

Description of Calculations to Support NRC's Supplement to the Yucca Mountain EIS

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Table of Contents	Page
1 Introduction	1
2 The Analytical Solution	4
3 Spreadsheet Implementation and Inputs	7
4 Post-Transport Calculations	10
5 Radionuclide Spreadsheets	12
6 Generation and Transport of New Nonradiological Release Term	14
7 Nonradiological Contaminant Spreadsheets	19
8 Summary of Changes to the Calculations from the Draft to Final Supplement.....	21
9 References	23

1 Introduction

This document provides a description of the calculations used to estimate environmental impacts in the U.S. Nuclear Regulatory Commission (NRC) staff's "Supplement to the U.S. Department of Energy's Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada" (NUREG-2184; hereafter referred to as "the Supplement"), issued in draft for public comment on August 13, 2015, and issued in final form in May 2016 (Agencywide Documents Access and Management System (ADAMS) accession number ML16127A067). The calculations described in this document were confirmed and updated while the draft Supplement was available for public comment. Those updates resulted in some small changes in specific calculated values in some of the tables in the draft Supplement. The revised values along with an explanation of the differences with the draft version were included in the final version of the Supplement. None of the changes in values were significant enough to affect the conclusions in the Supplement.

The methodology for estimating the impacts to the affected environment approximately follows that used in the Department of Energy (DOE) analysis (DOE, 2009, 2014) cited in the Supplement. In completing its analysis, however, the NRC staff made several modifications and corrections to the methodology and inputs used by DOE, as well as performed new calculations. Primarily, the revisions by the NRC staff:

- (i) Incorporated corrections in both radiological and nonradiological contaminant calculation spreadsheets, including cell formula and input value corrections;
- (ii) Substantially revised the nonradiological contaminants repository release source term, including revision of the calculation of transport to the regulatory compliance location;

- (iii) Added new calculations for a fourth affected environment location, the State Line area for radiological and nonradiological contaminants, in addition to the locations of Amargosa Farms, Furnace Creek, and Middle Basin in the DOE analysis;
- (iv) Incorporated linkages between different steps of the calculation to facilitate automatic updating, where one file replaces several unlinked files; and
- (v) Added summary information to the first worksheet in each file that is directly tied to the tables in the draft supplement, including unit conversions, values at 10,000-years and 1 million-years following permanent closure, peak values, and year of peak value.

All modifications to the DOE analysis described in this report were incorporated into the NRC results presented in the final version of the Supplement.

The DOE technical descriptions and calculations in spreadsheets, referred to here as the DOE Calc Package (ADAMS ML11082A018), were provided by DOE in 2009 to support the first version of the “Analysis of Postclosure Groundwater Impacts for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada” (DOE, 2009). The DOE Calc Package was not updated in DOE’s update to this document (DOE, 2014). The present document does not replace the DOE methodology descriptions in the DOE Calc Package, but rather supplements, adds corrections, and improves transparency for calculation results that were incorporated into the Supplement. Therefore, the descriptions in the DOE Calc Package remain useful for understanding the calculations. The DOE descriptions were in the following DOE Calc package files:

- CalcPkg_Rad1_DHL_4-21-09.pdf
- CalcPkg_Met1_DHL_4-26-09.pdf
- CalcPkg_Evap1_DHL_4-22-09.pdf

These descriptions along with the DOE Excel spreadsheet files in the DOE Calc package (ADAMS ML11082A018) may be requested directly from the NRC Public Documents Room (<http://www.nrc.gov/reading-rm/pdr.html>, or contact 800-397-4209 or 301-415-4737).

The spreadsheets in the DOE Calc Package were used by the NRC staff as templates for the staff calculations. To the extent practicable, the files discussed here indicate changes made by the NRC staff to the DOE spreadsheets by using a different color font to distinguish them from the original DOE entries. Note that some changes, such as the addition of worksheets and linkages, were not practicable to show with different colors.

The NRC spreadsheets cited in this document are in ADAMS document ML15245A624, and are available upon request from the NRC Public Documents Room by referencing:

- “Supporting Files for NUREG-2184, Draft Report for Comment, August 2015”

The NRC’s Public Document Room may be reached using 1-800-397-4209 or 301-415-4737, or <http://www.nrc.gov/reading-rm/pdr.html>.

Overview of Calculations

The overall process used for calculating impacts is as follows:

1. Source terms for
 - a. The list of radionuclides were taken from DOE (2014). These were taken from the Total System Performance Assessment (TSPA) results from the license application (DOE 2008a, Safety Analysis Report). These source terms used the TSPA transport convolution to produce results of mass reaching the 18 km compliance boundary as a function of time.
 - b. Nonradiological contaminants molybdenum (Mo), nickel (Ni), and vanadium (V) were based on corrosion rates and surface area of the amount of metal in the repository. A set of new source terms developed by the NRC staff considered the total amount of introduced material used in the engineered barriers and other construction in the repository, and capped the repository release source term when that material was entirely gone. The DOE (2014) nonradiological source terms were uncapped (i.e., corrosion and release continue for 1 million years regardless of the amount of metal that was calculated to be released from the repository).
 - c. Uranium, as both a radionuclide and a toxic chemical, mass flux for each isotope to the affected environment was calculated following the methodology for the radionuclides. For the toxicity impact, the uranium isotopes were summed to a total uranium value to use in estimating body intake.
2. Transport of radiological contaminants from the repository to the regulatory compliance location, as noted in step 1a, was taken directly from the TSPA (DOE, 2008a) results for 18 km (i.e., transport performed directly in TSPA). TSPA output results were transformed by DOE (2014) into mass rates (grams/year) that were used as input for step 4, below.
3. Transport of nonradiological contaminants (Mo, Ni, V) to the regulatory compliance location (18 km) in the Excel spreadsheets
 - a. As in the DOE (2014) approach, the effect of transport in the unsaturated zone was not incorporated into the calculations, but rather, the NRC corrosion release mass flux of metals was conservatively applied to the unsaturated zone-saturated zone (UZ-SZ) boundary.
 - b. As in the DOE (2014) approach, the TSPA breakthrough curves for saturated zone transport of radiological contaminants from the UZ-SZ boundary to the regulatory compliance location at 18 km were used as analogs for the nonradiological contaminants. The repository release rate was multiplied by the fractions in the breakthrough curves to represent transport. The breakthrough curves were selected by DOE by taking curves for elements with similar transport properties to Mo, Ni, and V. The transformation produced mass rates at the compliance location that were used as input for step 4.
4. Transport of radiological and nonradiological contaminants to locations beyond the compliance location was performed using an analytical solution for one-dimensional transport (see Section 2, The Analytical Solution).
5. The mass flux arriving at downstream locations was used to estimate (i) water and soil concentrations, (ii) dose and body intake using biosphere exposure pathways relevant to that downstream location, and (iii) mass balance calculations indicative of how much

contaminant there was between compliance location and a downstream location, and how much contaminant there was at the downstream location.

2 The Analytical Solution

An analytical solution is used for transport from the 18-km regulatory compliance location to downstream affected environments. This section discusses the support for the analytical solution in the DOE Calc Package as documented in the general literature, and the implementation of the analytical solution in the algorithm used in the DOE Calc Package spreadsheets.

Other aspects of the solution method and implementation that are not discussed below, such as the treatment of the ingrowth of radionuclides, are provided in the descriptions in the DOE Calc Package.

Equation for Transport

The advection-dispersion equation for one dimensional transport with a term for radioactive decay (see, for example, Bear, 1979; Fetter, 1993) is

$$R \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} - R\lambda C \quad (1)$$

where C is contaminant concentration, $C(x,t)$

D is dispersion coefficient

v is particle velocity

R is retardation $R=1+(\rho K_d/n)$

K_d is sorption coefficient, assuming linear sorption

ρ is bulk density

n is porosity

λ is first-order decay

x and t are distance and time

As usual for transport in porous media, particle velocity (v) is used instead of Darcy velocity (q), where $v = q/n$.

Equation for Analytical Solution

The analytical solution in Lapidus and Amundsen (1954) was cited by DOE (2014) and the DOE Calc Package for the solution to the advective-dispersive transport equation shown above. This solution is for a continuous point source, semi-infinite one-dimensional domain, and includes sorption. The γ term in Equation (9) of Lapidus and Amundsen (1952) is not defined in that paper, thus making it difficult to compare with the DOE equations. An expression for γ could possibly be deduced (it's likely a combination of several variables), but does not fully confirm the DOE analytical solution against the Lapidus and Amundsen (1952) solution. Instead, the DOE

solution was compared against another known form of the solution. Solutions are widespread in the scientific community, with the many different forms dependent on the users' preferences for grouping terms. In addition, a radioactive decay term was not included in the Lapidus and Amundsen (1954) solution, but as described below, it can readily be included.

To confirm that the DOE (2014) solution from the Calc Package was correct, it was compared to the solution¹ in Wexler (1992) for the concentration ratio, excluding decay for now:

$$\frac{C}{C_0} = \frac{1}{2} \left[\operatorname{erfc} \left\{ \frac{x}{2\sqrt{D^R t}} - \frac{v^R t}{2\sqrt{D^R t}} \right\} + \exp \left(\frac{v^R x}{D^R} \right) \operatorname{erfc} \left\{ \frac{x}{2\sqrt{D^R t}} + \frac{v^R t}{2\sqrt{D^R t}} \right\} \right] \quad (2)$$

C is contaminant concentration $C(x,t)$, and C_0 is source term $C(0,t)$

D^R is dispersion adjusted for retardation ($D^R = D/R$),

v^R is particle velocity adjusted for retardation ($v^R = v/R$),

erfc is the complementary error function

\exp is the exponential function

As done in the DOE (2014) Calc Package, the second term was dropped because it is only significant for solutions at short distances (Wexler, 1992). Hence, the solution becomes

$$\frac{C}{C_0} = \frac{1}{2} \left[\operatorname{erfc} \left\{ \frac{x}{2\sqrt{D^R t}} - \frac{v^R t}{2\sqrt{D^R t}} \right\} \right] \quad (3)$$

The DOE solution in the Calc Package included decay and sorption, and was written in terms of flux (not concentration). The flux ratio, instead of concentration ratio, is equal to the product of the concentration ratio and the volumetric water flux. To account for radioactive decay, the right-hand-side in the DOE solution (Equations 4 and 9) was multiplied by the term $\exp(-\lambda t_d)$, where λ is the decay constant and t_d defined below. This approximation for decay is discussed in more detail below in regards to a formal incorporation of decay (first-order chemical transformation) into the advection-dispersion equation. The DOE (2014) solution for nonradiological contaminants (or radionuclides when decay is not included) is

$$\frac{C}{C_0} = \frac{1}{2} \left[\operatorname{erfc} \left\{ \frac{1 - \frac{t}{t_d}}{2 \sqrt{\frac{D t}{x v t_d}}} \right\} \right] \quad (4)$$

where $t_d = \frac{x}{v} \left[1 + \frac{\rho K_d}{n} \right]$ was defined by DOE and was described as the midpoint of the breakthrough curve. This can also be written $t_d = x / v^R$, using the notation for the retarded particle velocity. Also, note that particle velocity = distance / time.

¹ See Wexler, 1992; page 20, equation 61. The terminology and symbol definitions used here differ from those used in Wexler (1992). See also Bear (1979).

The DOE equation for nonradiological contaminants (Equation 4) can be shown to be equivalent to the solution in Equation 3, as follows. For the denominator in Equation 4, substitution for t_d led to

$$2\sqrt{\frac{D t}{v x t_d}} = 2\sqrt{\frac{D t}{v x \left\{ \frac{x}{v} \left[1 + \left(\frac{\rho K_d}{n} \right) \right] \right\}}} = 2\sqrt{\frac{D t}{x^2 \left[1 + \left(\frac{\rho K_d}{n} \right) \right]}} = \frac{2}{x} \sqrt{D^R t} \quad (5)$$

For the numerator in Equation 4, substitution for t_d led to

$$1 - \frac{t}{t_d} = 1 - \frac{t}{x/v \left[1 + \left(\frac{\rho K_d}{n} \right) \right]} = 1 - \frac{v t}{x \left[1 + \left(\frac{\rho K_d}{n} \right) \right]} = 1 - \frac{v t}{x R} = 1 - \frac{v^R t}{x} \quad (6)$$

Next, substitution of the rearranged denominator and numerator in Equations 5 and 6 into the DOE solution in Equation 4

$$\frac{C}{C_0} = \frac{1}{2} \left[\operatorname{erfc} \left\{ \frac{1 - \frac{t}{t_d}}{2 \sqrt{\frac{D t}{v x t_d}}} \right\} \right] = \frac{1}{2} \left[\operatorname{erfc} \left\{ \frac{1 - \frac{v^R t}{x}}{\frac{2}{x} \sqrt{D^R t}} \right\} \right] \quad (7)$$

Expansion of the numerator and rearrangement gave the Wexler (1992) solution

$$\frac{C}{C_0} = \frac{1}{2} \left[\operatorname{erfc} \left\{ \frac{1}{\frac{2}{x} \sqrt{D^R t}} - \frac{\frac{v^R t}{x}}{\frac{2}{x} \sqrt{D^R t}} \right\} \right] = \frac{1}{2} \left[\operatorname{erfc} \left\{ \frac{x}{2 \sqrt{D^R t}} - \frac{v^R t}{2 \sqrt{D^R t}} \right\} \right]. \quad (8)$$

Therefore, the base equation for the solution from the DOE Calc Package was confirmed by comparison to a solution in the general scientific literature.

The full solution as implemented in the DOE Calc Package required some additional adjustments. These were: (i) incorporate decay, (ii) put the solution into a form for mass flux (instead of concentration), and (iii) use a mathematical identity that relates complementary error functions to error function [$\operatorname{erf}()$]. Radioactive decay was incorporated by multiplying the retarded solution by $\exp(-\lambda t_d)$; this expression for decay is discussed in more detail below. To solve for mass flux, note that $F(\text{g/yr}) = C(\text{g/L}) \times \text{water flux}(\text{L/yr})$, and also $F/F_0 = C/C_0$. The mathematical identity used in the development is $\operatorname{erfc}() = 1 - \operatorname{erf}()$. These transformations led to the following equation, which DOE implemented in their spreadsheets:

$$\frac{F}{F_0} = \frac{1}{2} \left[1 - \operatorname{erf} \left\{ \frac{1 - \frac{t}{t_d}}{2 \sqrt{\frac{D t}{v x t_d}}} \right\} \right] \exp(-\lambda t_d) \quad \text{for } t \leq t_d \text{ and } t > t_d \quad (9)$$

The DOE Calc Package described and implemented two separate equations in their spreadsheets, one each for $t \leq t_d$ and $t > t_d$. Because the argument of the error function becomes negative for large t , DOE created a second equation that kept the argument at a positive value, and then used an “IF” statement in the worksheet to choose one or the other

equation. DOE created the second equation using the identity for error functions of $erf(-z) = -erf(z)$. Staff notes that only Equation 9 is needed, not two equations as indicated by DOE. Recent versions of Excel handle error functions with negative arguments correctly, so only one equation is needed for calculations at all times once handling by Excel is confirmed. Because these extra computations do not alter the results, no changes were made by the NRC staff to the implemented algorithm in the spreadsheets for the analytical solution. Also, an error was found in Equation 5 of the DOE (2014) Calc Package description; however, this error was not propagated to the formulas implemented in the DOE spreadsheets.

The approximation for decay used in the DOE (2014) Calc Package simply multiplies the solution for advection-dispersion with sorption by “ $\exp(-\lambda t_d)$.” This approximation neglects dispersion for the impact of decay (note that multiplying the decay constant by the midpoint of breakthrough curve factors in the advection component of transport). Given the relatively large times and distances, not incorporating dispersion for the decay component of the equation was not expected to result in any significant change in the results, because it is correct in an average sense. Furthermore, not incorporating dispersion would lead to the same estimate or an underestimate of the concentration. In regard to estimating peak concentrations, some deviations may occur for contaminants where the midpoint of the breakthrough curve (t_d) is greater than the simulation time (geological stability, or 1 million years, for the EIS); actually, it is the release time to the 1 million year mark, compared to the t_d , that is important. If need be, the solution in Equation (10) could be implemented as a comparison because it considers directly both advection and dispersion for sorption and decay; this solution is found in Bear (1979) and Wexler (1992, Equation 60).

$$\frac{C}{C_0} = \frac{1}{2} \left[\exp \left\{ \frac{x}{2DR} (v^R - U) \right\} \operatorname{erfc} \left\{ \frac{x - Ut}{2\sqrt{DRt}} \right\} + \exp \left\{ \frac{x}{2DR} (v^R + U) \right\} \operatorname{erfc} \left\{ \frac{x + Ut}{2\sqrt{DRt}} \right\} \right] \quad (10)$$

where

$$U = \sqrt{(v^R)^2 + 4\lambda DR}$$

As before, the second term may be significant only for short distances.

3 Spreadsheet Implementation and Inputs

This section describes changes made by the NRC staff to the DOE spreadsheets, including corrections and additions so the spreadsheet algorithm correctly conformed to established analytical solutions of the transport equation.

Changes to DOE Calc Package Spreadsheets

The NRC staff identified the following changes needed in DOE Calc Package spreadsheets:

1. DOE described (e.g., “CalcPkgRad1_DHL_4-21-09_Final.pdf”) the spreadsheets as being linked. As received, none of the links were in place.

- Entries in some DOE mass balance inventory spreadsheets did not have the same values for mass flux as calculated in the transport spreadsheets (those with the analytical solution to the transport equation). Therefore, it is possible that the links between spreadsheets were broken before the DOE Calc Package was finalized as the support package for DOE (2009).
 - The NRC staff implementation, instead of linking between spreadsheets, incorporated all necessary calculations into one spreadsheet for an affected environment location and climate.
 - For example, whereas DOE Calc Package used up to five different spreadsheets for a location and climate, the NRC staff used one spreadsheet that (i) calculated the transport from UZ-SZ boundary to 18 km (for metals only), (ii) calculated the mass flux for transport from the 18-km compliance location to the downstream discharge location, and calculated the soil and water concentration, (iii) calculated the total uranium for soil and water concentration and body uptake, (iv) calculated the Middle Basin evaporite concentration, body uptake, and dose separately from Furnace Creek estimates, and (v) calculated mass balance inventories.
 - A similar construction for radionuclides was done, however, a separate mass balance inventory spreadsheet (linked to the transport spreadsheets) was needed because of constraints in spreadsheet program when using locally and globally defined names.
2. The release term for initial time was nonzero for nonradiological contaminants (Mo, Ni, and V) at the 18-km regulatory compliance location in the spreadsheets of the DOE Calc Package.
- DOE used a spreadsheet implementation that relied on backward differencing of flux using 20 time steps as input to the superposition solution. If the mass flux at the initial time was nonzero, the implementation ignored the initial mass flux. For example, if the time(1) entry for mass flux is 200 g/yr, and the time(2) mass flux is 300 g/yr, then the first argument of the superposition solution was a delta mass flux of 100 g/yr (i.e., the initial 200 g/yr does not factor into the superposition solution). This is an artifact of using backward differencing and changes in mass flux to derive arguments for the superposition solution. In DOE's nonradiological contaminant spreadsheets, both the initial times and the corresponding released mass flux values at the regulatory compliance location were nonzero. The radiological spreadsheets had zero entries for the mass flux at the initial time (time=0 years), and thus were implemented correctly by DOE.
3. New source term for metals (Mo, Ni, V) implemented by the NRC staff.
- This new repository release source term had four steps for Mo and Ni (e.g., the released mass flux changes four times during the 1 million-year period for Mo and Ni), and two steps (rates) for V. In contrast, DOE had two steps (one rate for 0 to 500,000 years, and another rate for 500,000 to 1 million years).
 - DOE's uncapped repository release mass flux used the corrosion rate throughout million-year period without considering the amount of material released from the

repository. The NRC staff model stopped the released mass flux when all the metal in the repository had been corroded and released (i.e., when there is no metal left).

- The more complex repository release source term stretched the limits of sufficient resolution for the 20 time discretization used in the DOE spreadsheets for estimating the mass flux at the 18-km compliance location. Thus, a change was needed for the NRC staff's implementation in the spreadsheets from that used by DOE. This revised approach is described in Section 5 of this document, "Generation and Transport of New Nonradiological Release Term."
4. Two values for specific discharge were used in the DOE Calc Package spreadsheets. For radionuclide transport to Amargosa Farms under the present-day climate conditions, a value of 0.00553 m/d was used. For nonradiological (metals) transport, a value of 0.00613 m/day was used. For wetter climates, a factor of 3.9 was applied for both radiological and nonradiological contaminants. The NRC staff determined that 0.00613 m/day was the correct value to use, for the following reasons:
- DOE (2014) Table B-1 listed 0.00613 m/d for specific discharge for present climate, and cited Section 4.3 of SNL (2009) as the source.
 - The text on page 43 of SNL (2009) stated that the average specific discharge was 0.00553 m/d. The value 0.00613 m/d was not mentioned. However, from the histogram in Figure 14 in SNL (2009), which is a histogram of the distribution from which the average specific discharge was calculated, staff determined that 0.00613 m/d was the correct value.
 - Furthermore, Table 11 in SNL (2009) for the wet climate listed values for specific discharge. When considering the 3.9 factor, the entry in Table 11 was consistent with the 0.00613 m/d value for the present climate.

Therefore, the NRC staff's spreadsheets used a specific discharge value of 0.00613 m/d for Amargosa Farms and State Line transport calculations under the present-day climate in the Supplement. This increase of approximately 10% in the specific discharge led to an increase of approximately 1% in mass flux and, consequently, an equivalent increase in the calculated dose.

5. Other input changes in the NRC staff's spreadsheets included
- DOE used a path length of 16 km beyond the regulatory compliance location to Amargosa Farms for metals, but 17 km for radionuclide transport calculations. For consistency, the NRC staff used a distance of 17 km beyond the compliance location for both metals and radionuclides for Amargosa Farms.
 - The apparent inconsistency in Tables B-13 and B-14 in DOE (2014, 2009), showing total uranium was less than U-238 for soil concentration, appeared to be a typographical error, rather than errors in the spreadsheets. The inconsistency between Tables B-13 and B-14 was not reflected in the DOE Calc Package spreadsheets.
6. Changes to cell entries for formulas
- DOE used overwatering rate (0.079 m/yr) instead of irrigation rate (0.95 and 0.5 m/yr, for present-day and wet climates) in its metals spreadsheet for Amargosa Farms. Irrigation rate was correctly incorporated for radiological contaminants.

- Several instances of cell references in formulas repeated in a column were incorrectly set to reference the same cell, when relative cell references were needed along the columns of formulas. Examples were in the Pb-210 worksheet of Amargosa Farms, and the inhalation calculation for Mo in the nonradiological transport spreadsheets.

These six revisions and additions were implemented in the NRC staff spreadsheets.

4 Post-Transport Calculations

This section summarizes post-transport calculations used by the NRC staff for mass balance, soil and water concentrations, and dose and body intake.

Mass Balance/Inventory Calculations

The amount of material in the aquifer environment (dissolved in groundwater and sorbed to porous media solid) was calculated as the difference between the cumulative amount released at the regulatory compliance location (18 km) and the cumulative amount reaching a downstream affected environment. The latter was based on mass flux output of the one-dimensional analytical transport solution. The cumulative amount at each of the locations was calculated at any time by considering the mass flux for all prior time steps. Calculations were performed for each climate (present-day and cooler/wetter) at each of two downstream locations (Amargosa Farms and Furnace Creek/Death Valley). In the DOE Calc Package, this calculation was done in separate spreadsheets that were no longer linked to the transport spreadsheets.

The NRC staff reconstructed the spreadsheets for the inventory calculation. For metals, the NRC staff inventory calculation was included as a worksheet in the analytical transport spreadsheets, and the mass fluxes appropriately linked. For the radionuclides, the inventory calculation was performed in separate spreadsheets (due to conflicts with names used for local cell referencing). The NRC staff also converted the grams of contaminant to kilograms (metals) and Curies (radionuclides); for the latter, grams of each radionuclide were multiplied by its specific activity.

Groundwater Concentration Calculations

The groundwater concentrations (C_i) were calculated using the mass flux and the discharge. The latter was either the pumping rate, or the surface discharge rate.

For radionuclides:

$$C_i \text{ (pCi/L)} = \text{Mass Flux (g/yr)} * \text{specific activity (pCi/g)} / \text{discharge (L/yr)} \quad (11)$$

For nonradiological material:

$$C_i \text{ (mg/L) } = \text{Mass Flux (g/yr) } * 1000 \text{ (mg/g) } / \text{discharge (L/yr) } \quad (12)$$

Soil Concentration Calculations

Two methods were used dependent on the location, either the irrigation model or the evaporite model. Both methods are derived and described in the DOE description provided with the DOE Calc Package, and are only summarized here.

The irrigation models accounted for recycling of pumped water due to infiltration and drainage to the saturated zone. The concentration in the soil in units of mg/kg of soil, or ppm was

$$C_{soil} = \frac{[\text{Mass Flux(g/yr) } / (1-F) / Q_{pump}(\text{L/yr})] * IR(\text{m/yr}) * 1\text{E6}(\text{L/m}^3)(\text{mg/g})}{T_{soil} \text{ (m) } * \rho(\text{kg/m}^3) * \lambda_{eff}(\text{1/yr})} \quad (13)$$

where F is the fraction of water used for irrigation, Q_{pump} is the pumping rate, IR is the irrigation rate, T_{soil} is soil thickness of 0.25 m over which soil contamination concentration was calculated, ρ is soil bulk density of 1500 kg/m³, and λ_{eff} is the effective decay/leach/erosion constant described in the DOE Calc Package. The bracketed portion is the groundwater concentration (g/L) that is available for irrigation.

The evaporite model assumed total evaporation of the water and treated the residue as a soil. The concentration of contaminants is the ratio of contaminants in the water (C_i) to all other ions in the groundwater. The soil concentration (C_{soil}) for the evaporite model is

$$C_{soil}(\text{mg/kg}_s \text{ or ppm}) = C_i(\text{g/L}) / TDS(\text{g}_s/\text{L}) * 1\text{E6}(\text{mg/g})(\text{g}_s/\text{kg}_s) \quad (14)$$

where TDS is the Total Dissolved Solids in the groundwater. The contaminant groundwater concentration was calculated as the mass flux divided by the surface discharge.

Dose and Body Intake Calculations

The NRC staff followed the DOE approach for dose and body intake calculations described in DOE (2014) and DOE Calc Package:

- CalcPkg_Rad1_DHL_4-21-09.pdf
- CalcPkg_Met1_DHL_4-26-09.pdf
- CalcPkg_Evap1_DHL_4-22-09.pdf

Initial estimates for State Line used dose conversion factors from Table B-4 of DOE (2014). This was revised from the draft to the final Supplement, to the more conservative values in Table B-3 of DOE (2014).

5 Radionuclide Spreadsheets

Files in directory: .\Radionuclides*

For Amargosa Farms

- DoseAmFarms2003PumpingPresClimate.xls
- DoseAmFarms2003PumpingPresClimate-10K yr.xls (selected radionuclides)
- DoseAmFarms2003PumpingWetClimate.xls
- DoseAmFarms2003PumpingWetClimate-10K yr.xls (selected radionuclides)
- InventoryAmFarms2003PumpingPresClimate.xls
- InventoryAmFarms2003PumpingWetClimate.xls

For State Line/Franklin Well Area

- DoseStateLineWetClimate.xls

For Furnace Creek and Middle Basin in Death Valley

- DoseFurnaceCreek-DeathValley_PresClimate.xls
- DoseFurnaceCreek-DeathValley_WetClimate.xls
- InventoryFurnaceCreek-DeathValleyPresClimate.xls
- InventoryFurnaceCreek-DeathValleyWetClimate.xls

Se-79 Half-Life

The NRC staff reviewed the selenium-79 half-life and inventory because of possible inconsistencies.

The half-life of Se-79 is difficult to measure because of its slow decay and lack of gamma ray emission. Widely disparate values for its half-life have been reported in the literature, and these may have led to some inconsistencies in the DOE calculations for this radionuclide. The value for Se-79 half-life has previously been reported as 65,000 years (e.g., Nuclides and Isotopes: Chart of the Nuclides, 14th Edition, 1989). The interactive Chart of Nuclides on the website (<https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html>) of the International Atomic Energy Agency currently shows 327,000 years as the Se-79 half-life (with an uncertainty of 28,000 years; publication data as of May 31, 2016). DOE's Safety Analysis Report (SAR) for Yucca Mountain (DOE, 2008a) is inconsistent in the values used for the Se-79 half-life. SAR Table 2.3.10-5 (Biosphere) has a value of 1.13×10^6 year, while the text in SAR Section 2.4 indicated 290,000 years for the half-life. DOE's TSPA model used a value of 290,000 years, as confirmed by NRC staff examination (see Table 1). The specific activity of 0.0156 Ci/g in Table 1 was consistent with the stated half-life of 290,000 years.

The NRC staff also confirmed that the spreadsheets in the DOE Calc Package used a half-life of 290,000 years. For consistency, a half-life of 290,000 years was used throughout the calculations in the Supplement. The value for total Curies of Se-79 in Table 3-1 of the draft Supplement was calculated using the 1.13×10^6 year half-life from SAR Table 2.3.10-5. The value was recalculated for the final Supplement using the half-life of 290,000 years. This resulted in an increase in the calculated activity of Se-79 by a factor of 3.9, due to the greater specific activity from the shorter half-life.

Table 1. Information on Se-79 amount in inventory and value of half-life, excerpted from Goldsim TSPA (DOE, 2008a).

Half Life = 290,000 years

Specific Activity = 0.0156034 Ci/g

Inventory:

Waste Form	Inventory (g/WP)	Uncertainty Multiplier
CSNF	41.9	Uniform (0.85, 1.4)
DSNF	6.82	Triangular (0.45, 0.62, 2.9)
HLW	7.01	Triangular (0.7, 1.0, 1.5)

Key for Table 1: CSNF = commercial spent nuclear fuel; DSNF = defense spent nuclear fuel; HLW = high-level waste (other than SNF); WP = waste package

The total amount of Se-79 in the ~10% waste packages that were calculated to fail in the long term was 33,440 grams; which was based on 55.73 grams/WP of Se-79 assumed from TSPA for a representative waste package. DOE (2014), Table B-5, shows 16,800 grams Se-79 released from UZ-SZ boundary by 1 million years, of which the amount of 7,780 grams accumulated at Amargosa Farms. As a rough approximation, the latter value appeared to be too large when considering half-life. Not including what resides in the unsaturated zone (UZ) below the repository, the 16,800 g released from the UZ (and accounting for decay using a half-life of 290,000 years) was too high by a factor of five. Early waste package failure led to a small amount of Se-79 reaching Amargosa Farms at 10,000 years. Note that higher values of Se-79 reaching the environment were conservative for the assessment of impacts.

10,000-Year Recalculations

The DOE Calc Package recalculated 10,000-year values for selected radionuclides using a more time-resolved input mass flux at the regulatory compliance location, compared to the values of input mass flux for the million-year calculations. These spreadsheets were identified by the “10ky” added to the file names of the Amargosa Farms spreadsheets. DOE recalculated values of mass flux and dose for C-14, Cl-36, I-129, and Tc-99. The latter was the highest contributor to dose at 10,000 years for Amargosa Farms.

As with the calculations for the million-year period, the NRC staff (i) changed the specific discharge values, (ii) calculated groundwater concentrations in units of pCi/L, and (iii) as for all NRC spreadsheets, added linked summary information to the “Workbook” worksheet.

6 Generation and Transport of New Nonradiological Release Term

Calculation of transport of nonradiological metals from the repository to the affected environments described in DOE (2014) involved three steps: (i) estimate the release of metals from the repository and assume instantaneous transport to the unsaturated/saturated boundary below the repository, (ii) transport the metals to the compliance location using breakthrough curves with appropriate sorption coefficients, and (iii) transport metal from the compliance location to the affected environments using the same one-dimensional analytical solution as was used for radionuclides. The NRC staff revised the release rate of nonradiological metals from the repository, thus requiring changes to calculation spreadsheets for metals. The NRC staff revisions for steps (i) and (ii) are described below. Because the implementation for step (iii) remained the same as described in DOE (2014), and only the inputs and outputs changed, no further description is provided in this report for step (iii).

Development of NRC Source Term for Nonradiological Metals

The NRC staff developed a new source term for Mo, Ni, and V released from the repository for use in the Supplement. First, the staff recreated the DOE (2014) release inventory from steel (stainless steel type 316NG) and Alloy-22. The calculations in DOE (2014) considered the surface area and corrosion rate using an unbounded amount of source metal, which meant that the cumulative sum of Mo, Ni, or V released to the environment after 1 million years was greater than the amount used in the repository construction, including all waste packages. In the NRC model, after the source metal was fully corroded and released into the groundwater system, the source terms for Mo, Ni, or V were set to zero. A comparison of the DOE (unbounded) and NRC (capped) release inventories are given in Table 2.

DOE (2014) used the release rate calculated at 100,000 years and applied it to the period 0 to 500,000 years, then used the release rate from 1 million years and applied it to the period from 500,000 to 1,000,000 years. This was a simple step function (two steps).

Table 3 compares the release rates and inventories calculated by the DOE (2014) and the NRC Supplement models. In Table 3, the first part replicates the DOE (2014) inventory release, and the second part gives the NRC staff repository release rates utilizing the capped inventory.

Table 2. Description of information used for the repository release of metals (nonradiological contaminants).

Material	DOE EIS Rate and Basis {1 million year cumulative release}	Capped Rate and Basis {1 million year cumulative release}
Stainless steel type 316NG exposed in Repository	5,081 kg/yr over 1 million years [DOE 2008b, p. F-61] Ground Support [2.016 M m ²] Rock bolts [0.276 M m ²] Bearing Plates [0.024 M m ²] Corrosion rate 2.48×10^{-4} kg/y Density 7,980 kg/m ³ {Cumulative release: 5 M metric tons}	5,081 kg/yr over 10,000 years [DOE, 2008a, p. 1.3.6-11] Ground Support [25,428 metric tons] Rock bolts [6,653 metric tons] Bearing Plates – not listed in SAR Table {Cumulative release: 50,000 metric tons}
Stainless steel type 316NG internal to WPs	903 kg/yr from 0 to 500K years 6,737 kg/yr from 500K to 1 M years [DOE 2014 Calc doc pp. 1-6] 8213 CSNF WP Internals [4.21 M m ²] 3416 CDSP WP Internals [1.36 M m ²] 100K years breached WP (1,200 CDSP, 25 CSNF) – used for 0-500K years 1M years breached WP (2,390 CDSP, 4850 CSNF) – for 500K to 1M years Corrosion rate 2.48×10^{-4} kg/yr Density 7,980 kg/m ³ {Cumulative release: 3.8 M metric tons}	12 kg/yr from 0 to 500K years 162 kg/yr from 500K to 1 M years [RAI Response for Barriers, enclosure 1; ADAMS document ML092110474] WP failed by patches at 500K years (45 CDSP, 58 CSNF) for 0-500K years 1M years breached WP (546 CDSP, 969 CSNF) for 500K to 1M years; assume WP internals are gone after 500K years [DOE, 2008a, p. 1.5.2-26] 73.4 metric tons/CSNF WP loaded (assume 7.7 metric tons SNF and 8.3 metric tons alloy 22) = 57.4 metric tons of 316NG internals {Cumulative release: 87,000 metric tons}
Alloy 22	200 kg/yr over 1 million years [DOE 2008b, p. F-60-64] 11,117 WP surface area [387,589 m ²] Drip shield rail [28,732 m ²] Pallets [225,105 m ²] Corrosion rate 3.57×10^{-5} kg/yr Density 8,690 kg/m ³ {Cumulative release: 0.2 M metric tons}	200 kg/yr over 600K years [DOE, 2008a, p. 1.10.54] WP dimensions of Inner D – 183 cm; Outer D – 188 cm; Length – 555 cm; lids 2.54 cm thick; WP mass of 8,247 kg and total for 11,117 WP of 92,000 metric tons; Drip shield rails 1,246 metric tons (SAR 1.3.6-12); Pallets 14,288 metric tons (SAR 1.3.6-11) {Cumulative release: 0.12 M metric tons}

Table 3. The (top) NRC staff replication of DOE release inventory, and (bottom) NRC capped release model inventory (See file: NRC_Metal_Cumulative_Release_Calcs.xlsx)

DOE EIS Model

Time (yr)	Exposed 316 rate (kg/yr)	Internal 316 rate (kg/y)	Alloy 22 rate (kg/y)	Cumul 316NG (kg)	Cumul Alloy 22 (kg)	Cumul Mo (kg)	Cumul Ni (kg)	Cumul V (kg)
0	5,018	9.03E+02	200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	5,018	9.03E+02	200	5.92E+07	2.00E+06	1.77E+06	8.25E+06	7.00E+03
50,000	5,018	9.03E+02	200	2.96E+08	1.00E+07	8.85E+06	4.12E+07	3.50E+04
100,000	5,018	9.03E+02	200	5.92E+08	2.00E+07	1.77E+07	8.25E+07	7.00E+04
200,000	5,018	9.03E+02	200	1.18E+09	4.00E+07	3.54E+07	1.65E+08	1.40E+05
300,000	5,018	9.03E+02	200	1.78E+09	6.00E+07	5.31E+07	2.47E+08	2.10E+05
400,000	5,018	9.03E+02	200	2.37E+09	8.00E+07	7.08E+07	3.30E+08	2.80E+05
500,000	5,018	9.03E+02	200	2.96E+09	1.00E+08	8.85E+07	4.12E+08	3.50E+05
600,000	5,018	6.74E+03	200	4.14E+09	1.20E+08	1.21E+08	5.65E+08	4.20E+05
700,000	5,018	6.74E+03	200	5.31E+09	1.40E+08	1.53E+08	7.17E+08	4.90E+05
800,000	5,018	6.74E+03	200	6.49E+09	1.60E+08	1.85E+08	8.70E+08	5.60E+05
900,000	5,018	6.74E+03	200	7.66E+09	1.80E+08	2.18E+08	1.02E+09	6.30E+05
1,000,000	5,018	6.74E+03	200	8.84E+09	2.00E+08	2.50E+08	1.17E+09	7.00E+05

NRC Capped Release Model

Time(yr)	Exposed 316 rate (kg/yr)	Internal 316 rate (kg/yr)	Alloy 22 Rate (kg/yr)	Cumul 316NG (kg)	Cumul Alloy 22 (kg)	Cumul Mo (kg)	Cumul Ni (kg)	Cumul V (kg)
0	5,018	1.20E+01	200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	5,018	1.20E+01	200	5.03E+07	2.00E+06	1.55E+06	7.18E+06	7.00E+03
50,000	0	1.20E+01	200	5.08E+07	1.00E+07	2.72E+06	1.18E+07	3.50E+04
100,000	0	1.20E+01	200	5.14E+07	2.00E+07	4.18E+06	1.76E+07	7.00E+04
200,000	0	1.20E+01	200	5.26E+07	4.00E+07	7.11E+06	2.92E+07	1.40E+05
300,000	0	1.20E+01	200	5.38E+07	6.00E+07	1.00E+07	4.08E+07	2.10E+05
400,000	0	1.20E+01	200	5.50E+07	8.00E+07	1.30E+07	5.24E+07	2.80E+05
500,000	0	1.20E+01	200	5.62E+07	1.00E+08	1.59E+07	6.39E+07	3.50E+05
600,000	0	1.62E+02	200	7.24E+07	1.20E+08	1.92E+07	7.73E+07	4.20E+05
700,000	0	1.62E+02	0	8.86E+07	1.20E+08	1.96E+07	7.93E+07	4.20E+05
800,000	0	1.62E+02	0	1.05E+08	1.20E+08	2.00E+07	8.12E+07	4.20E+05
900,000	0	1.62E+02	0	1.21E+08	1.20E+08	2.04E+07	8.32E+07	4.20E+05
1,000,000	0	1.62E+02	0	1.37E+08	1.20E+08	2.08E+07	8.51E+07	4.20E+05

Table 4 illustrates the check of the NRC staff's replication of the DOE inventory release, and provides a comparison of the cumulative amounts at 1 million years. The DOE (2014) cumulative values in the table above are from the file "Metals Inventory Released at UZ-SZ.xls" in the DOE Calc Package (ADAMS ML11082A018). The DOE model shows greater release of all three metals than the NRC model, and the difference is most significant for Ni.

Table 4. Cumulative amounts released from the repository at 1 million years

Cumulative amount	DOE (2014)	Replication of DOE release	NRC capped release model
Mo, kilograms	2.52E+8	2.50E+8	2.08E+8
Ni, kilograms	1.183E+9	1.17E+9	8.51E+7
V, kilograms	7.0E+5	7.0E+5	4.2E+5

Implementation of Metals Transport to Regulatory Compliance Location

As previously noted, the DOE (2014) inventory and release model had a single step change at 500,000 years (i.e., the 100,000-year release value used for the period 0 to 500,000 years, and the 1-million-year value used for the period 500,000 to 1 million years, with both rates applied at the UZ-SZ boundary). The NRC repository inventory and release model had four steps with a constant release rate in each step (Figure 1). The different release mass fluxes for each metal occur in four steps that reflected the contributions from the different materials corroding at different rates. For Mo and Ni, the rates were as follows

- 0 to 10,000 years: 154,750 g/yr Mo and 718,000 g/yr Ni
- 10,000 to 500,000 years: 29,300 g/yr Mo and 115,840 g/yr Ni
- 500,000 to 600,000 years: 33,050 g/yr Mo and 133,840 g/yr Ni
- 600,000 to 1 million years: 4,050 g/yr Mo and 19,440 g/yr Ni

For V, two repository release mass fluxes were used: a release rate of 700 g/yr for 0 to 600,000 years, and no release for 600,000 to 1 million years. In the implementation of the analytical solution for transport to the regulatory compliance location (18 km) described below, the repository released mass flux rate for Mo and Ni were combined for the middle two steps. The NRC model showed a substantial pulse release during the first 10,000 years as the rock support material corrodes. The Mo and Ni release rates were approximately the same as those in the DOE (2014) model for the first 10,000 years, but the DOE rates continued to 500,000 years while the NRC rates drop at 10,000 years.

The NRC staff modified the DOE approach for metals to accommodate the earlier and greater number of step changes in the repository release rate. The DOE Calc Package spreadsheets were set up for 20 time increments at which to calculate the mass flux reaching the 18-km compliance location, which was adequate resolution for the simple shape of the mass flux at the regulatory compliance location that resulted from a single step change in release mass rate from the repository (applied at the UZ-SZ boundary) in the DOE model. Improved fidelity of the calculated mass flux arrival values at the 18-km compliance location was obtained by

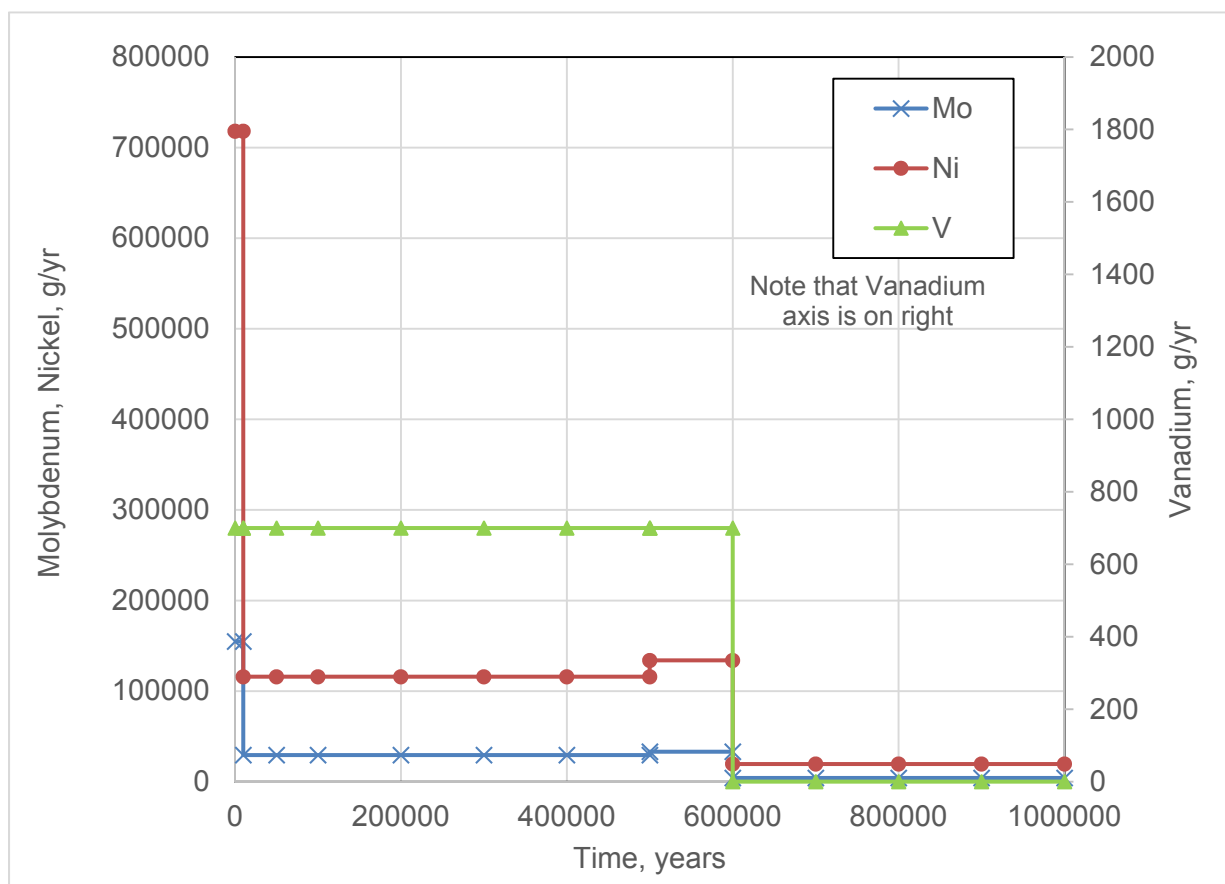


Figure 1. The NRC capped release model mass flux of Mo, Ni, and V

manipulation of the time increments in a way that considered the timing of step changes in the repository source term. The number of time increments used to calculate mass flux arrival at the 18-km compliance location became the number of superimposed solutions used with the one-dimensional analytical transport solution to calculate mass flux to affected environments beyond the compliance location.

The staff considered two methods for modifying the DOE calculation:

- (i) Change the number of superimposed solutions implemented in the numerous transport spreadsheets (implemented by changing the algorithms implemented in each of the 32 radionuclide worksheets in each of the spreadsheets for location and climate), or,
- (ii) Refine the method by separating the NRC repository release flux rates into discrete steps, individually calculating the transport of the steps to the compliance location using the breakthrough curve and then further on to the downstream affected environments using the superposition-based implementation of the analytical transport solution, then summing the results of each of those separated repository release rate steps.

Either method should lead to the same results for the Supplement. The second approach was much simpler to implement, and therefore was selected. The second approach was only complicated by DOE's extensive use of locally defined names for cell references. Multiple use of the same name in a spreadsheet, where the named term has a different defined value in each worksheet of the spreadsheet complicated moving or copying worksheets. Therefore, a new set of spreadsheets were created, instead of revising the DOE (2014) calculation spreadsheets.

Initially, the NRC approach for the transport of metals (nonradiological contaminants) from the UZ-SZ boundary to the regulatory compliance location at 18 km approximated the decay portion after the end of a pulse (under the assumption that the peak was the most important metric). However, after issuance of the draft Supplement, the post-pulse approximation was dropped and replaced with the more accurate use of the breakthrough curves from the TSPA applied on a shifted time scale (time since the source term pulse had stopped). This was a more tedious approach as breakthrough fractions had to be individually looked up, and generally interpolated, for times since release of the multirate source term. This revised approach made a slight difference in some of the values for the peaks and the timing of the peak value. The recalculation had the greatest effect on results for elements with large sorption coefficients, such as nickel.

For Mo and Ni, the repository release mass flux was separated into three separate rate curves (note that the transport calculation for the metal release from the repository to the regulatory compliance location at 18 km causes the original step function to become a curve). Whereas the NRC model had four different mass flux rates at the repository, the middle two steps were duration-weighted into one step for Mo and Ni to simplify the spreadsheet implementation. The middle two steps were approximately the same values (within ~ 3%), so there is little impact from this simplification. Transport calculation were made for each curve, and the three results were summed for the total mass flux reaching the regulatory compliance location; see approach (ii) above. The vanadium repository release term was a single step function, which did not need to be separated into three curves.

7 Nonradiological Contaminant Spreadsheets

Whereas the mass balance for radionuclides required a separate spreadsheet, the calculations for metals included: (i) source term and transport to the compliance location, (ii) transport beyond 18 km, (iii) processing to water and soil concentration and body uptake, and (iv) inventory accumulation, which could all be done in one spreadsheet for each metal at each location. Calculations by DOE (2014) in the DOE Calc Package were performed with all three metals in one spreadsheet; with separate spreadsheets for each location. But there was no

linking between source term, transport, and inventory in the spreadsheet files as received from DOE (DOE Calc Package files).

For the NRC spreadsheets, the inventory for metals was calculated in the same spreadsheet as the transport calculations, thus allowing for automatic updating between the source term, transport, and mass balance calculations. The revised approach with the NRC release source term split them into separate spreadsheets for Mo, Ni, and V and for each location. Using separate spreadsheets for each metal also eliminated the need to disentangle the orphaned cell referencing and reconcile the definition issues in the DOE Excel spreadsheet files.

Files in directory: .\Metals*

Amargosa Farms

Metal_Mo_AmFarms2003PumpingPresClimate.xls
Metal_Mo_AmFarms2003PumpingWetClimate.xls
Metal_Ni_AmFarms2003PumpingPresClimate.xls
Metal_Ni_AmFarms2003PumpingWetClimate.xls
Metal_V_AmFarms2003PumpingPresClimate.xls
Metal_V_AmFarms2003PumpingWetClimate.xls

State Line/Franklin Well Area

Metal_Mo_StateLineWetClimate.xls
Metal_Ni_StateLineWetClimate.xls
Metal_V_StateLineWetClimate.xls

Furnace Creek & Middle Basin of Death Valley

Metal_Mo_FurnaceCreekPresClimate.xls
Metal_Mo_FurnaceCreekWetClimate.xls
Metal_Ni_FurnaceCreekPresClimate.xls
Metal_Ni_FurnaceCreekWetClimate.xls
Metal_V_FurnaceCreekPresClimate.xls
Metal_V_FurnaceCreekWetClimate.xls

Observations

While rechecking the implementation for nonradiological input, transport, and post-processing, several observations became evident.

- Comparison of the effect of pulse duration versus t_d noted that there was a higher impact at greater specific discharge
 - Example: Molybdenum in Furnace Creek/Middle Basin had higher impact during wet climate conditions compared to that during present-day climate conditions.
 - Higher specific discharge meant the midpoint of the breakthrough curve (13,600 years) for a wet climate was approximately the same time length as the pulse duration (for the 10,000-year pulse); compared to $t_d = 53,000$ years for the present-day climate. Therefore, longitudinal dispersion reduced the present-day peak impact, but negligibly affected the peak for wet climate.

- Nickel: the flux-out peak was much smaller than the flux-in peak because the midpoint of breakthrough curve was not reached by 10,000 years when the pulse stopped.
- Pu-242 appeared at the location for the wet climate in the NRC Supplement calculation, but did not appear for the present-day climate, due to the interplay between the value of its sorption coefficient and the value of the specific discharge rate.

8 Summary of Changes to the Calculations from the Draft to Final Supplement

After lock-down of the draft supplement text for issuance for public comment, several changes to the results in the spreadsheets occurred as part of a confirmation process prior to submitting the spreadsheets for public availability. These changes were all reflected in the final Supplement. Several minor errors were found and improvements in the approach were implemented as part of the process of (i) cleaning up the files, (ii) improving transparency and linkages between different parts of the calculations, and (iii) confirming table entries in the draft report locked down in early August 2015. Whereas some values in the tables in the draft supplement changed, none of the changes in values were significant enough to modify conclusions in the draft report. Many of the changed entries decreased, though some increased. None of the increases were significant, often modifying the last significant digit recorded in the draft supplement tables. Four specific changes are listed below.

1. Improved handling of multirate release of metals
 - The initial NRC approach approximated the decay portion of pulses for the transport from UZ-SZ boundary to the 18-km regulatory compliance location. This was improved by interpolating points on the breakthrough curve for changes to the input mass flux at the UZ-SZ boundary. The decay portion of a pulse (the part after the pulse ends), was incorporated by continuing the pulse rate and adding a negative source term that starts at the time when the input pulse ends or decreases.
 - The first cut approximation was generally confirmed by the more direct utilization of the breakthrough curve and superposition. Small differences were noted for timing of peak results for contaminants that have large sorption coefficients (e.g., Ni).
2. Correction of cell formula for soil concentration of metals at Amargosa Farms and State Line:
 - This error occurred in the DOE Calc Package files for Amargosa Farms. In addition, initially NRC carried over this error in creating the State Line files, which had used Amargosa Farms as starting point/template.
 - For nonradiological contaminants at Amargosa Farms, DOE used the overwatering rate (0.079 m/yr) to determine metals soil concentrations, instead of the irrigation rate (0.95 m/yr present-day climate, and 0.5 m/yr wet climate).

- The overwatering rate should only be used to calculate the leach rate constant (one of three terms in the effective rate constant λ_{eff} ; see DOE description in their Calc Package).
 - For radionuclides, the soil concentration correctly used the irrigation rate times the mass flux divided by pump rate.
3. Two values for specific discharge were used in the DOE Calc Package spreadsheets. For radionuclide transport to Amargosa Farms for the present-day climate, a value of 0.00553 m/d was used. Whereas, for nonradiological (metals) transport, a value of 0.00613 m/day. For wet climates, a factor of 3.9 was applied for both radiological and nonradiological contaminants. The NRC staff determined that 0.00613 m/day was the correct value to use (see Section 3, Item 4). Therefore, in NRC's spreadsheets, 0.00613 m/d was used for the present-day climate for Amargosa Farms and State Line transport calculations. This change in the specific discharge, approximately a 10% increase, led to approximately a 1% increase in mass flux and consequently dose. Therefore, many entries for Amargosa Farms in the Supplement did not change because they were only reported to the second significant digit.
 4. Mass balance and inventory calculations needed to be updated due to the changes for items 1 (new repository release term and transport for metals) and 3 (specific discharge). The effect on entries in the Supplement to the EIS was not significant.

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