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Modeling Soil/Radionuclide Removal for Yucca Mountain Biosphere Dose Assessments

Richard Aguilar
Sandia National Laboratories
P.O. Box 5800, MS-0776
Albuquerque, NM 87185-0776

raguilar@sandia.gov

Anthony J. Smith
Duke Engineering & Services
Las Vegas, NV

Introduction

Land resources that are continuously irrigated with contaminated water may experience an increase in soil contaminant levels. The degree of contaminant increase can be alleviated by surface processes, including erosion. Soil erosion rates on agricultural land are dependent upon the various land use patterns (types of crops grown) and management techniques practiced by the land-owners. Therefore, estimates of annual surface soil loss are needed to assess the degree of potential build up of radioactivity in lands subjected to on going irrigation with contaminated water. This paper describes a method for estimating potential surface soil removal rates (cm/yr) from agricultural land in the vicinity of the proposed Yucca Mountain repository and the modeling approach used to assess the potential dose effect from build up of radionuclides in soils.

Modeling Approach

For the Yucca Mountain project's performance assessment (PA) the biosphere's lower boundary is established at the bottom of the agricultural plow layer (assumed to be 6.0 inch or approximately 15-cm depth) (Leigh et al. 1993, Section 5.2.1, p. 5-4). Introduced contaminants, including radionuclides, are either retained within the soil or are removed by one of four major mechanisms (radioactive decay,

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surface removal, leaching, or uptake by flora or fauna – predominantly plant uptake). The decay, leaching, and plant uptake processes are considered as submodel components in the GENII-S code (Leigh et al. 1993), the computational computer model used for the biosphere modeling. The code calculates a biosphere dose conversion factor (BDCF) for each of the radionuclides considered in the analysis by assuming a unit concentration of that radionuclide in the groundwater and then evaluating the dilution of the activity due to radionuclide removal from, or retention within, the soil layer.

To incorporate the soil loss mechanism, it is assumed that erosion rates are increased in land used for agricultural and/or domestic purposes (CRWMS M&O 2000a, Section 5.1). The rate of soil removal by erosion under natural conditions is in approximate equilibrium with the rate of formation resulting from the weathering of underlying parent material including bedrock, alluvium, and any other material. Under these conditions, the soil depth (or thickness) is maintained at a near constant depth (Troeh et al. 1980, p. 4). Anthropogenic activities, including tilling of cropland, removal of vegetation, and grazing of pasture or rangeland, typically tend to increase the natural rate of soil removal for a given environment. When the formation of new soil cannot keep pace with the increased erosion rate, the soil profile progressively becomes thinner until a new equilibrium is established or the soil is removed entirely (Troeh et al. 1980, pp. 5-6).

Annual loss estimates used for the Yucca Mountain PA are based upon soil loss tolerance indices (*T*-values) that define maximum allowable annual surface loss, in tons per hectare per year, beyond which the continued productivity of land resources are compromised (USDA NRCS 2000, Exhibit 618-14). USDA-established soil-loss tolerance indices, *T*-values, are considered sound, reasonable, and defensible representations of the maximum annual losses that would potentially occur in the Amargosa Valley area, now and in the future, if current institutional controls (such as federal, state, and county agricultural extension services) remain in place. Additional annual soil losses would lead to a decline in productivity and the land would subsequently be taken out of its current use.

The first step was to determine the properties of the dominant soils occurring within the area of interest, Lathrop Wells in the Amargosa Valley. This area is hydrologically located down-gradient from Yucca Mountain and has been designated as the location of the hypothetical critical group for the purpose of the biosphere model (64 FR 8640, Section VI – *Reference Biosphere and Critical Group for Yucca Mountain*). The six major soil series occurring within a 5-km radius about Lathrop Wells are listed in Table 1.

Table 1. Loss Tolerance (*T*) and Bulk Density (ρ) and Particle-size Distribution Properties of the Major Soils Used for Agricultural Production in the vicinity of Lathrop Wells, NV.

Soil Series[a]	Soil Loss Tolerance Factor (*T*) (t/ ha/yr)	Bulk Density(ρ) [b] (g/cm^3)	Particle-Size Class	Surface Horizon Texture
Arizo	11.21	1.40 – 1.55	Sandy-skeletal	Very gravelly fine sand
Commski	11.21	1.40 – 1.60	Loamy-skeletal	Very gravelly fine sandy loam
Corbilt	8.97	1.35 – 1.50	Coarse-loamy	Gravelly fine sandy loam
Sanwell	11.21	1.40 – 1.60	Loamy-skeletal	Gravelly fine-sandy loam
Shamock	4.48	1.50 – 1.70	Coarse-loamy	Gravelly fine-sandy loam
Yermo	11.21	1.40 – 1.60	Loamy-skeletal	Cobbly sandy loam

Notes: [a] Data extracted from CRWMS M&O (1999), Figure 1, pp. 2-3 and Appendix C.
[b] CRWMS M&O 2000a, Table 1, Soil Bulk Density.

To calculate annual depth reduction (cm/yr) for each of the major soils the annual erosion rate (tons/ha/yr) corresponding to their *T*-values were multiplied by the reciprocal of the bulk density (ρ). For example, the annual loss for the Arizo soil was calculated as follows:

T = 11.21 t/ha/yr
$\rho = 1.40\ g/cm^3$ or $1.40 \times 10^{-6}\ t/cm^3$

The annual depth reduction for this soil is:

$$11.21 \text{ t/ha/yr} \times \frac{1.0 \text{ cm}^3}{1.4 \times 10^{-6} \text{ t}} \times \frac{1 \text{ m}^2}{10{,}000 \text{ cm}^2} \times \frac{1.0 \text{ ha}}{10{,}000 \text{ m}^2} = 0.08 \text{ cm/yr}$$

The assumption is made that the surface soil has a radionuclide distribution of radionuclides with depth that is constant over the (15 cm) rooting zone (Napier, et al 1988 section 4.6.2). For cultivated land, this is justified by assuming plowing (roto-tilling for home gardens) to this depth provides this uniform mixing.

Next the annual input of radionuclides to soil is considered in the GENII-S calculations (Leigh et al. 1993, Section 5.3).

To account for the radionuclide build up in soil, BDCFs were calculated for each of six periods of cumulative years of irrigation with contaminated groundwater (CRWMS M&O 2000b, Section 6.1). With these calculations, it was possible to evaluate whether potential build up of radioactivity in soil would change the estimated radiation doses. The irrigation time periods are the number of years that the land has been irrigated with contaminated groundwater before the dose conversion factors are calculated. The periods of previous irrigation are related to the rate of removal of contaminants by leaching and radioactive decay. The first BDCFs were calculated under the assumption of no prior irrigation (i.e., radionuclide contamination in soils is absent). The remaining five irrigation periods were selected so that the BDCFs at each period would be approximately equally spaced between their no-prior irrigation values and their asymptotic levels.

Annual Soil Depth Reduction Estimates

Annual depth reduction estimates corresponding to soil *T*-values for the six soils are generally between 0.06 and 0.08 cm/yr (Table 2). An exception is the Shamock series, which is a moderately deep, gravelly-fine sandy loam soil (CRWMS M&O 1999, Appendix C) and is less resistant to soil erosion than the other deeper soils before experiencing a reduction in productivity. The annual depth reduction estimates in Table 2 represent a reasonable range of potential maximum annual losses that would be allowed to occur assuming that current government (federal, state, county) institutional controls remain in place. For Yucca Mountain PA modeling purposes, a conservative bounding estimate was also made, i.e., that which would result in highest potential dose to a receptor. Under this assumption, erosion would be eliminated altogether. This scenario is considered to be conservative because this would result in the minimal removal of radionuclides from the modeled soil layer and the maximum radiation dose to the receptor. For the purposes of modeling radionuclide build up, the recommended values for potential annual soil loss were therefore established as zero as a conservative estimate and 0.06 cm/yr as a reasonable representation of loss for dose assessment (CRWMS M&O 2000b, Section 4.1.2). At an annual removal rate of 0.06 cm/yr, the complete 15-cm surface soil depth considered in the biosphere modeling would be removed in approximately 250 years (i.e., 15-cm divided by 0.06 cm/yr).

Table 2. Calculated Best Estimate Annual Depth Reductions for the Soils in the Vicinity of Lathrop Wells, Amargosa Valley

Soil Series	***T* Value (t/ha/yr)**	**Bulk Density (*ρ*) (g/cm^3)**		**Annual Soil Depth Reduction (cm/yr)**	
		Lower Range	**Upper Range**	**Lower Bulk Density Estimate**	**Upper Bulk Density Estimate**
Arizo	11.21	1.40	1.55	0.080	0.072
Commski	11.21	1.40	1.60	0.080	0.070
Corbilt	8.97	1.35	1.50	0.066	0.060
Sanwell	11.21	1.40	1.60	0.080	0.070
Shamock	4.48	1.50	1.70	0.030	0.026
Yermo	11.21	1.40	1.60	0.080	0.070

Coupling Irrigation Build Up with Annual Soil Losses

In the final step of the analysis, the mechanism of soil loss was included into the time evolution of BDCFs. For those radionuclides exhibiting less than 20% increase due to continuous irrigation the recommended BDCFs for dose assessment were conservatively approximated by the BDCFs generated for longest irrigation period considered (CRWMS M&O 2000b, Section 6.5). For those radionuclides exhibiting more than 20% build up, it was determined that the effects of surface soil removal should be considered – the five radionuclides considered and the build up factors from GENII-S calculations are shown in Table 3.

The radionuclide accumulation in soil was model by the equation

$$\frac{dq(t)}{dt} = I - \lambda q(t) \qquad \text{(Eq. 1)}$$

where:

q = concentration of radionuclides in soil (pCi/m^2),

I = radionuclide input rate (pCi/m^2/yr),

λ = loss from the mechanisms considered (yr^{-1}).

The solution of this build up equation translates to an equation for BDCFs where C and B are constants:

$$BDCF(t) = C + B(1 - e^{-\lambda t})/\lambda \qquad \text{(Eq. 2)}$$

This equation was fitted to the GENII-S prediction as a function of irrigation period. The optimized fit gave an agreement to within a percent or so of the GENII-S point values. Having established a GENII-S removal rate λ_{GENII}, the additional loss mechanism of soil erosion is incorporated into Eq 3 as $\lambda_{new} = \lambda_{GENII} + \lambda_{erosion}$.

The asymptotic build up factors after including soil erosion are given in Table 3. Comparison of the build up factors prior to and after considering soil loss indicates that erosion only has a significant effect on those radionuclides (^{229}Thorium, ^{243}Americium) where the GENII-S build up times (Column 2 in Table 3) are long in comparison to the estimated soil depletion time; i.e., large ratio between the soil build up factor prior to considering soil removal (Column 3) and the maximum soil build up factor after considering soil removal (Column 4)

Table 3. Biosphere Dose Conversion Factor (BDCF) and Soil Build Up Factors for Radionuclides Introduced to the Biosphere Through Irrigation with Contaminated Groundwater.

Radionuclide	Irrigation Period #6 (Years of Prior Irrigation)	Soil Build Up Factor (Ratio of Period #6 BDCF to Period #1 BDCF)	Max Soil Build Up Factor with Soil Loss
^{229}Thorium	8448	3.74	1.19
^{137}Cesium	78	2.36	2.18
^{90}Strontium	53	1.53	1.50
^{243}Americium	5031	1.98	1.10
^{232}Uranium	93	1.27	1.24

Summary and Conclusions

The estimates of annual soil depth reduction reported in Table 2 are applicable for calculations of cumulative radionuclide build up as a result of irrigation with contaminated groundwater. The radionuclide content removed annually by surface soil removal can be subtracted from the annual irrigation input of radionuclides. Time evolution for the BDCFs as a function of irrigation times provided a basis for discerning whether or not the annual soil removal merits consideration in the biosphere dose calculations. For those radionuclides predicted to yield low build up (less than 20%) there is no need to consider soil removal in subsequent dose calculations and the BDCFs representing maximum build up as a function of prior irrigation are recommended for dose calculations. However, for those radionuclides where the GENII-S build up times are long in comparison to the soil depletion time (i.e., multiples of 250 years), the cumulative effects of annual surface soil removal can have a significant effect on the BDCF values and should be considered in the dose assessment.

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