key conclusions that can be drawn from the sensitivity analysis results shown in Tables 2 and 3. First, deterministically modeled RBD values for both surface and subsurface soil contamination scenarios are significantly influenced by parameters that relate to the emission of gamma radiation from residual byproduct Ra-226 in soils (indoor shielding and indoor/outdoor occupancy factors, along with the areal dimensions of the contaminated zone). This makes sense as direct exposure to gamma radiation is the dominant dose pathway responsible for the RBD.

Secondly, the deterministic RBD for subsurface soil is also strongly influenced by the density of the cover due to shielding of gamma radiation and a direct relationship with the rate of cover erosion. Varying the cover density not only significantly changes the RBD, but also changes the year in which the RBD occurs (446 ± 150-220 years). The subsurface RBD is also influenced by the solid/solute partitioning coefficient (K_d) for Ra-226 in soils as this governs the respective leach rate and the max dose for subsurface soils does not occur until the cover has eroded away (while the cover is eroding, Ra-226 has time to leach out of the contaminated zone). Precipitation and soil erodibility factors also have a strong influence on the subsurface RBD due to their direct relationships with erosion of cover soils.

Finally, model parameters related to other dose pathways (plant or meat ingestion) have negligible or no influence on the RBD. Because there are a number of model parameters that have a significant impact on the deterministically modeled RBD, it is appropriate to perform a probabilistic analysis where respective parameters are allowed to vary in the modeling to help account for real-world variability.

3.5 Uncertainty Analysis

Uncertainty analysis is a probabilistic procedure used to consider uncertainty in the modeled result (in this case the RBD) due to variability in model input parameters. It is commonly used to determine a probabilistic value at a specified percentile of the model output distribution (e.g. the median). An uncertainty analysis was performed using RESRAD-OFFSITE default distributions (where available) for parameters identified through sensitivity analysis to have significant impacts on the deterministic RBD. Where default distributions were not available, simple triangular or normal (Gaussian) distributions were assumed, with statistical attributes (min/max, mode, mean, std. dev.) selected based on regulatory specifications, available pertinent information, and/or professional judgment.

Uncertainty analysis in RESRAD-OFFSITE was not available for two of the identified parameters (soil density and erodibility factor for cover soils). For all other identified parameters, probabilistic utilities in RESRAD-OFFSITE were used to generate model input distributions. The results (Figure 8) are assumed to represent reasonable approximations of variability in these parameters for the modeled scenarios. Sampling specifications for the uncertainty analysis included a random seed number, with three repetitions of 1000 semi-random value selections from the parameter distributions shown in Figure 8. The sampling algorithm used was Latin Hypercube (a modified version of Monte Carlo sampling that ensures representative sampling in the tails of the distributions).

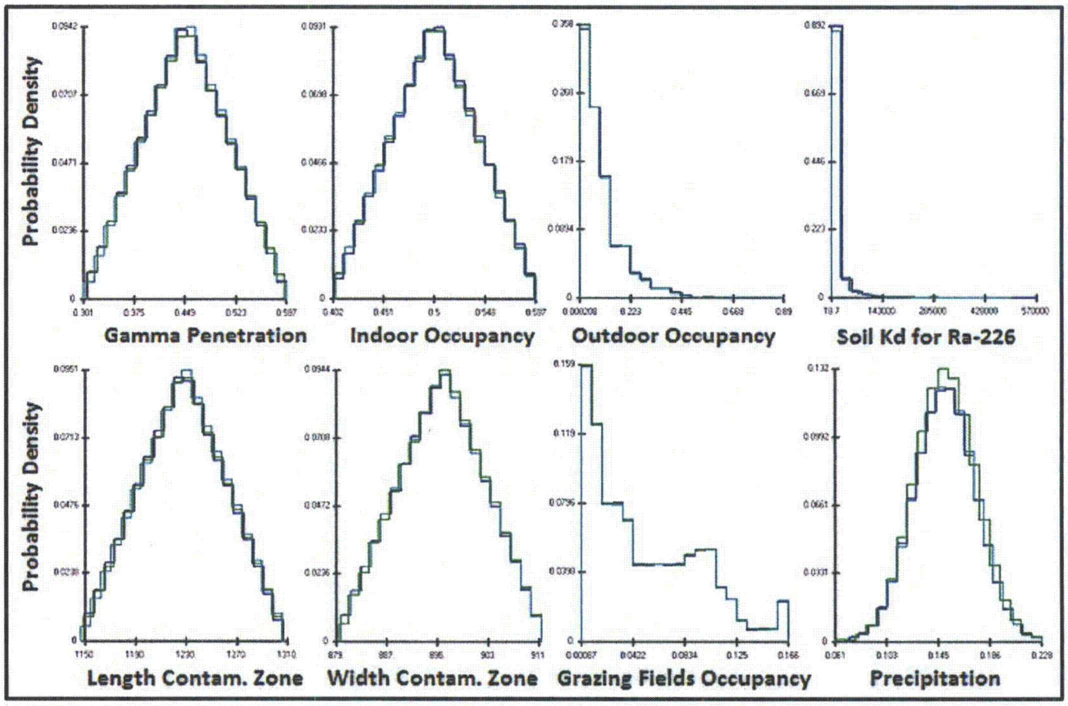

Figure 8: Assumed probability distributions for RBD modeling parameters selected for inclusion in the uncertainty analysis based on sensitivity analysis results.

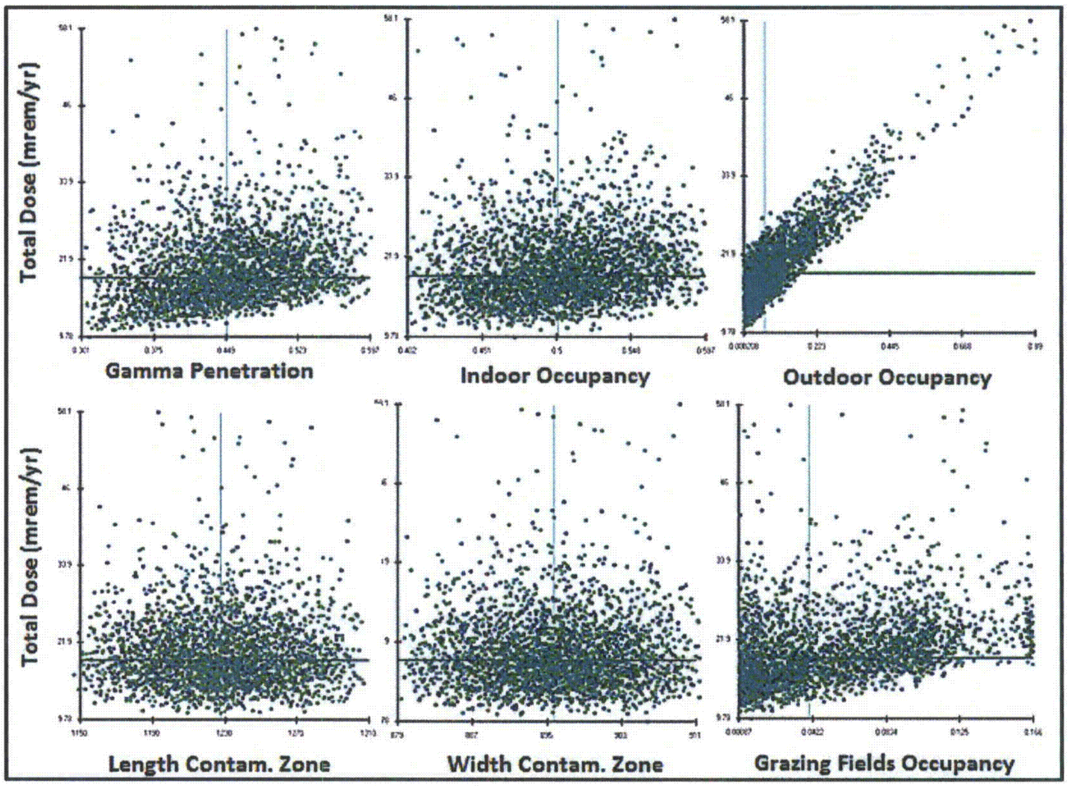

Figure 9: Uncertainty analysis output: relationships between maximum total dose for the contaminated surface soil scenario versus model parameters selected based on sensitivity analysis results.

For the contaminated surface soils scenario, uncertainty analysis output indicates that when multiple parameters are allowed to vary in the model, there is not a significant correlation between the areal dimensions of the contaminated zone and dose (Figure 9). Outdoor occupancy within the contaminated zone has a strong correlative relationship with maximum dose. Other parameters have only slight to mild individual correlations with maximum dose (Figure 9), yet inclusion of each of these parameters in a multiple regression model appears to improve the amount of variation in dose that is explained by the full predictive model ($R^2 = 0.91$).

For the contaminated subsurface soils scenario (15-30 cm layer with 15 cm of clean cover), the areal dimensions of the contaminated zone were excluded from the uncertainty analysis based on a lack of correlation with dose for the surface soils scenario (Figure 9). However, two additional variables were added to the analysis, including annual precipitation and the K_d for soil Ra-226 due to their potential influence on dose as previously indicated. The uncertainty analysis output indicates that when multiple parameters are allowed to vary, there is not a significant correlation between these additional two parameters and the total dose. The other parameters (outdoor occupancy, grazing field occupancy, gamma penetration factor, and indoor occupancy) exhibit correlative relationships with total dose that are similar to those shown in Figure 9, though maximum doses are greater.

Final output results from of the uncertainty analysis modeling described above represent populations of predicted RBD values that appear to approximate normal or somewhat lognormal distributions for the surface and subsurface soil contamination scenarios (Figure 10). Figure 10 provides probabilistic and statistical information regarding the potential amount of uncertainty associated with the modeled RBD due to variability in occupancy factors and other influential parameters with respect to the primary dose pathway (external dose from direct radiation) under a resident rancher receptor scenario at the Sweetwater Uranium Project site.

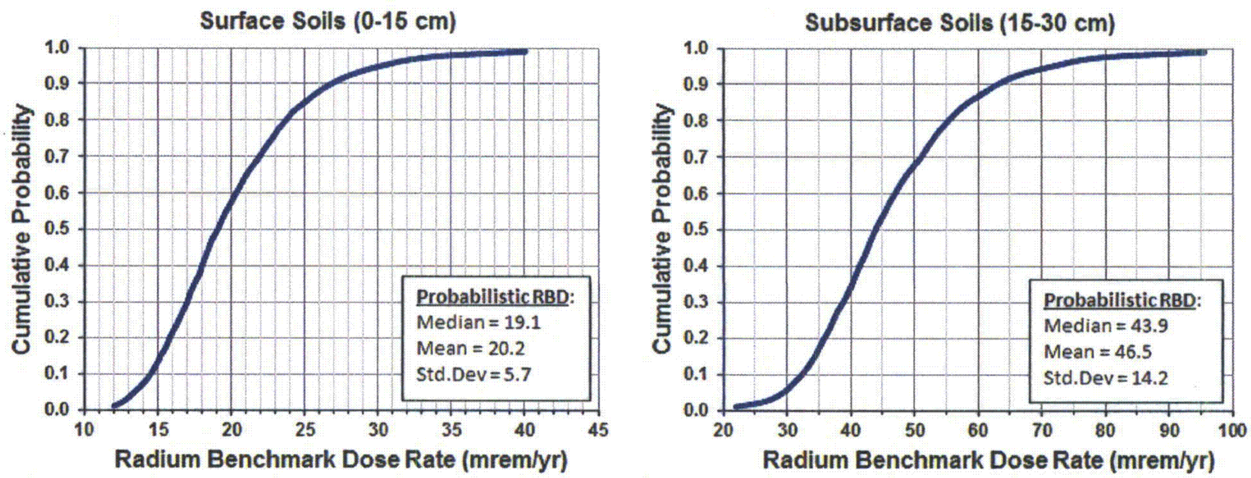

Figure 10: Probabilistic RBD output results from uncertainty analysis modeling for 5 pCi/g of residual byproduct Ra-226 and Pb-210 in surface soils (left) and 15 pCi/g in subsurface soils (right) for a future rancher residing at the former Sweetwater Uranium Project site.

The most probable RBD values for each soil contamination scenario, after accounting for variability in multiple input parameters that influence the dominant dose pathway, are represented by measures of central tendency such as the median or the mean. Because the median is slightly lower in each case (i.e. more conservative in terms of calculating DCGLs for radionuclides other than Ra-226), median values from each distribution of RBD results (19.1 mrem/yr for surface soils, and 43.9 mrem/yr for subsurface soils) were selected as the final RBD values for use in determination of DCGLs for uranium and Th-230.

4. SOIL CLEANUP CRITERIA FOR TH-230

Based on the probabilistic RBD for surface soils (19.1 mrem/yr), a Th-230 soil concentration required to produce an equivalent maximum dose rate (a DCGL for Th-230) was modeled using the same receptor scenario, exposure pathways, and parameter assumptions. To accomplish this, a hypothetical and mathematically convenient soil concentration of 100 pCi/g was modeled for use in a scaling equation (Equation 1) to determine the DCGL for Th-230 at the RBD. Equation 1 is provided as follows:

$$\frac{\text{DCGL}}{\text{RBD}} = \frac{\text{Radionuclide Conc. of 100 pCi/g}}{\text{Max Dose from 100 pCi/g}} \qquad \text{Equation 1}$$

<u>Where</u>:

DCGL = Derived Concentration Guideline Level for radionuclide (pCi/g)
RBD = Probabilistic RBD (19.1 mrem/yr for surface soils, 43.9 pCi/g for subsurface soils)

For Th-230, the maximum dose from 100 pCi/g in surface soils (0-15 cm) is 40.3 mrem/yr (occurring at 258 years). Scaling this result against the surface soils RBD with Equation 1 results in a DCGL for Th-230 in surface soils of 47.4 pCi/g. A temporal plot of the dose due to Th-230 at this DCGL in surface soils is shown in Figure 11. The dose is almost entirely attributable to direct exposure to gamma radiation due to the ingrowth of Ra-226. The maximum dose occurs at year 258 then declines as the effect of erosion losses begins to exceed the effect of Ra-226 ingrowth. Contributions from ingestion pathways are negligible (Figure 11).

Because the calculated DCGL for residual byproduct Th-230 concentrations in surface soils is higher than the numeric limit cited in NUREG-1620 (based on build-up of Ra-226 in excess of 5 pCi/g within 1000 years), further assessment was not necessary. Residual byproduct Ra-226 concentrations after the cleanup are expected to be near background levels and thus, the more restrictive numeric limit for Th-230 of 14 pCi/g will be used as the cleanup level for Th-230 in surface soils.

For subsurface soils (15-30 cm with 15 cm of clean cover), the maximum dose from 100 pCi/g of residual byproduct Th-230 is 89.1 mrem/yr (occurring at 525 years). Scaling this result against the subsurface soils RBD with Equation 1 results in a DCGL for Th-230 in subsurface soils of 49.3 pCi/g. A temporal plot of the dose due to Th-230 at this DCGL in subsurface soils is shown in Figure 12. Again the dose is

almost entirely attributable to direct exposure to gamma radiation due to the ingrowth of Ra-226. The maximum dose occurs at year 525 then declines as the effect of erosion losses begins to exceed the effect of Ra-226 ingrowth. Contributions from ingestion pathways are negligible (Figure 12).

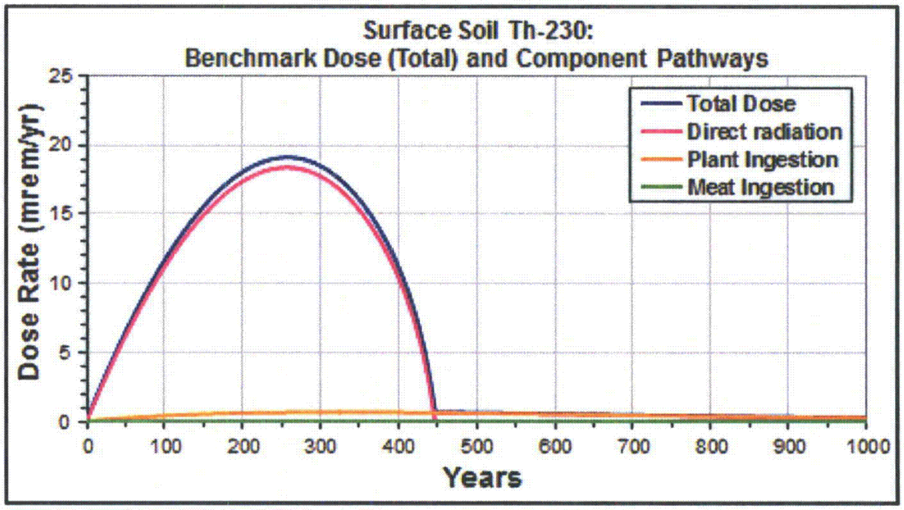

Figure 11: Modeled dose for a derived soil Th-230 concentration (DCGL) of 47.4 pCi/g in surface soils (0-15 cm).

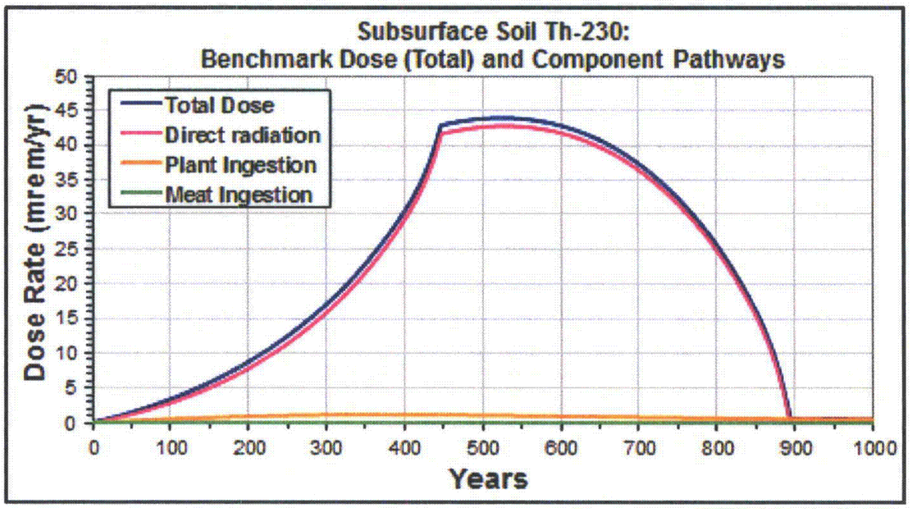

Figure 12: Modeled dose for a derived soil Th-230 concentration (DCGL) of 49.3 pCi/g in surface soils (0-15 cm).

Because the calculated DCGL for residual byproduct Th-230 concentrations in subsurface soils is higher than the numeric limit cited in NUREG-1620 (based on build-up of Ra-226 in excess of 5 pCi/g within 1000 years), further assessment was not necessary. Residual byproduct Ra-226 concentrations after the cleanup are expected to be near background levels and thus, the more restrictive numeric limit for Th-230 of 43 pCi/g will be used as the cleanup level for Th-230 in subsurface soils.

5. SOIL CLEANUP CRITERIA FOR URANIUM

Based on the probabilistic RBD for surface soils (19.1 mrem/yr), a natural uranium (U-nat) soil concentration required to produce an equivalent maximum dose rate (a DCGL for U-nat) was modeled using the same receptor scenario, exposure pathways, and parameter assumptions. A hypothetical soil concentration of 100 pCi/g was modeled for use in the scaling equation (Equation 1) to determine the DCGL for U-nat at the RBD. The isotopic composition of U-nat that was modeled based on the following natural radiological abundances: 48.9% each for U-238 and U-234, and 2.2% for U-235.

For U-nat, the maximum dose from 100 pCi/g in surface soils (0-15 cm) is 5.9 mrem/yr (at t = 0 years). Scaling this result against the surface soils RBD with Equation 1 results in a DCGL for U-nat in surface soils of 324 pCi/g. A temporal plot of the dose due to U-nat at this DCGL in surface soils (Figure 13) shows that the dose is almost entirely attributable to direct gamma radiation due to short-lived decay products and U-235. The maximum dose occurs at t = 0 years and declines until the contaminated surface layer erodes away. Contributions from ingestion pathways are negligible (Figure 13).

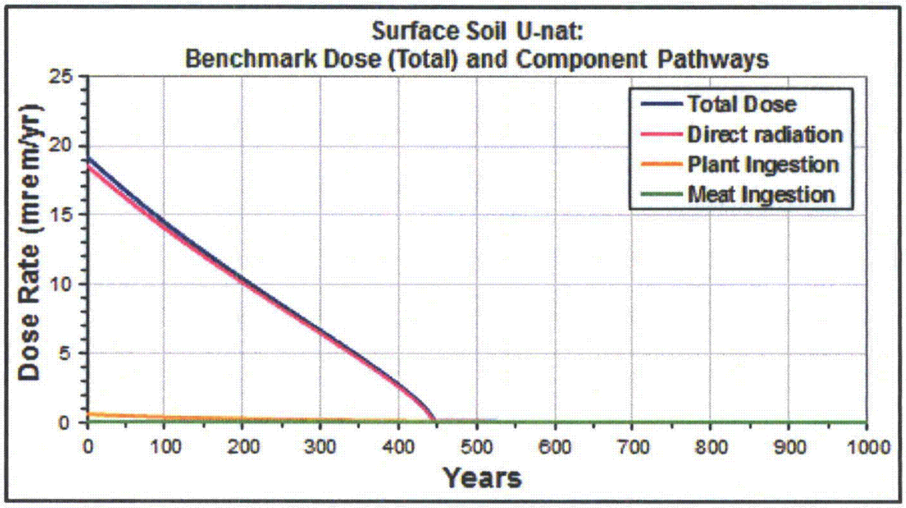

Figure 13: Modeled dose for a derived soil U-nat concentration (DCGL) of 324 pCi/g in surface soils (0-15 cm).

For subsurface soils (15-30 cm with 15 cm of clean cover), the maximum dose from 100 pCi/g of residual byproduct U-nat is 2.35 mrem/yr (occurring at 447 years). Scaling this result against the subsurface soils RBD with Equation 1 results in a DCGL for U-nat in subsurface soils of 1,868 pCi/g. A temporal plot of the dose due to U-nat at this DCGL in subsurface soils is shown in Figure 14. Again the dose is almost entirely attributable to direct gamma radiation, with small contributions from ingestion pathways.

Appendix H of NUREG-1620 indicates that chemical toxicity should also be considered in deriving a soil uranium concentration limit if soluble forms of uranium are present. Soluble uranium associated with residual byproduct material at the site is highly unlikely. The mill operated for only two years and

yellowcake was dried with a 4-hearth high-fired calciner. The chemical form of any related releases to the environment would have been insoluble, and this is likely true for ore dust as well. Any soluble forms of uranium that could have conceivably been released to surface soils during operations decades ago is unlikely to still be present near the soil surface after more than 30 years of oxidation and leaching.

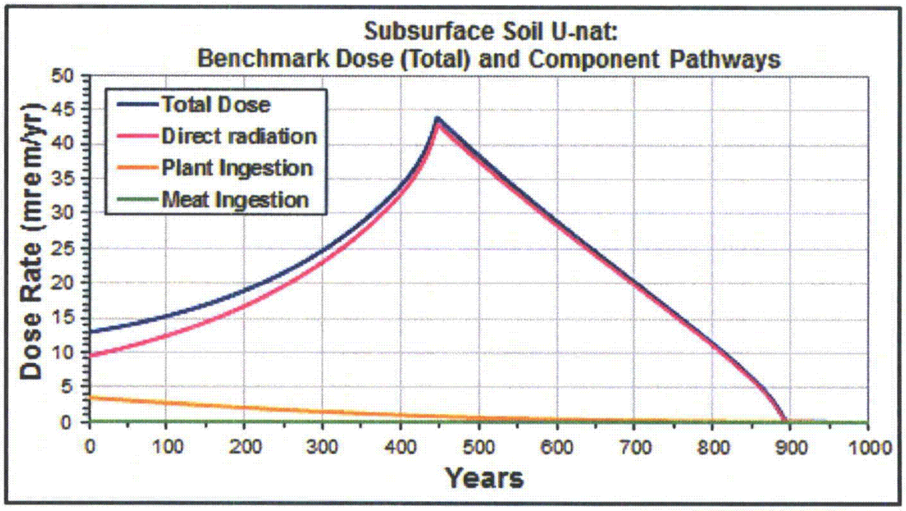

Figure 14: Modeled dose for a derived soil U-nat concentration (DCGL) of 1,868 pCi/g in subsurface soils (15-30 cm).

In addition, NUREG-1620 indicates that solubility and respective inhalation Class for the chemical form of uranium should be considered when deriving the DCGL for uranium. Occupational inhalation doses from uranium at the site are calculated based on the Class Y (insoluble) allowable limit on intake (ALI) (10 CFR 20, Appendix B). For the purposes of developing a DCGL for uranium based on the RBD, the RESRAD-OFFSITE modeling demonstrates that inhalation is not an important pathway for the modeled receptor scenario (essentially no dose from inhalation of airborne particulate radionuclides). This finding is consistent with the results of decades of air monitoring at the site. Default dose conversion factors from FGR 11 were thus used to model inhalation doses from uranium.

6. CRITERIA SUMMARY AND SITE APPLICATION

6.1 Summary of Soil Cleanup Criteria

The preceding soil decommissioning criteria (derived soil concentration guideline levels representing site-wide "$DCGL_W$" criteria) for the Sweetwater Uranium Project site, based on the Radium Benchmark Dose Approach as required by 10 CFR 40 Appendix A Criterion 6(6), are summarized in Table 4. These criteria represent the maximum above-background concentrations of residual 11.e(2) byproduct radionuclides in soil that would meet NRC criteria for release of the site for unrestricted future use. The $DCGL_W$ criteria in Table 4 do not include the additional ALARA requirement specified in Criterion 6(6). Appendix H of NUREG-1620 describes removing an additional 2 inches of soil as a potentially appropriate measure to fulfill this requirement, though at this site, there are indications of naturally

occurring elevated levels of radionuclides in subsurface soils (discussed further later in this Section) and this potential must be considered in a context of the ALARA requirement.

Table 4: Final soil decommissioning criteria (site-wide $DCGL_W$ values) for the Sweetwater Uranium Project site based on 10 CFR 40, Appendix A, Criterion 6(6) regulatory requirements for uranium mills.

Soil Decommissioning Criteria for Surface Soils (0-15 cm)				
Radionuclide	RBD (mrem/yr)	Modeled $DCGL_W$ (pCi/g)	Numeric Standard (pCi/g)	Final Soil $DCGL_W$ (pCi/g)*
Ra-226	19.1	-	5	5
Th-230	19.1	47.4	14	14
U-nat	19.1	324	-	324

Soil Decommissioning Criteria for Subsurface Soils (> 15 cm)				
Radionuclide	RBD (mrem/yr)	Modeled $DCGL_W$ (pCi/g)	Numeric Standard (pCi/g)	Final Soil $DCGL_W$ (pCi/g)*
Ra-226	43.9	-	15	15
Th-230	43.9	49.3	43	43
U-nat	43.9	1,868	-	1,868

*Pending application of ALARA requirements of Criterion 6(6)

As previously indicated, any 100 m^2 area containing more than one of these byproduct radionuclides must meet the sum of fractions or "unity rule", which for this site is defined as follows:

$$\frac{Conc._{U\text{-}nat}}{DCGL_{U\text{-}nat}} + \frac{Conc._{Th\text{-}230}}{DCGL_{Th\text{-}230}} + \frac{Conc._{Ra\text{-}226}}{DCGL_{Ra\text{-}226}} \leq 1 \qquad \text{Equation 2}$$

The unity rule is typically applied during site remediation and final status surveys in accordance with the methodologies described in MARSSIM, the Multi-Agency Radiation Survey and Site Investigation Manual (NRC, 2000). MARSSIM assumes that concentrations will be relatively uniform after remediation, and does not call for sampling individual 100 m^2 areas to demonstrate compliance. Instead, larger "survey units" are evaluated based on discrete soil sampling and gamma surveys (with gamma/radionuclide correlations) to demonstrate compliance with individual wide-area DCGLs (termed "$DCGL_W$") as well as the unity rule. The DCGLs developed in this report represent $DCGL_W$ criteria. For small elevated areas (hot spots), a different DCGL (termed "$DCGL_{EMC}$") is calculated based on area factors (AFs) (NRC, 2000).

6.2 Area Factors

Following the basic approach described in MARSSIM, AFs were modeled for contaminated surface soils under the resident rancher scenario based on the $DCGL_W$ values provided in Table 4, along with the

modeled dose for this scenario for various sizes of the contaminated zone (ranging from the full area shown in Figure 2 down to 2 m^2) (Figure 15). The resulting AFs for radiologically elevated areas smaller than 100,000 m^2 (about 25 acres) are shown in Figure 16.

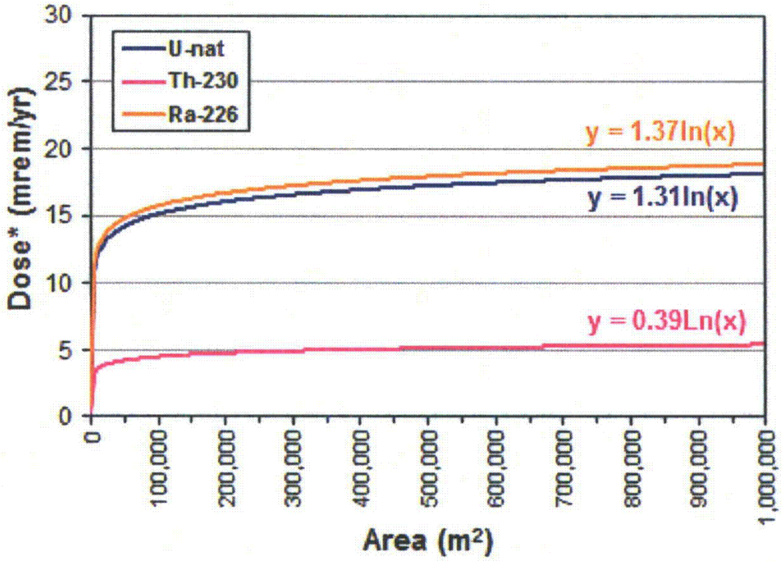

Figure 15: Modeled relationships between dose and area of surface soil contamination. *Note that the curve for deterministically modeled Ra-226 dose was normalized against the probabilistic RBD (19.1 mrem/yr). The maximum dose for U-nat is slightly lower due to prediction error in the fitted curve. The Th-230 dose is well below the RBD as the $DCGL_W$ used (14 pCi/g) is based on a numeric criterion rather than the RBD. Negative intercept terms for these non-linear regressions were set to zero (although this over-predicts actual modeled doses for very small areas, it avoids unrealistic negative values and is conservative for calculating area factors).

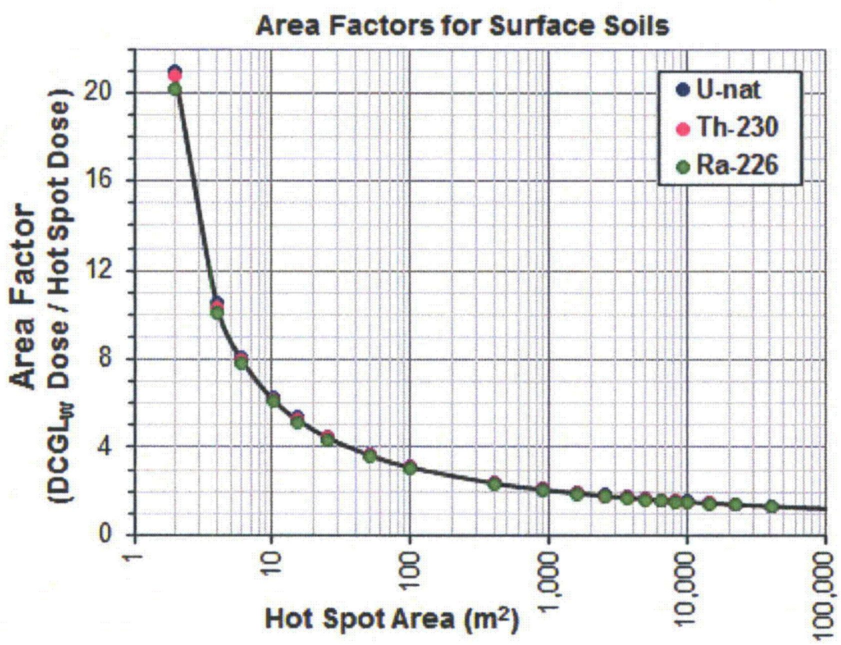

Figure 16: Modeled AFs for surface soils based on the relationships between dose and area of contamination in Figure 15.

These AFs can be used to easily determine the concentration of U-nat or Ra-226 in surface soils across a small "hot spot" that would comply with the probabilistic RBD (19.1 mrem/yr) for uniform residual concentrations across the entire contaminated zone[1] as shown in Figure 2. In the case of Th-230, these AFs can also be used to determine hot spot compliance with the 5.6 mrem/yr dose attributable to the numeric $DCGL_W$ of 14 pCi/g for Th-230. These hot spot criteria ($DCGL_{EMC}$ values) are calculated by multiplying the applicable $DCGL_W$ value from Table 4 by the appropriate AF from the curve in Figure 16 for the size of the identified hot spot in question (Equation 3). An example calculation of a $DCGL_{EMC}$ for elevated Ra-226 across a hypothetical 10 m^2 hot spot is as follows:

- AF for 10 m^2 (from Figure 16) = 6
- $DCGL_W$ for Ra-226 = 5 pCi/g
- Hot spot criterion: $DCGL_{EMC} = DCGL_W \times AF$ Equation 3

$$= 5 \text{ pCi/g} \times 6 = 30 \text{ pCi/g}$$

Thus, in this example, 30 pCi/g represents the maximum average above-background concentration of residual byproduct Ra-226 in surface soils within a 10 m^2 hot spot that would maintain compliance with the overall probabilistic Radium Benchmark Dose for the entire site (19.1 mrem/yr). If Th-230 and/or U-nat were also elevated within in this hypothetical hot spot, the unity rule (Equation 2) would apply.

Area factors for hot spots in subsurface soils (15-30 cm depth with 15 cm of clean cover) were also developed and results (Figure 17) are nearly identical to those developed for surface soils. Under the same receptor scenario, AFs for doses from direct gamma radiation do not vary significantly for different source radionuclides or variable soil concentrations (Abelquist, 2008). In this case, the direct radiation pathway is dominant in both model scenarios and respective total doses are proportional.

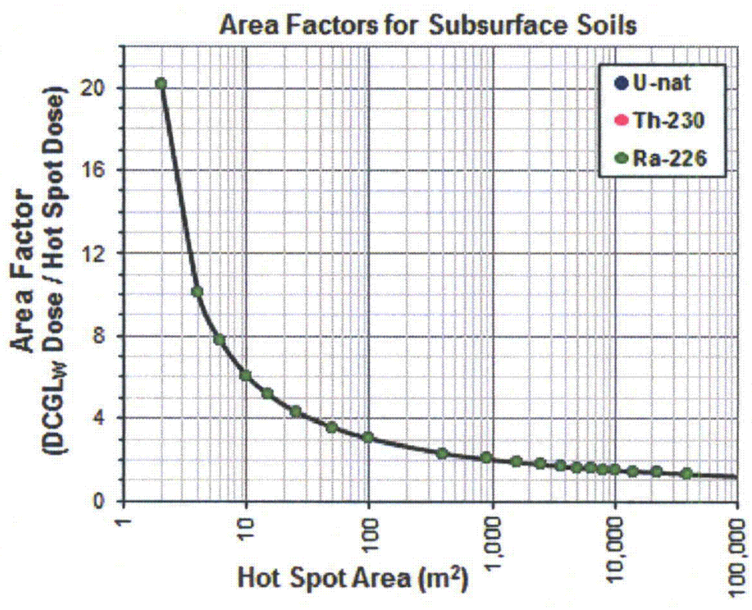

Figure 17: Modeled AFs for subsurface soils based on modeled dose/area relationships for subsurface soil contamination.

[1] The calculated scenario-specific AFs for this site are similar to generic example AFs provided in Table 5.6 of MARSSIM for Ra-226 and U-238 [differences in the MARSSIM examples are due to a much smaller base reference area (10,000 m^2), possible differences in dose pathways and other model parameter selections, and greater complexity in the receptor scenario and environmental parameters considered with RESRAD-OFFSITE modeling].

6.3 Application of Soil Cleanup Criteria

A MARSSIM-based approach for evaluating compliance with soil cleanup criteria as described in the previous Sections will be used during site decommissioning. This approach requires consistency in interpretation of the technical intent and areal basis for the numeric 5/15 soil radium standard and soil cleanup criteria based on the RBD approach. For example, if the 5 pCi/g numeric standard for Ra-226 in surface soils (analogous to a $DCGL_W$ based on the RBD approach) is evaluated for a single 100 m^2 hot spot based on MARSSIM principles, the concentration that would be in compliance with the 19.1 mrem/yr Radium Benchmark Dose is 15 pCi/g. This would indicate regulatory compliance based on dose (which is consistent with the intent of the RBD approach as well as with MARSSIM), but not if compliance were to be judged based on the numeric 5/15 rule for any single 100 m^2 area. This issue requires further discussion with respect to the regulatory intent, history and relationship between the numeric 5/15 soil radium standard and the RBD approach.

Based on NUREG-1620 guidance, realistic receptor scenarios and modeling parameters are required for RBD modeling, and the modeled contamination zone is to be based on the extent of known or expected areas of impacts across the site (NRC, 2003; NRC, 1998). For uranium mill sites, the contaminated area usually represents an area large enough to realistically accommodate the modeled future receptor scenario. A farmer or rancher could not realistically reside on and derive a living from a 100 m^2 area, and modeling the RBD on this basis would not be reasonably or scientifically justified. As detailed below, the regulatory intent of the numeric 5 pCi/g concentration limit as specified for surface soils in the 5/15 rule was to limit doses from large areas of contamination, while the *areal dimensions* of the 5/15 rule (100 m^2) were specified for analytical reasons.

When the U.S. Environmental Protection Agency (EPA) originally promulgated the numeric 5/15 soil radium standard for uranium mills (as codified in 40 CFR 192) under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), the intent of the 5 pCi/g criterion for surface soils was to limit health risks (doses) from gamma radiation to acceptable levels for unrestricted use by members of the public (EPA, 1998). The Final Environmental Impact Statement that was used by the EPA as the basis for ultimately selecting the 5/15 rule to meet their responsibility for developing standards for uranium mills under UMTRCA (EPA, 1983), included related evaluations based on health risks from indoor radon and external radiation from a finite contaminated soil layer thickness with infinite plane horizontal dimensions. This selection was not based on health risks from a small 100 m^2 contaminated area.

The rationale for the 100 m^2 areal dimensions specified in the numeric 5/15 soil radium standard was related to analytical considerations concerning the sensitivity of radiation detection instruments (EPA, 1992; EPA, 1998). This was particularly true for the 15 pCi/g subsurface portion of rule, which was specifically intended to facilitate detection of buried tailings with radiological survey instruments (EPA, 1998). In addition to protecting human health, analytical cost-efficiency was a prominent consideration in deriving UMTRCA standards as Federal funds were involved.

In 1998, the NRC clearly recognized this distinction while evaluating the proposed Radium Benchmark Dose approach for pending rulemaking with respect to license termination issues at uranium mills as the Agency utilized a contaminated area of 300 acres for RESRAD modeling to assess resulting RBD values under various receptor scenarios (NRC, 1998). It is clear that the NRC's intent in developing the RBD approach and Criterion 6(6) was to determine DCGLs for uranium and thorium that are benchmarked against the total dose due to uniform concentrations of residual Ra-226 at the numeric 5 pCi/g standard across the entire footprint of impacted areas, and this dose is the basis under which compliance with both the numeric 5/15 soil radium standard and the RBD should be evaluated under 10 CFR 40 Appendix A and Criterion 6(6) requirements.

Compliance with the original intent of the 100 m^2 areal dimensions of the 5/15 rule can be achieved by ensuring that the analytical methods to be employed during final status surveys for evaluation of soil Ra-226 concentrations across the site can detect an average above-background concentration of 5 pCi/g or less across areas as small as 100 m^2. This aspect of compliance relates to the "sensitivity" of the survey, and will be addressed with a combination of an appropriate degree of gamma survey coverage (e.g. approaching 100% coverage of remediated areas), an adequate minimum detectable concentration (MDC) for gamma survey systems (known in MARSSIM as the "scan MDC"), and sufficient soil sampling for statistical testing under MARSSIM (NRC, 2000). Determination of compliance with the overall soil cleanup criteria developed in this report (the $DCGL_W$ values in Table 4) will be fundamentally based on compliance with the Radium Benchmark Dose as assessed using MARSSIM methods, including application of the AFs provided in Figures 16 and 17 for evaluation of small areas of elevated soil concentrations that may be detected during final status surveys.

In addition to the reasons indicated above, this dose-based MARSSIM approach will be particularly important at this site for another reason. As indicated in Section 2.10 of the license renewal application, there is considerable evidence of a naturally mineralized zone of significantly elevated levels of these radionuclides that underlies the entire footprint of facilities and disturbed areas at the site, with depths ranging from near surface expression in southern portions of the site, to a depth of about 80 feet to the northwest in the direction of the mine. Background concentrations as previously established for surface and subsurface soils may not be applicable in the immediate vicinity of mill facilities during soil cleanup. The gross cleanup criteria to be applied in these areas must take this into account in order to avoid cleanup of naturally occurring mineralization and a counterproductive remedial outcome. Such remediation could actually increase the "background" dose to levels that exceed the above-background Radium Benchmark Dose. This would be inconsistent with the intent of Criterion 6(6), including its ALARA requirements.

Given the above considerations, and because it may be difficult in some areas to distinguish residual byproduct contamination near the soil surface from underlying naturally occurring mineralization, this dose-based approach using MARSSIM methods, including the $DCGL_W$ criteria in Table 4 and area factors in Figures 16 and 17, will be important for optimizing the effectiveness of soil decommissioning at the site. The approach is expected to achieve an acceptably protective remedial outcome that is consistent with the technical intent of the numeric 5/15 soil radium standard as well as with the Radium

Benchmark Dose Approach, yet will also minimize the potential for unnecessary excavation and disposal of large quantities of naturally occurring mineralization, which itself could create new and unintended risks to remediation workers, the public and the environment.

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