ECF-HANFORD-20-0091
Revision 1

Calculation of Groundwater Pathway Radiological Dose for the Hanford Site Composite Analysis Null-Space Model Carlo Flow Model Set

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract 89303320DEM000030

CPCCo Central Plateau Cleanup Company

P.O. Box 1464
Richland, Washington 99352

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By Sarah Harrison at 12:56 pm, Apr 06, 2022

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Terms

CA	composite analysis
COPC	contaminant of potential concern
CY	calendar year
ECF	environmental calculation file
ICF	integrated computational framework
MODFLOW	MODular Groundwater FLOW (code)
MT3DMS	Modular Three-Dimensional Transport Multi-Species
NSMC	null space Monte Carlo
P2R	Plateau to River
TED	total effective dose
UCN	unformatted concentration (file)
UDF	unit dose factor

1 Purpose

The purpose of this environmental calculation file (ECF) is to present the results of the exposure route-specific and total radiological dose assessments for the groundwater pathway based on the null space Monte Carlo (NSMC) groundwater concentrations as a part an uncertainty analysis for the updated Hanford Site Composite Analysis (CA). The Plateau-to River (P2R) Groundwater Model (CP-57037, *Model Package Report: Plateau to River Groundwater Model Version 8.3*) is the CA base case that simulates the fate and transport of radiological contaminants within the saturated zone of the uppermost aquifer beneath the Central Plateau and downgradient to the Columbia River. An NSMC analysis was performed to identify and quantify the potential uncertainties associated with the P2R Model. The result of the NSMC analysis is a set of flow and transport simulations that provide an estimated range of possible outcomes that are used to quantify the uncertainty associated with the simulated base case concentrations.

2 Background

The results of the NSMC groundwater flow and transport model presented in ECF-HANFORD-20-0075, *Application of a Null-Space Monte Carlo Flow Model Set to the Composite Analysis Base Case Fate and Transport Modeling* provide 100 realizations of equally probable future predictions of radionuclide groundwater concentrations. The NSMC results are developed for 16 radionuclides evaluated in the CA at each time step of the groundwater flow and transport model from calendar year (CY) 2018 to CY 12070 at each of the active P2R/Modular Three-Dimensional Transport Multi-Species (MT3DMS) grid cells. At each MT3DMS model cell and model time step, the predicted radionuclide concentrations in the groundwater are multiplied by the unit dose factor, which are provided in the data package CP-64491, *Hanford Site Composite Analysis Data Package: Exposure Scenarios and Radionuclide Specific Dose Conversion Factors,* to provide a radionuclide-specific dose.

The NSMC evaluates the impact of uncertainty in two aspects of the groundwater flow and transport model, namely the saturated zone hydraulic properties and groundwater recharge[1]. It is noted that other sources of uncertainty that are not included in the NSMC uncertainty analysis can impact predicted groundwater concentrations. The other uncertainties include the following:

- Radionuclide inventory and discharge volume at past liquid discharge sites that affect the magnitude and timing of radionuclide transfer to groundwater
- Vadose zone hydraulic properties and natural recharge, including the presence of surface barriers that reduce the natural recharge, that affect the rate of radionuclide transfer to groundwater
- Release rate of radionuclides to the vadose zone from solid waste sources

[1] The hydraulic properties (i.e., hydraulic conductivity) of the saturated zone hydrostratigraphic units and the long-term steady-state recharge rate are related in the NSMC runs by the observed water levels used to calibrate the groundwater flow model. For example, increasing the recharge rate would result in an increase of the hydraulic conductivity to calibrate the flow model to the observed water levels. If the recharge rate is overestimated, then the calibrated hydraulic conductivity would also be overestimated resulting in an overestimate of the calibrated specific discharge and dilution. The P2R groundwater flow model calibration is also significantly affected by the magnitude of anthropogenic discharge, which affects the model-predicted water levels used for model calibration during the times that anthropogenic discharge was greatest in the 200 East and 200 West Areas during Hanford operations.

- Initial concentration of mobile radionuclides (i.e., tritium [H-3), technetium-99 [Tc-99], iodine-129 [I-129], and uranium-238 [U-238][2]) in groundwater
- Transport properties, including longitudinal and transverse dispersion, of the saturated zone sediments

The NSMC analysis represent a large amount of information to postprocess. The approach taken in Rev. 0 of this ECF was to search for the maximum predicted total dose anywhere outside three boundaries of potential interest over two different time periods. The boundaries include beyond the Inner Area boundary, beyond the 1998 CA compliance boundary, and beyond the Outer Area boundary. The two periods of interest are the compliance period from CY 2070 to CY 3070 and beyond the compliance period (i.e., from CY 3070 to CY 12070).

Representative results from the Rev. 0 NSMC analysis for the peak predicted dose beyond CA compliance boundary during the compliance and postcompliance periods are illustrated in Figure 1 and Figure 2, respectively. These Rev. 0 results indicate that for this performance metric, the uncertainty in the saturated zone hydraulic properties and recharge rates had almost no effect on the predicted peak dose. This is because the predicted peak doses were controlled by the assumed initial radionuclide concentration. In the case of the compliance period, the base case peak dose of 19.2 mrem/yr is controlled by the initial concentration of strontium-90 (Sr-90) in the vicinity of the Gable Mountain Pond.
The location of the predicted peak dose for Sr-90 during the compliance period is shown in Figure 3. In the case of the postcompliance period, the base case peak dose of 6.6 mrem/yr is controlled by the initial concentration of I-129 downgradient of the 200 East Area. Figure 4 shows the location of I-129 peak dose of 6.6 mrem/yr. In both cases, the uncertainty in groundwater flow has an insignificant effect over the almost 100 realizations simulated (Figure 1 and Figure 2).

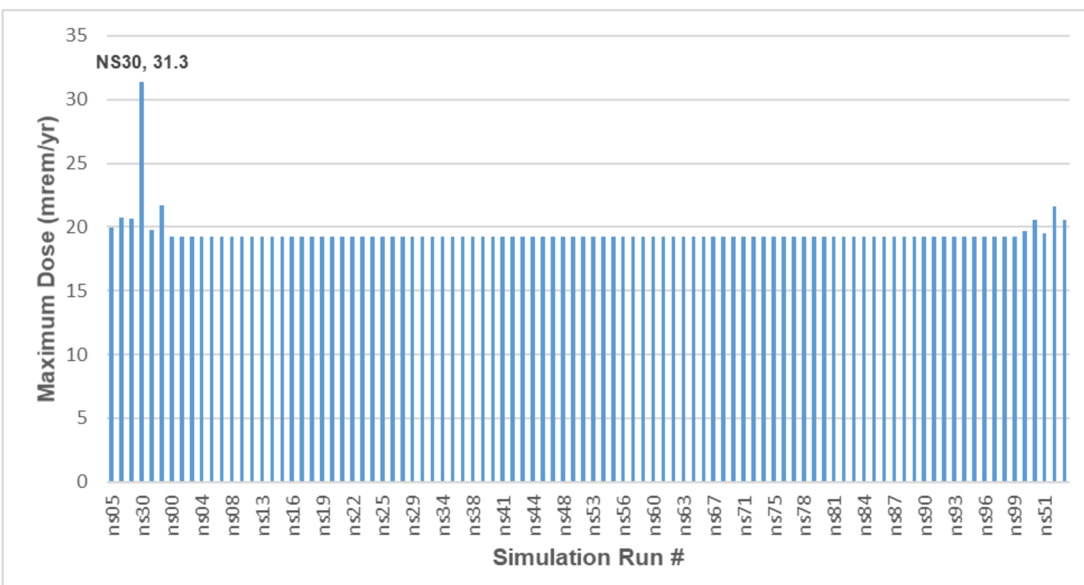

Figure 1. Calculated Maximum Groundwater Pathway Dose During Compliance Period (CY 2070 to CY 3070) for Locations Beyond the 1998 CA Domain Boundary for NSMC Uncertainty Analysis

[2] Sr-90, which is not considered mobile given an expected distribution coefficient of 22 mL/g, is also assigned an initial groundwater concentration because of past liquid discharge to the Gable Mountain Pond and the 216-B-5 reverse well. Carbon-14 is considered mobile, but is not assigned an initial groundwater concentration because there are no observed carbon-14 groundwater plumes on the Central Plateau with concentrations greater than the *Safe Drinking Water Act of 1974* maximum contaminant level of 2,000 pCi/L.

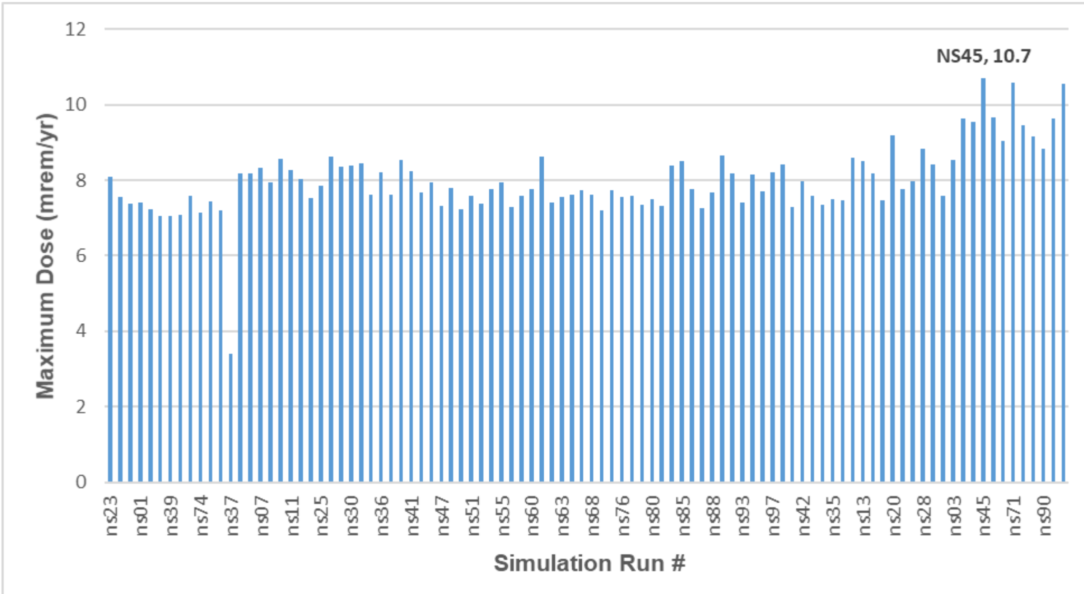

Figure 2. Calculated Maximum Groundwater Pathway Dose After Compliance Period (CY 3070 to CY 12070) for Locations Beyond the 1998 CA Domain Boundary for NSMC Uncertainty Analysis

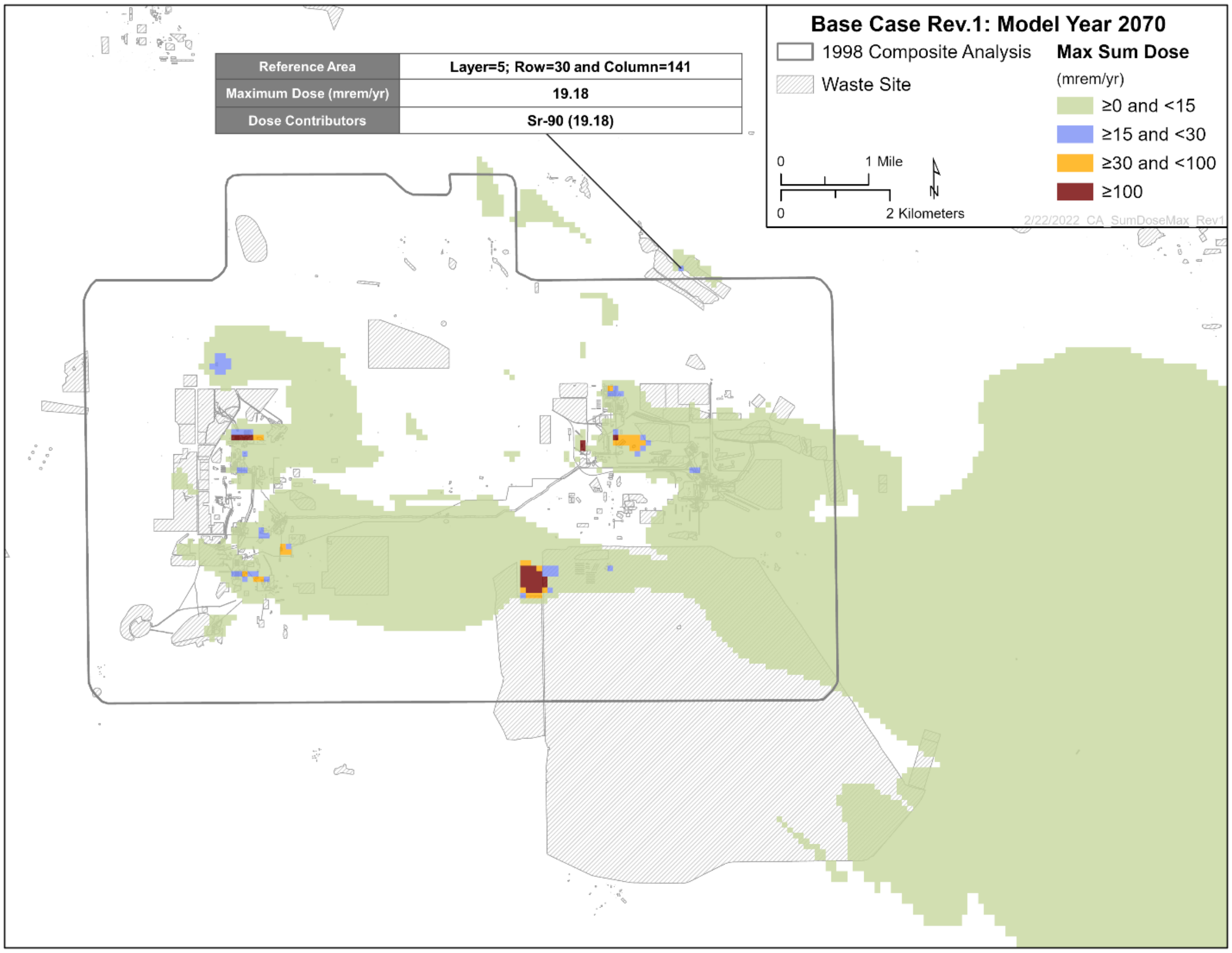

Figure 3. Location of Sr-90 Peak Dose During the Compliance Period (CY 2070 to CY 3070)

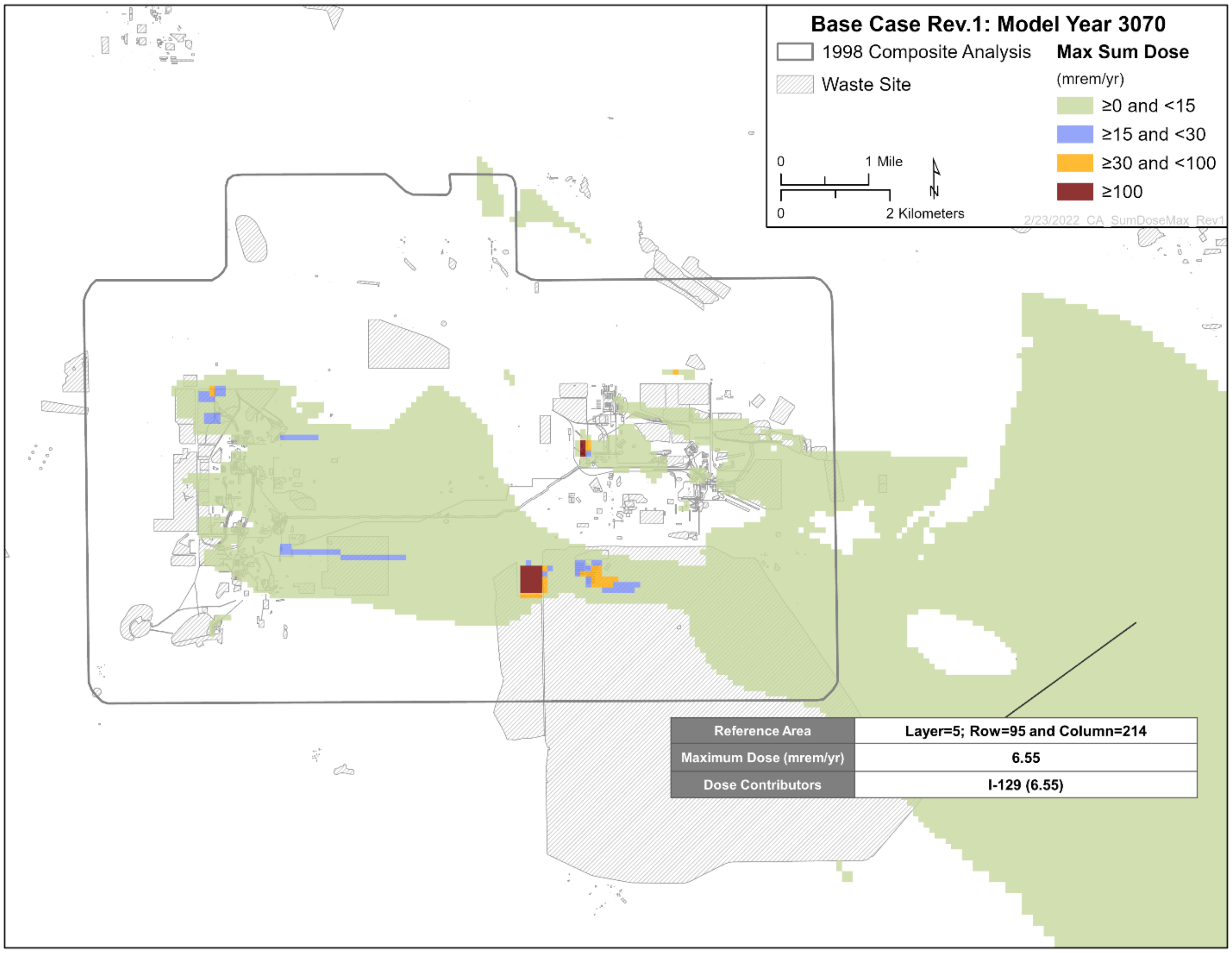

Figure 4. Location of I-129 Peak Dose Beyond the Compliance Period (CY 3070 to CY 12070)

To provide a more transparent indication of the impact of uncertainty in groundwater flow on the predicted dose, an alternative approach was adopted. The approach uses the base case groundwater dose results presented in ECF-HANFORD-20-0079, *Calculation of Groundwater Pathway Radiological Dose for the Hanford Site Composite Analysis Base Case*, and the CA visualization tool[3] to identify specific locations in the MT3DMS model domain that yield higher predicted doses for specific mobile dose-significant radionuclides at locations Beyond the 1998 CA Domain Boundary, hereinafter referred to as the CA compliance boundary. Using this approach, four radionuclides of interest (i.e., carbon-14 [C-14], Tc-99, I-129, and U-238) were evaluated at several locations along the CA compliance boundary as shown in Figure 5. The radionuclides and locations selected for the evaluation of the NSMC results are

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[3] The CA visualization tool was developed to allow the user an interactive means of examining the spatial and temporal variation in total dose and individual radionuclide dose and groundwater concentration for the 16 radionuclides evaluated in the CA. The visualization tool allows the user to choose a radionuclide of interest and display a map view of the spatial distribution of the predicted radionuclide concentrations and doses associated with that radionuclide as well as the summed doses for all 16 radionuclides. The user can use a sliding time bar to scroll through the temporal variation in concentration and dose and zoom into times and areas of interest in the model domain to aid in the interpretation of the results. In addition, the user can click on any location within the model domain to render a time history of either radionuclide concentration or dose for the radionuclide of interest at that selected location.

identified in Table 1. The base case predicted peak concentrations and doses for these selected radionuclides and locations are listed in Table 2. The peak concentrations and doses occur at two time periods of interest, namely within the compliance period (i.e., corresponding to CY 2070 at the start of the compliance period and beyond the compliance period (i.e., corresponding to about CY 3570). The radionuclides and locations are summarized in Table 1.

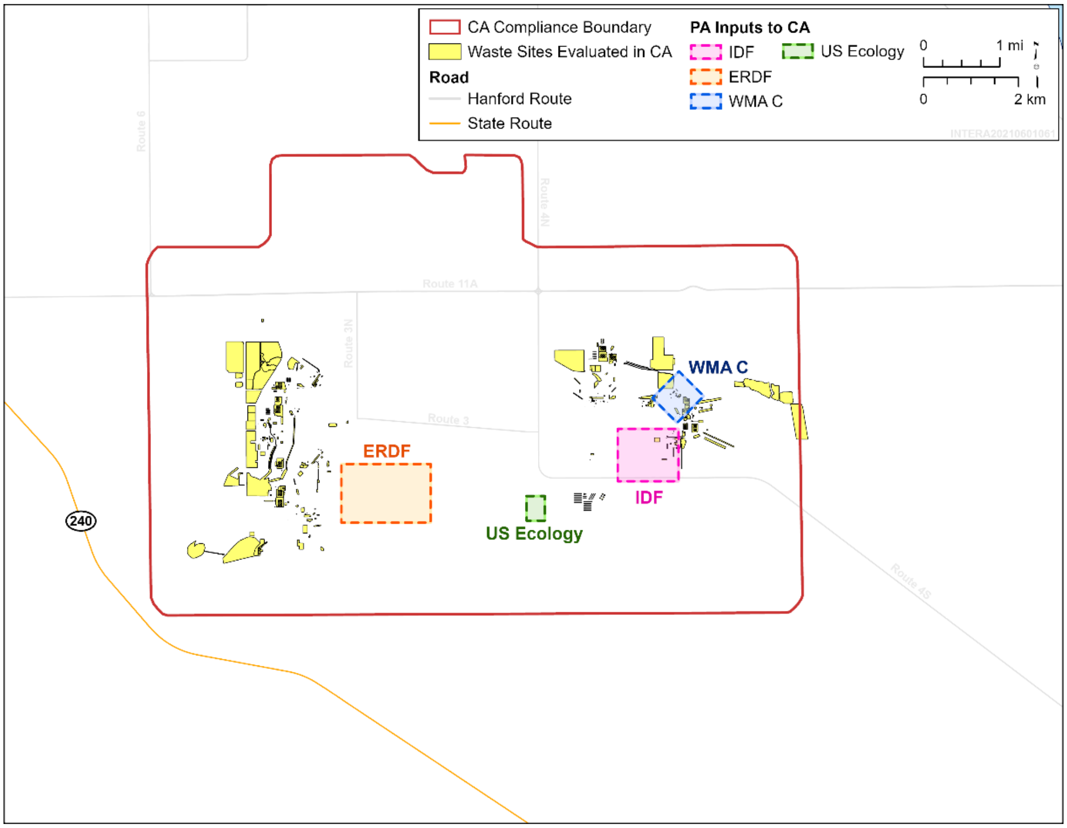


Figure 5. Location of Beyond the 1998 CA Domain Boundary for the NSMC Uncertainty Analysis

Table 1. Selection of Representative Radionuclides and Locations

Radionuclide	Location	Comments
C-14	x = 577800, y = 135900	Location is along the eastern edge of the CA compliance boundary beneath the 216-B-3C Pond.
Tc-99	x = 577800, y = 132100	Location is along the southeastern corner of CA compliance boundary.
	x = 572100, y = 140800	Location to east of northern CA compliance boundary, west of Gable Mountain Pond.
I-129	x = 572100, y = 140800	Location to east of northern CA compliance boundary, west of Gable Mountain Pond.
	x = 577800, y = 136500	Location is along the eastern edge of the CA compliance boundary to the east of the 216-B-3C Pond.
	x = 577800, y = 133400	Location is along the southeastern corner of the CA compliance boundary where the CA compliance boundary intersects the high conductivity zone.
U-238	x = 577800, y = 132100	Location is along the southeastern corner of CA compliance boundary.
	x = 577800, y = 135000	Location is along the eastern edge of the CA compliance boundary.

CA = composite analysis
x = Easting
y = Northing

Table 2. The Impact of Saturated Zone Hydraulic Conditions on Predicted Dose

Radionuclide	Base Case Results		Comments/Key Sources
	Peak Concentration and Dose	Calendar Year	
C-14	1,800 pCi/L 6.3 mrem/yr	2150	The source of the C-14 is discharge to the 216-B-3C Pond and subsequent transfer to groundwater.
Tc-99	300 pCi/L 1.1 mrem/yr	3500	The peak concentration is the result of release and transfer to groundwater from the BC Cribs and Trenches.
	480 pCi/L 2.0 mrem/yr	2070	Peak concentration stays unchanged for entire 1,000-yr compliance period and 9,000-yr postcompliance sensitivity analysis period due to low groundwater flow rates in deeper hydrostratigraphic units in this area. Source of Tc-99 contamination in 2018 is likely the result of discharge to the BY Cribs.

Table 2. The Impact of Saturated Zone Hydraulic Conditions on Predicted Dose

Radionuclide	Base Case Results		Comments/Key Sources
	Peak Concentration and Dose	Calendar Year	
I-129	1.4 pCi/L 1.6 mrem/yr	2070	Peak concentration stays unchanged for entire 1,000-yr compliance period and 9,000-yr postcompliance sensitivity analysis period due to low groundwater flow rates in deeper hydrostratigraphic units in this area. The source of the I-129 contamination in 2018 is likely the result of discharge to the BY Cribs.
	1.1 pCi/L 1.3 mrem/yr	2070	The source of the I-129 contamination in 2018 is likely the result of discharge to 216-A-8 and 216-A-24 Cribs.
	1.3 pCi/L 1.5 mrem/yr	2070	The concentration slowly declines during the 10,000-yr simulation period. The source of the I-129 contamination in 2018 is likely the result of discharge to the 216-A-5 and 216-A-10 Cribs.
U-238	0.84 pCi/L 0.17 mrem/yr	3500	The peak concentration is a result of transfer to groundwater from US Ecology site.
	12.7 pCi/L 2.6 mrem/yr	2080	The source of the U-238 contamination in 2018, which is likely the result of discharge at 241-BX-102 past leak.

The locations and base case dose results for these radionuclides are depicted in Figure 6 and Figure 7 for the two time periods of interest.

Data package CP-64491 presents the radionuclide-specific unit dose factors (UDFs) for the following six soil types within the Hanford Central Plateau: Rupert sand, Hezel/Koehler sand, Dunesand, Burbank loamy sand, Ephrata sandy loam, and Esquatzel/Kiona/Pasco/Scooteney Stoney/Warden silt loam. A soil- and radionuclide-specific UDF was calculated for each of the following exposure routes using the All-Pathways Representative Person scenario:

- Ingestion of water
- Ingestion of homegrown crops (fruits and vegetables)
- Ingestion of beef
- Ingestion of milk
- Ingestion of eggs
- Ingestion of poultry
- Incidental ingestion of soil
- Inhalation of soil particulates
- Inhalation of water vapor
- External exposure

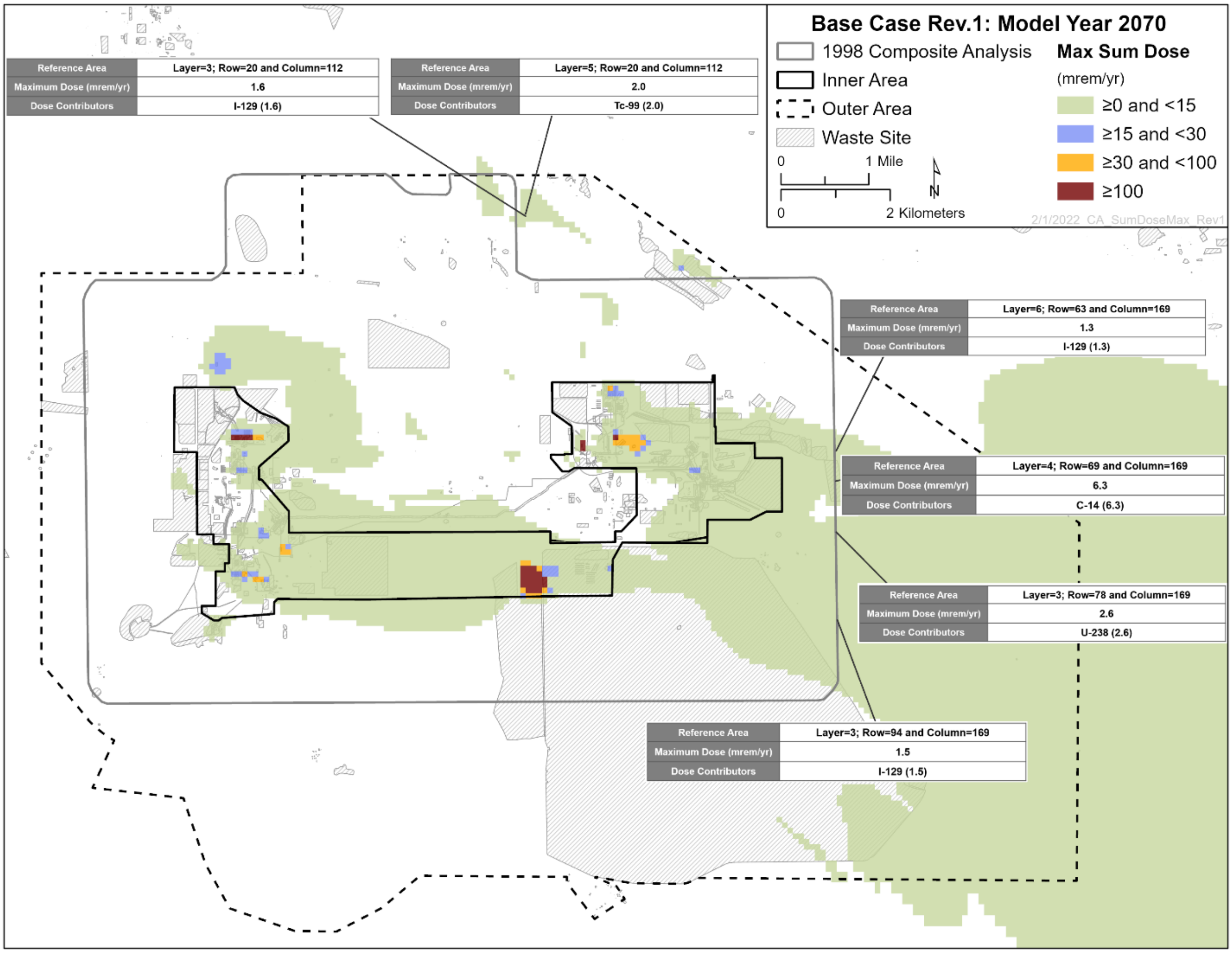


Figure 6. Locations of Peak Doses for Null Space Monte Carlo Analysis at Start of Compliance Period (CY 2070) for Locations Beyond the 1998 CA Domain Boundary

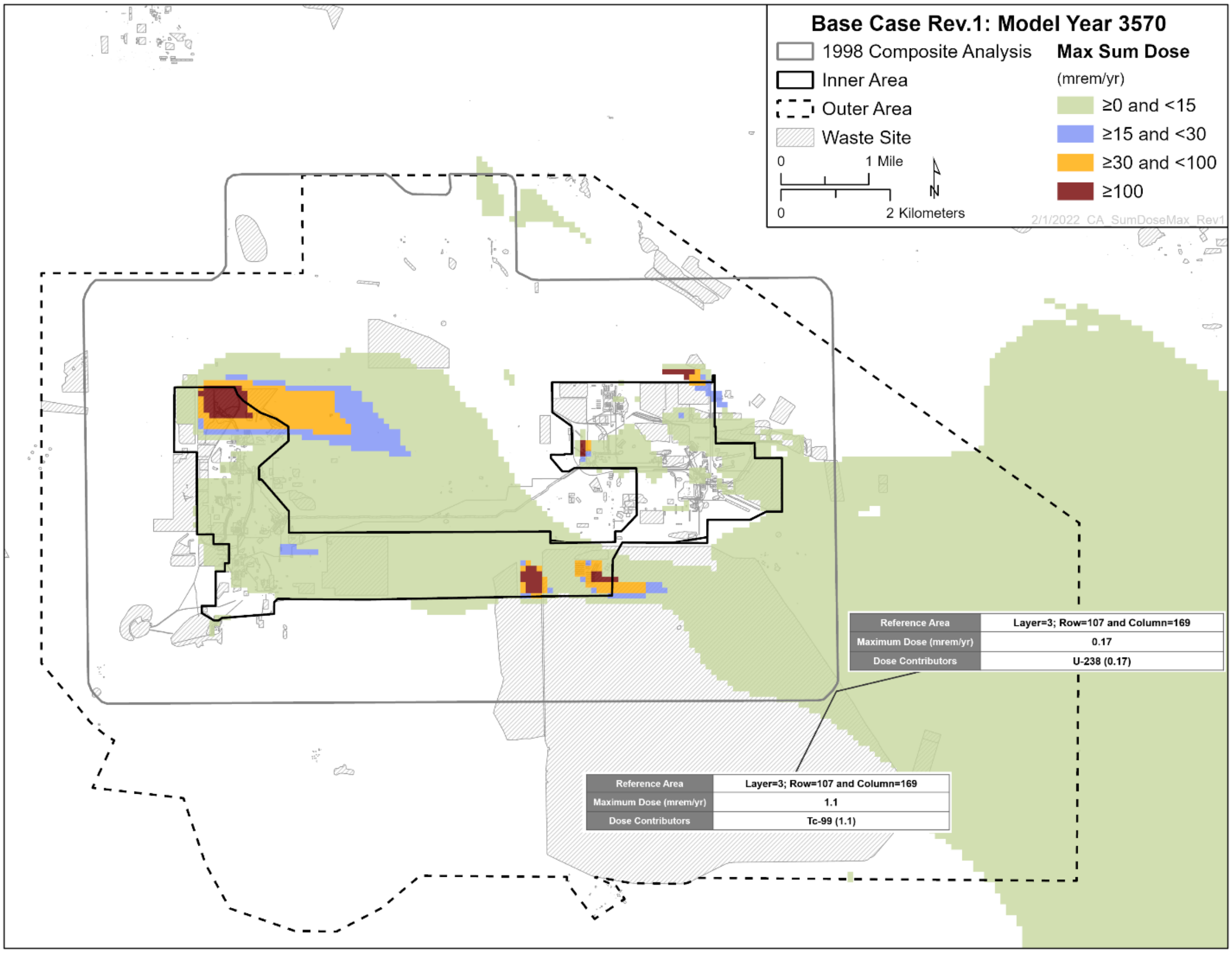


Figure 7. Locations of Peak Doses for Null Space Monte Carlo Analysis After Compliance Period (CY 3070 to CY 12070) for Locations Beyond the 1998 CA Domain Boundary

The exposure-route specific UDFs were then summed together to calculate the total UDF for each Hanford-specific contaminant of potential concern (COPC).

In accordance with DOE-STD-5002-2017, *DOE Standard - Disposal Authorization Statement and Tank Closure Documentation*, the resulting projected maximum doses were compared against the following two performance objectives to demonstrate compliance.

- Primary total effective dose (TED) limit – 100 mrem/yr
- CA administrative TED limit – 30 mrem/yr

3 Methodology

The projected maximum dose ranges were calculated based on 96 groundwater flow simulation results for the CA compliance boundary for the two compliance time periods. The methodologies for calculating total dose are described in the below sections.

3.1 Calculation of Maximum Total Dose at CA Compliance Boundary and Two Timeframes for Each Groundwater Flow Simulation Result

For each of the 96 groundwater flow simulation results, three different dose calculator tools, (ca-dosecalc, ca-sumdoseDB, and ca-maxdoseDB) were used to calculate the projected maximum total annual dose for the CA compliance boundary for the two compliance time periods as summarized in Section 2.
The methodology is as follows:

Step One: Calculation of COPC-specific Dose based on Location, Elapsed Time Interval, and Exposure Route

The ca-dosecalc tool calculates the COPC-specific radiological dose (mrem/yr) for each exposure route, each grid block of the saturated zone model domain, and elapsed time interval. The ca-dosecalc tool multiplies the modeled radionuclide concentration (in picocuries per liter, pCi/L) for a COPC by the corresponding soil and exposure route-specific UDFs (in mrem/yr per pCi/L) for each saturated zone model domain grid block and elapsed time interval where the COPC concentration is greater than or equal to a defined COPC-specific threshold concentration.

Step Two: Calculation of Total Dose from all COPCS for an Exposure Route for Each Location and Elapsed Time Interval

The ca-sumdoseDB tool calculates a total dose resulting from all COPCs. The ca-sumdoseDB tool sums the exposure route-specific dose from each contributing COPC at each saturated zone model domain grid block and elapsed time interval.

Step Three: Calculation of Maximum Total Dose from all COPCs and all Exposure Routes for Each Location and Elapsed Time Interval

The ca-maxdoseDB tool calculates the total dose for all exposure routes from all COPCs and computes the maximum total dose for a user-defined location and a user-defined time interval. The ca-maxdoseDB was used to determine location and time of the maximum total doses within the user-defined location and time interval.

3.2 Calculation of the Ranges of Maximum Total Doses at the CA Compliance Boundary and Two Compliance Time Periods for All Groundwater Flow Simulation Results

The maximum total dose at the CA compliance boundary and two compliance time periods for all 96 groundwater flow simulations were utilized to calculate the ranges of maximum total doses which were then compared against two performance objectives defined in Section 2 to demonstrate compliance.

4 Assumptions and Inputs

Assumptions and inputs for this calculation are presented in the following sections.

4.1 Assumptions

CP-64491 documents the exposure assumptions, equations, and methods for the All-Pathways Representative Person exposure scenario used to calculate radionuclide specific unit dose factors for groundwater pathway.

COPC-specific threshold concentrations were calculated to reduce the computational time required for calculating groundwater doses over a period of 10,000 years by focusing on groundwater concentrations that are significant to the dose calculation. Application of the threshold values is strictly for computational efficiency in the dose calculation and does not impact the calculation and identification of peak groundwater pathway dose or its location in time and space. Table 3 presents the results of radionuclide-specific threshold concentrations for the four radionuclides evaluated in the groundwater pathway.

Table 3. Radionuclide-Specific Threshold Groundwater Concentrations

Radionuclide	Radionuclide-Specific Threshold Concentration (pCi/L)
C-14	4.6
I-129	0.2
Tc-99	35.6
U-238	0.7

4.2 Inputs

The following sections describe the inputs for the dose calculation.

4.2.1 Calculation of Dose

The ca-dosecalc requires the following information in the form of input files to calculate the dose relative to location, elapsed time interval, and exposure route. The calculation of dose for NSMC analysis required the evaluation of 96 simulations, each of which includes unformatted concentration (UCN) files for four individual COPCs.

The following required inputs are common to the dose calculations for all simulations and COPCs and are maintained as individual work products in the integrated computational framework (ICF).

- MODular Groundwater FLOW (MODFLOW) Grid shapefile: ./MFGRID/v8.3/data/grid_274_geo.shp
- MODFLOW Grid-Soils Indices file: ./SOILIND/v1.0/data/mfgrid_soil_indices.csv
- Soil-specific UDF file: ./GWUDF/v1.0a/data/Soil_Specific_UDF_CA.csv and /GWUDF/v1.1/data/Soil_Specific_UDF_CA.csv [H-3 only]

The following required inputs are common to the dose calculations for all simulations and COPCs and are maintained as input data for the Sensitivity Case 5 Dose Calculation work product in the ICF.

- Exposure Routes file: ./DOSE/v2.0/[pending]/inputs/pathways.csv and ./DOSE/v2.1/[pending]/inputs/pathways.csv [H-3 only]
- COPC-specific Thresholds file: ./DOSE/v2.0/[pending]/inputs/copcs.csv and ./DOSE/v2.1/[pending]/inputs/copcs.csv [H-3 only]

Each dose calculation requires a UCN (concentrations) file specific to a simulation and a COPC. The UCN files are maintained as a work product in the ICF.

- NSMC-generated COPC-specific UCN (concentrations) file: ./P2RNSU/v1.0/data/tran/[simulation run]/avg/[COPC]/P2RGWM.ucn where [simulation run] = ns00, ns01,…., ns98, ns99 and for each simulation run, [COPC] = c-14, cl36, i129, tc99, trit, u233, u234, u235, u238

4.2.2 Calculation of Total Dose from all COPCs by an Exposure Route for Each Location and Elapsed Time Interval

The ca-sumdoseDB tool requires the following information in the form of input files to calculate the total dose resulting from all COPCs applicable to an exposure route relative to location and elapsed time interval. The following files are generated by the ca-dosecalc tool and are maintained as dose work products in the ICF.

- Sr-90-specific dose files: ./DOSE/v1.0/data/base/avg/sr90/sr90.csv
- H-3-specific dose files: ./DOSE/v2.1/data/sen5/[simulation run]/avg/trit/trit.csv where [simulation run] = ns00, ns01,…., ns98, ns99
- Remaining COPC-specific dose files: ./DOSE/v2.0/sens/[simulation run]/avg/[COPC]/[COPC].csv where [simulation run] = ns00, ns01,…., ns98, ns99 and for each simulation run, [COPC] = c-14, cl36, i129, tc99, u233, u234, u235, u238

4.2.3 Calculation of Maximum Total Dose from all COPCs and all Exposure Routes for Each Location and Elapsed Time Interval

The ca-maxdoseDB tool requires the following information in the form of inputs files to calculate the maximum total dose for a spatial extent and timeframe.

The following required inputs are common to the maximum total dose calculations for all simulations and are maintained as a work product in the ICF.

- Spatial Extent Definition file(s) (defines the MODFLOW grid cells that overlap the user-defined spatial extent):
  - ./CPCA98P2R/v1.0/data/Inner_Area/P2R_Cells_On_and_Outside_Inner_Area_Boundary.csv
  - ./CPCA98P2R/v1.0/data/Outer_Area/P2R_Cells_On_and_Outside_Outer_Area_Boundary.csv
  - ./CPCA98P2R/v1.0/data/CA98/P2R_Cells_On_and_Outside_CA98_Boundary.csv

Each maximum total dose calculation requires the following information for all simulations.

- Start and end dates (in years) for user-defined time intervals. The dates are documented in JSON- formatted configuration files maintained as inputs for the maxdose work product in the ICF: ./MAXSUMDOSE/v2.1/data/inputs.configFile-[simulation run].json where [simulation run] = ns00, ns01,…, ns98, ns99

Each maximum total dose calculation requires a file generated by the ca-sumdoseDB tool specific to a simulation. These files are maintained as a sumdose workproduct in the ICF.

- Total Dose by Exposure Route file: ./SUMDOSE/v2.1/data/outputs/totalDosens[simulation run].csv where [simulation run] = 00, 01,…, 98, 99

5 Software Applications

The following sections document that the utility calculation software tool used in this ECF complies with requirements of Central Plateau Cleanup Company's controlled software management procedure.

5.1 Approved Software

The tools used to calculate the dose results documented in this ECF (ca-dosecalc, ca-sumdoseDB, and ca-maxdoseDB) are approved utility calculation software in compliance with Central Plateau Cleanup Company's controlled software management procedure that implements U.S. Department of Energy quality assurance requirements including DOE O 414.1D, *Quality Assurance*. The software is a set of utility codes included in CHRPC-04032, *Composite Analysis/Cumulative Impact Evaluation (CACIE) Utility Codes Integrated Software Management Plan*. The utility codes were tested and qualified for use in compliance with the requirements specified in CHPRC-04032 and as documented in the consolidated tool package attachments for the tools.

5.1.1 Description

The following information identifies the approved utility calculation software used for the calculation of dose documented in this ECF.

- **Composite Analysis/Cumulative Impact Evaluation Utility Codes Hanford Information Systems Inventory Entry:** 4503
- Dose Calculator (ca-dosecalc)
  - **Software Version:** v1.1
  - **Software Git SHA:** 1cc4d017c7afdad176e4f6df077aad74b76a3398
  - **Git Repository Version:** 4.1 (Sr-90 only), 4.2, and 5.5 (H-3 only)
  - **Git Repository SHA:** e8b8396bb36cf3a9feba128d454250522ddd74d7 (Sr-90 only), 83fd29e41185e0f8b8560c5b83469c1e189a5931, and 0aa1814c488f0fb4b0f33450499687fc3447c726 (H-3 only)
- Sum Dose Calculator (ca-sumdoseDB)
  - **Software Version:** v1.1
  - **Software Git SHA:** 96a676aa748be44788529527e046420e13812957
  - **Git Repository Version:** v5.5
  - **Git Repository SHA:** 0aa1814c488f0fb4b0f33450499687fc3447c726

- Max Dose Calculator (ca-maxdoseDB)
  - **Software Version**: v1.0
  - **Software Git SHA:** 327f1bdd340a5b3b887102df4e76f04db66656b1
  - **Git Repository Version:** v5.5
  - **Git Repository SHA:** 0aa1814c488f0fb4b0f33450499687fc3447c726

5.1.2 Software Installation and Checkout

Verification that the utility calculation software specified in Section 5.1.1 is qualified for use is documented in the log files maintained as output in the ICF for each work product generated as documented in this ECF. The log files document the tool used, software and repository versioning, quality assurance status of the code, and software user, workstation, and operating platform. The Software Installation and Checkout (SICO) form can be found in Appendix A of this ECF. The ICF Submittal Form can be found in Appendix B of this ECF.

5.1.3 Statement of Valid Software Application

The preparers of this calculation attest that the software identified and used for this calculation is appropriate for the application and has been used within the range of intended uses for which it was tested and accepted.

6 Calculation

The following section presents the results of the original projected maximum dose calculations for the CA compliance boundary and two compliance periods. The original calculations were verified independently by utilizing the methodology, assumptions, and inputs described in Sections 3 and 4.

6.1 Original Calculation

For each of the 96 groundwater flow simulations, three different dose calculator tools, (CA-dosecalc, CA-sumdoseDB, and CA-maxdoseDB) were used to calculate the highest projected total annual doses at the CA compliance boundary within two compliance time periods (from CY 2070 to CY 3070 and from CY 3070 to CY 12070).

6.2 Verification of Original Calculation

Verification calculations were performed independently using the methodology described in Sections 3 and 4 of this ECF. The files have been archived under this ECF number in the ICF.

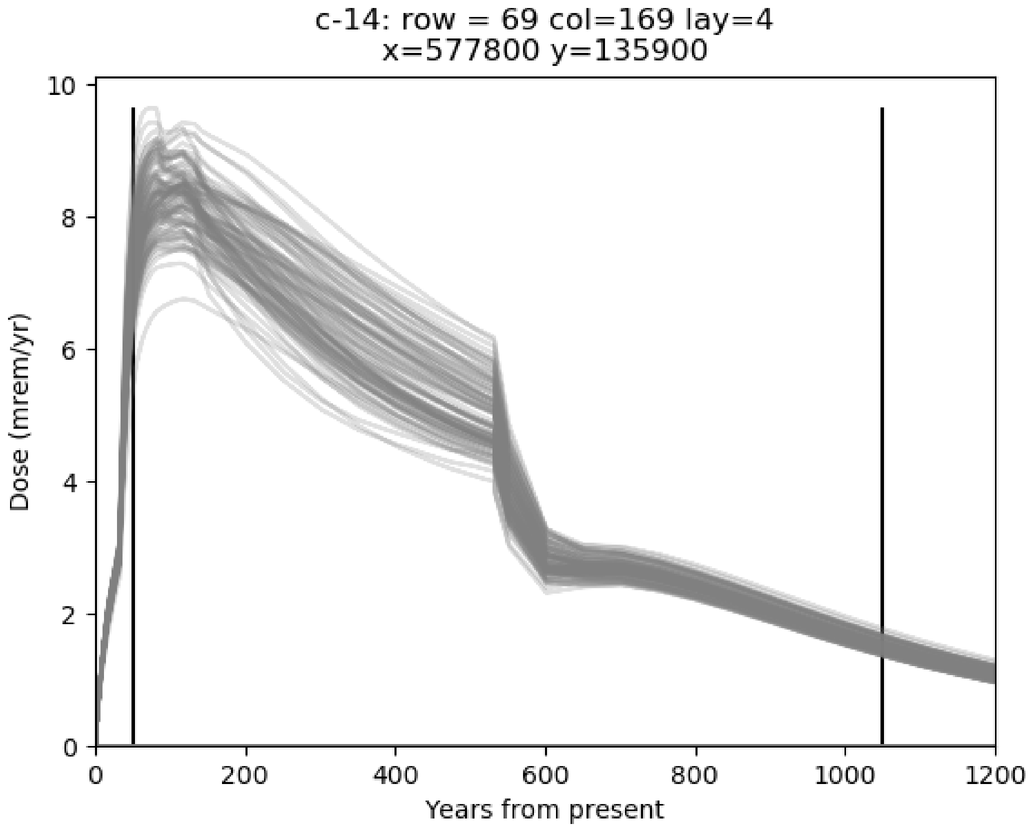
6.3 Results of Comparison between Original and Verification Calculations

Reviews of original and verification calculation results did not identify any error associated with the maximum dose calculation for groundwater pathway at three compliance boundaries and two timeframes.

7 Results/Conclusions

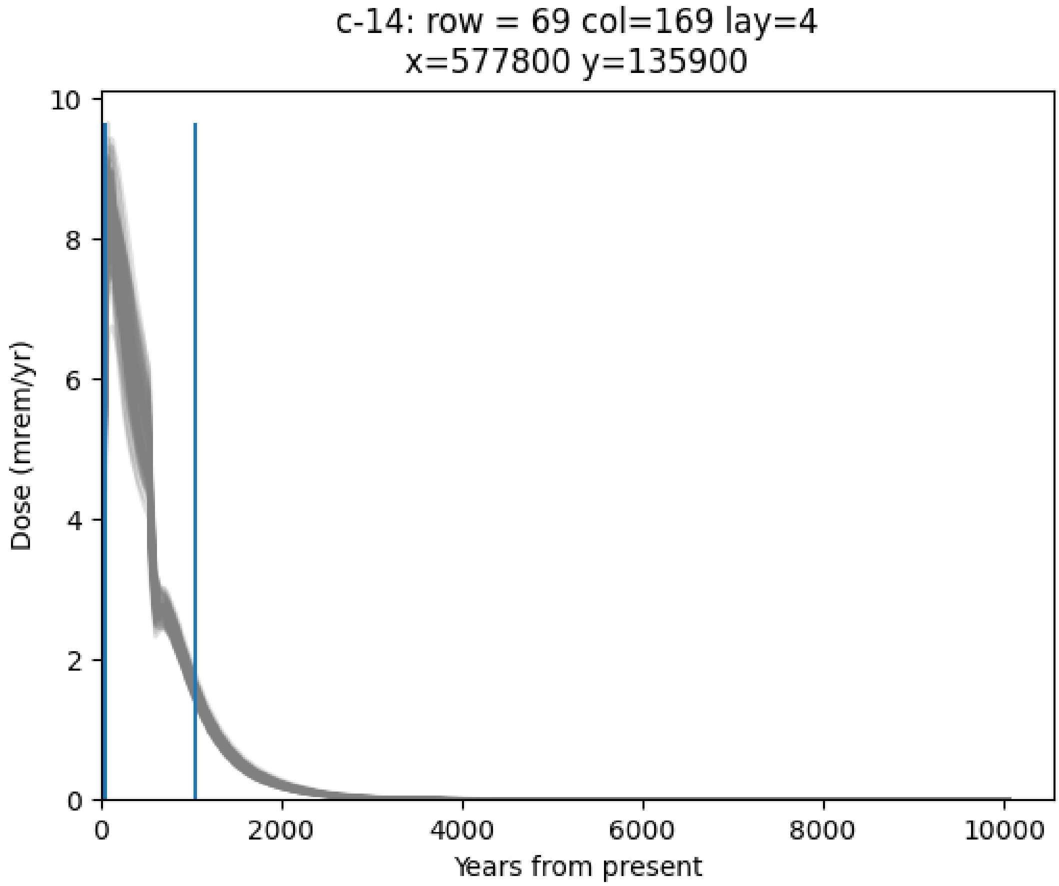
The groundwater dose realizations from the NSMC analyses for the selected locations for the four radionuclides of interest are shown for the compliance period and the postcompliance period in Figure 8 and Figure 9.

For this specific location along the eastern edge of the CA compliance boundary beneath the 216-B-3C Pond (x = 577800; y = 135900), C-14 had a maximum peak dose of 9.6 mrem/yr approximately 30 years following the start of the compliance period (CY 2070 to CY 3070) and then slowly declined throughout the compliance period (Figure 8) until reaching zero approximately 2,300 years from present (Figure 9). The maximum dose for C-14 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

Figure 8. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for C-14 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

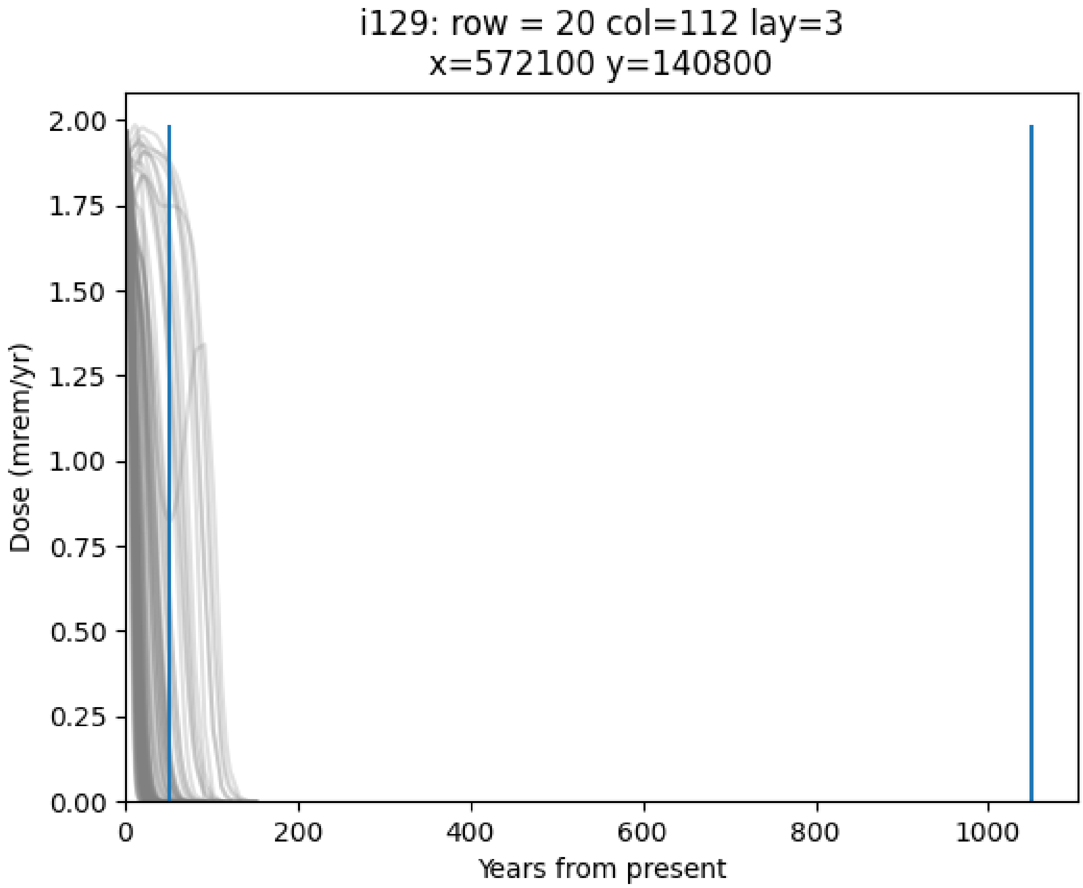


Note: Compliance period indicated by vertical lines.

Figure 9. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for C-14 at the Selected Location for the Compliance (CY 2070-3070) and Postcompliance Periods (CY 3070 to CY 12070)

For this specific location along the eastern edge of the CA compliance boundary beneath the 216-B-3C Pond (x = 577800; y = 135900), C-14 had a maximum peak dose of 9.6 mrem/yr approximately 30 years following the start of the compliance period (CY 2070 to CY 3070) (Figure 8), which is followed by a steady decline until approximately 2,300 years from the present where the dose eventually reaches zero (Figure 9). The maximum dose for C-14 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.

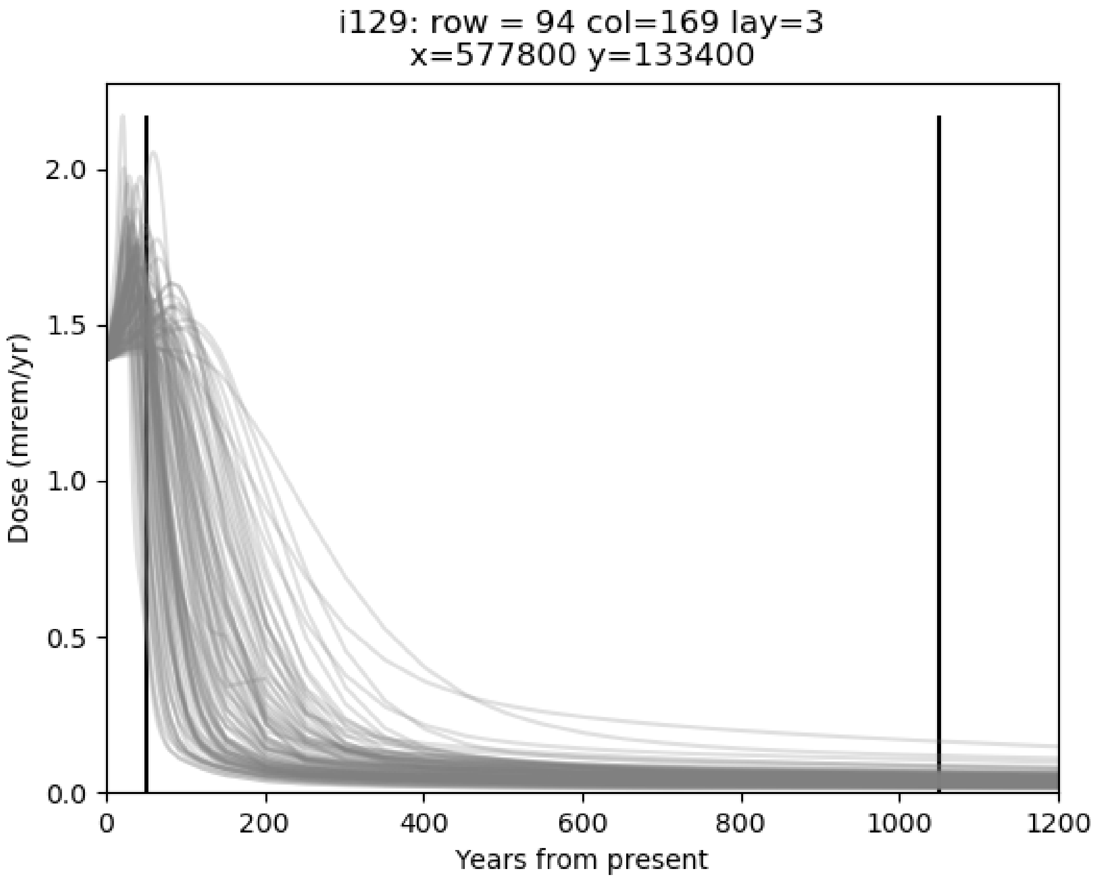
For this specific location east of northern CA compliance boundary, west of Gable Mountain Pond (x = 572100; y = 140800), I-129 had a maximum peak dose of 1.98 mrem/yr prior to the start of compliance (CY 2070) and rapidly declined until approximately 150 years from the present where the dose reaches zero (Figure 10). The maximum dose for I-129 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

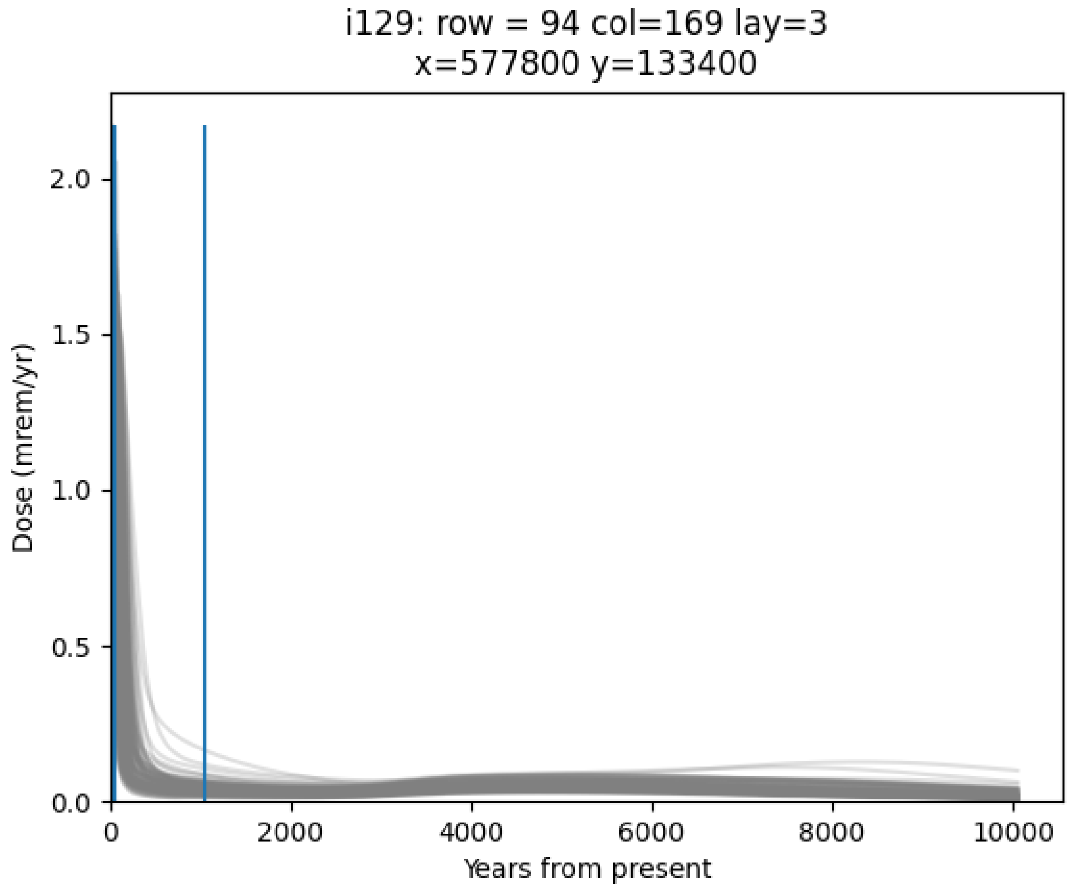
Figure 10. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for I-129 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

For this specific location along the southeastern corner of the CA compliance boundary where the CA compliance boundary intersects the high conductivity zone (x = 577800; y = 133400), I-129 had a maximum peak dose of 2.17 mrem/yr prior to the start of the compliance period (CY 2070 to CY 3070) (Figure 11) and then the dose slowly declines until the dose plateaus to less than 0.1 mrem/yr approximately 2,000 years from present (Figure 12). The maximum dose for I-129 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

Figure 11. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for I-129 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

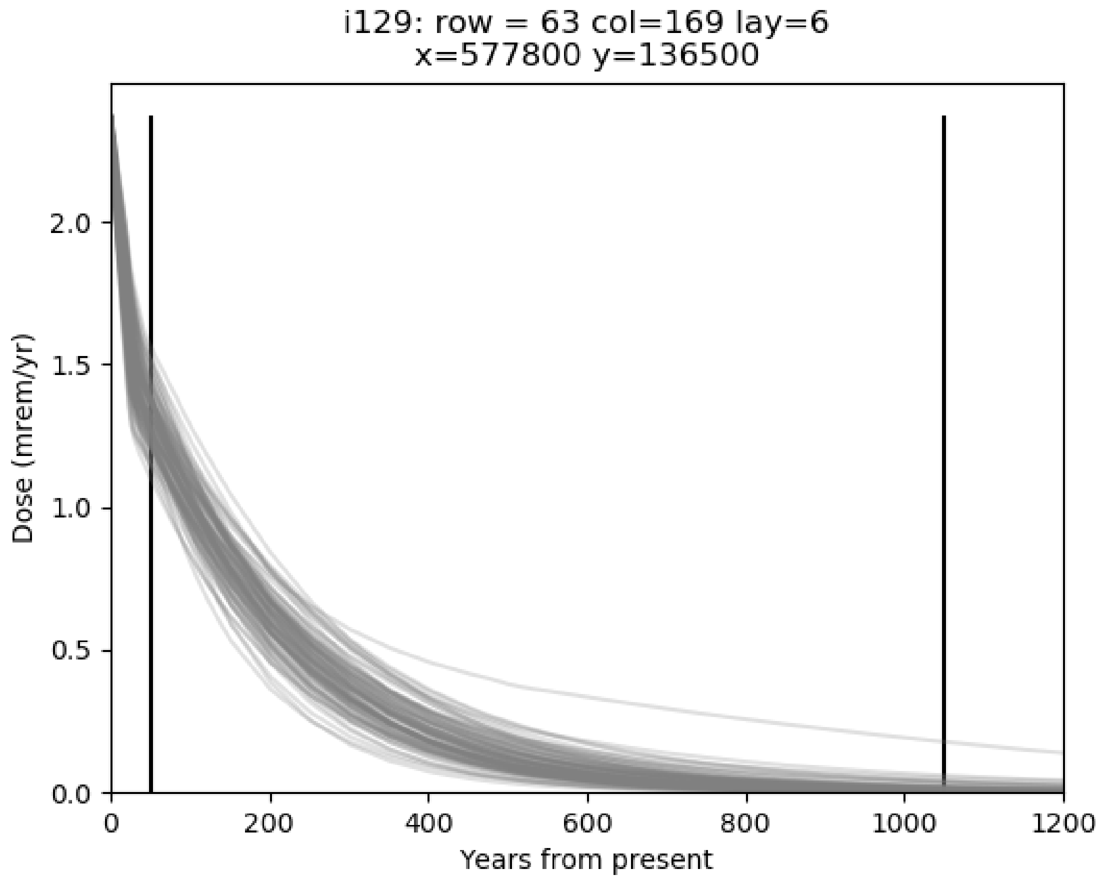


Note: Compliance period indicated by vertical lines.

Figure 12. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for I-129 at the Selected Location for the Compliance (CY 2070 to CY 3070) and Postcompliance Periods (CY 3070 to CY 12070)

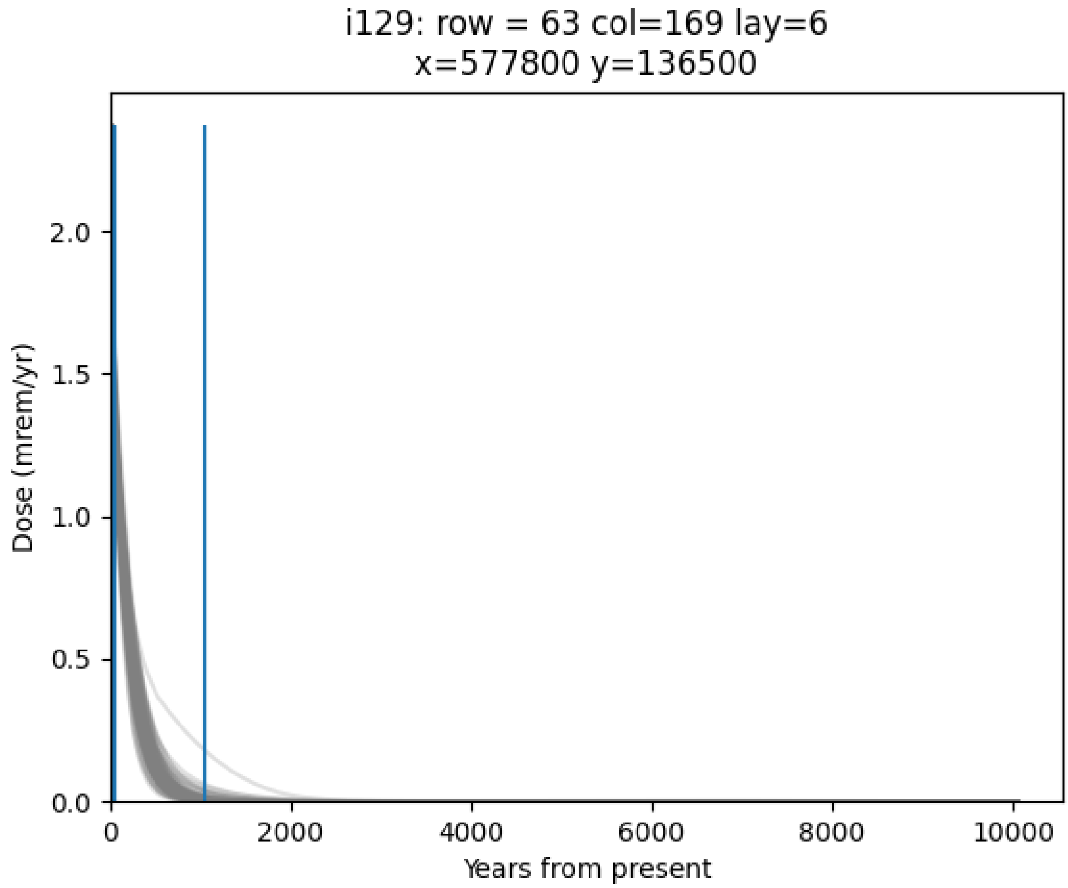
For this specific location along the southeastern corner of the CA compliance boundary where the CA compliance boundary intersects the high conductivity zone (x = 577800; y = 133400), I-129 had a maximum peak dose of 2.17 mrem/yr prior to the start of the compliance period (CY 2070 to CY 3070) (Figure 11) and then began to decline until the dose plateaus to less than 0.1 mrem/yr approximately 2,000 years from present (Figure 12). The maximum dose for I-129 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.

For this specific location along the eastern edge of the CA compliance boundary to the east of the 216-B-3C Pond (x =577800; y = 136500), I-129 had a maximum peak dose of 2.37 mrem/yr prior to the start of the compliance period (CY 2070 to CY 3070) (Figure 13) and then the dose declined throughout the compliance period until 2,000 years from present where the dose reaches zero (Figure 14). The maximum dose for I-129 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

Figure 13. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for I-129 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

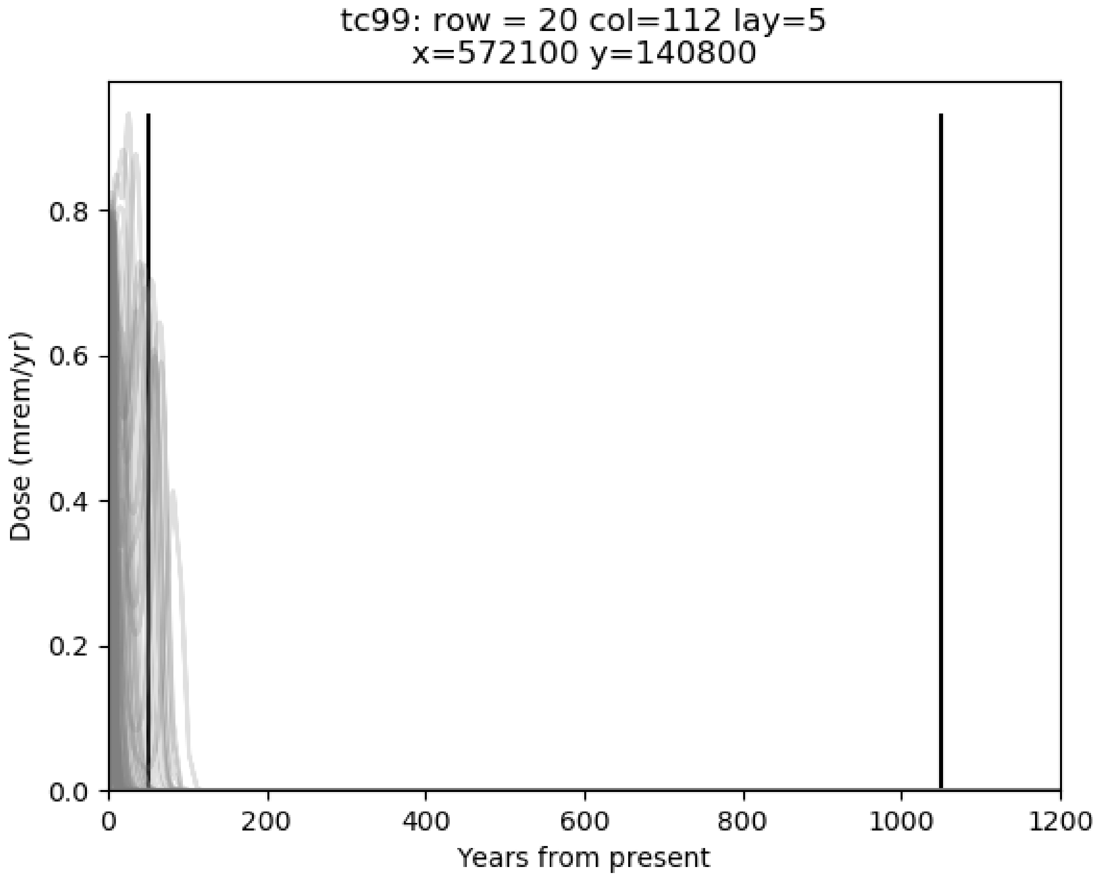


Note: Compliance period indicated by vertical lines.

Figure 14. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for I-129 at the Selected Location for the Compliance (CY 2070 to CY 3070) and Postcompliance Periods (CY 3070 to CY 12070)

For this specific location along the eastern edge of the CA compliance boundary to the east of the 216-B-3C Pond (x = 577800; y = 136500), I-129 had a maximum peak dose of 2.37 mrem/yr prior to the start of the compliance period (CY 2070 to CY 3070) (Figure 13) that was followed by a rapid decline until 2,000 years from present where the dose reaches zero (Figure 14). The maximum dose for I-129 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.

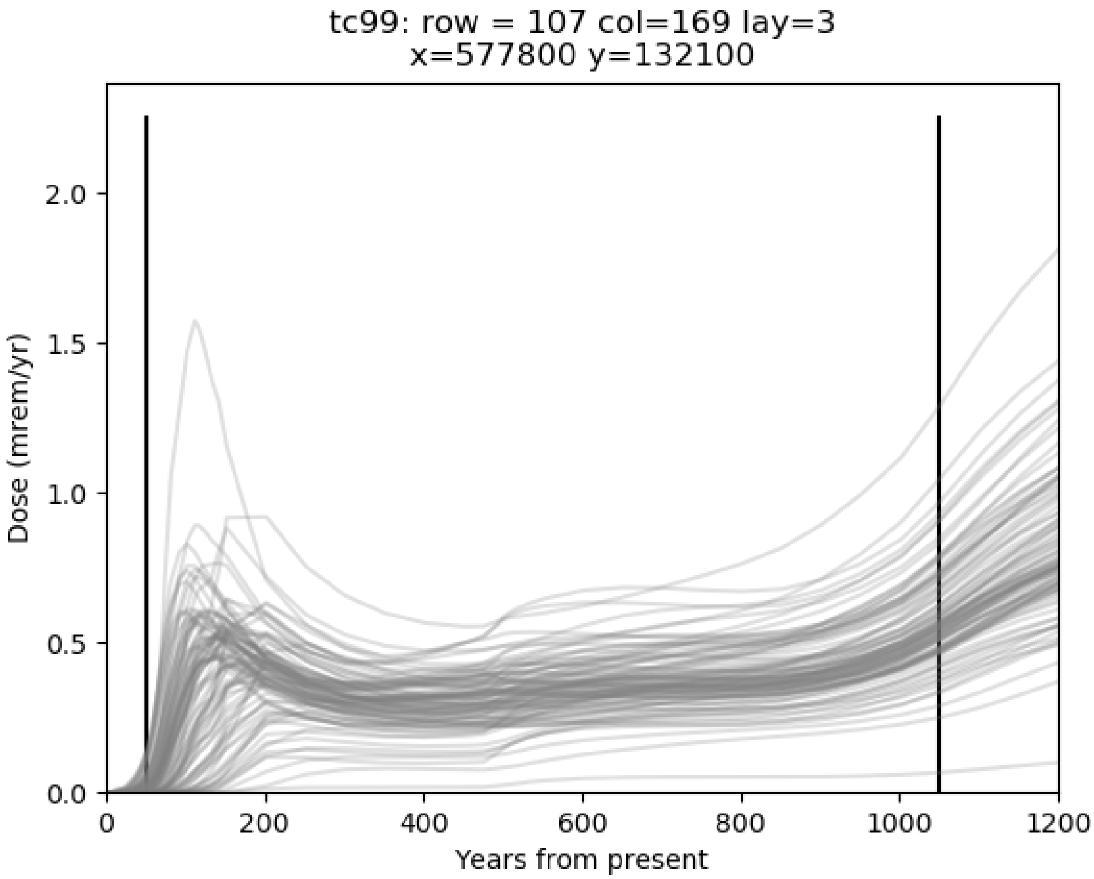
For this specific location east of northern CA compliance boundary, west of Gable Mountain Pond (x = 572100; y = 140800), Tc-99 had a maximum peak dose of 0.93 mrem/yr prior to the start of the compliance period (CY 2070 to CY 3070) that was followed by a rapid decline reaching a dose of zero less than 100 years from present (Figure 15). The maximum dose for Tc-99 is below both the primary TED limit of 100 mrem/yr and CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

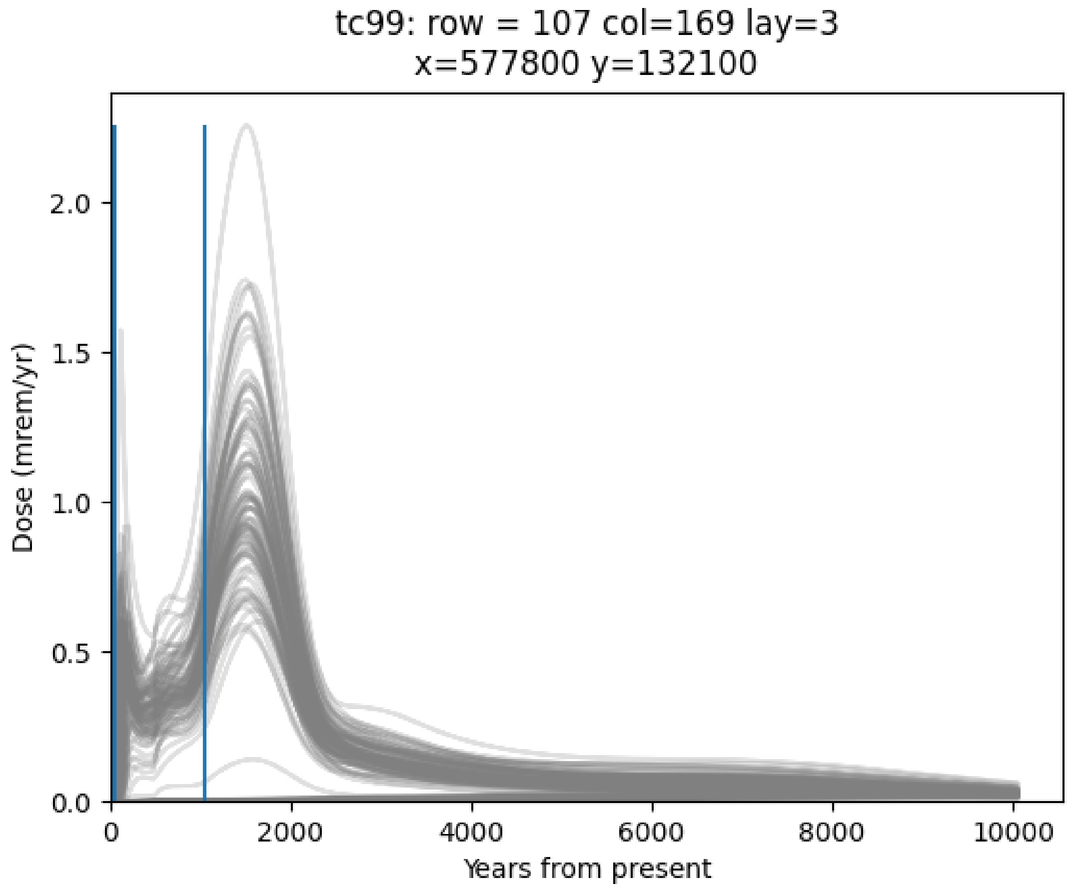
Figure 15. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for Tc-99 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

For this specific location along the southeastern corner of CA compliance boundary (x = 577800; y = 132100), the Tc-99 dose increased approximately 150 years from present and plateaued at a dose of approximately 0.5 mrem/yr until the end of the compliance period when the dose began to increase (Figure 16). Tc-99 had a maximum peak dose of 2.26 mrem/yr which was not reached until after the compliance period ended (CY 2070 to CY 3070) (Figure 17). The maximum dose for Tc-99 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

Figure 16. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for Tc-99 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

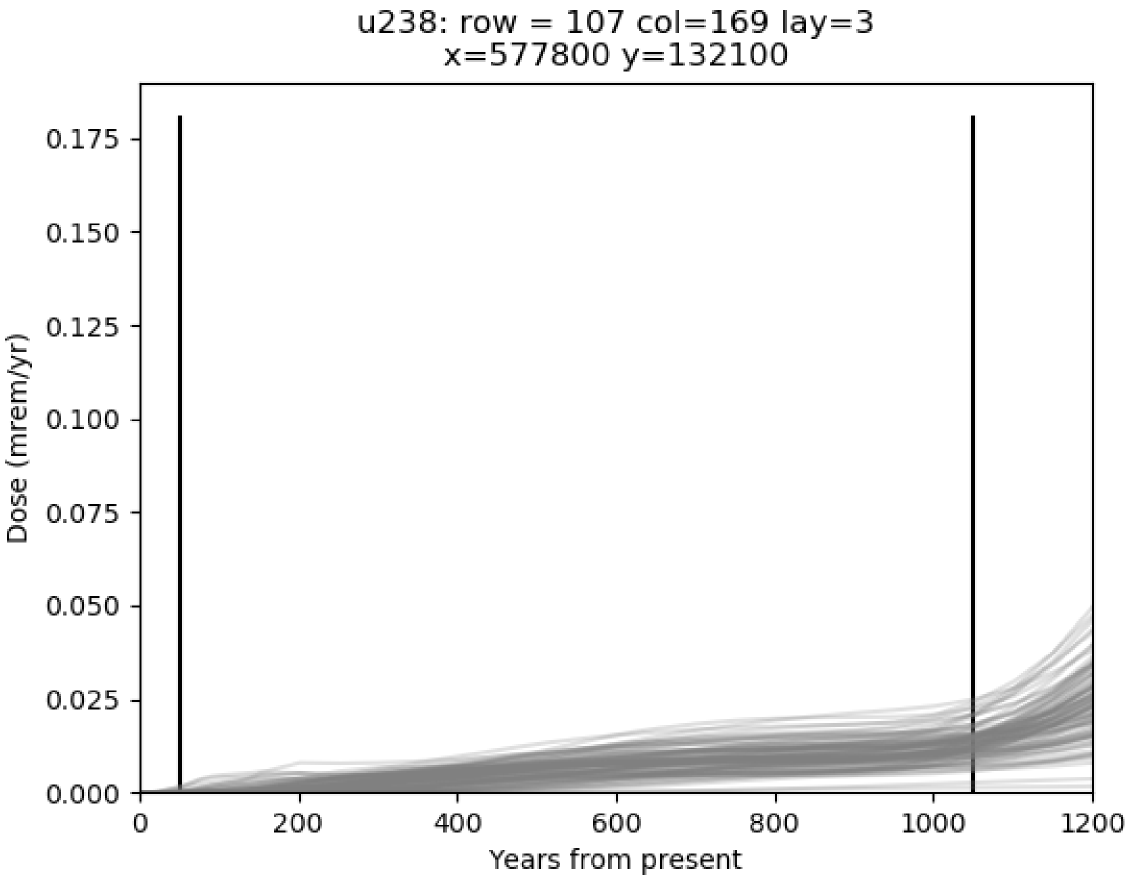


Note: Compliance period indicated by vertical lines.

Figure 17. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for Tc-99 at the Selected Location for the Compliance (CY 2070 to CY 3070) and Postcompliance Periods (CY 3070 to CY 12070)

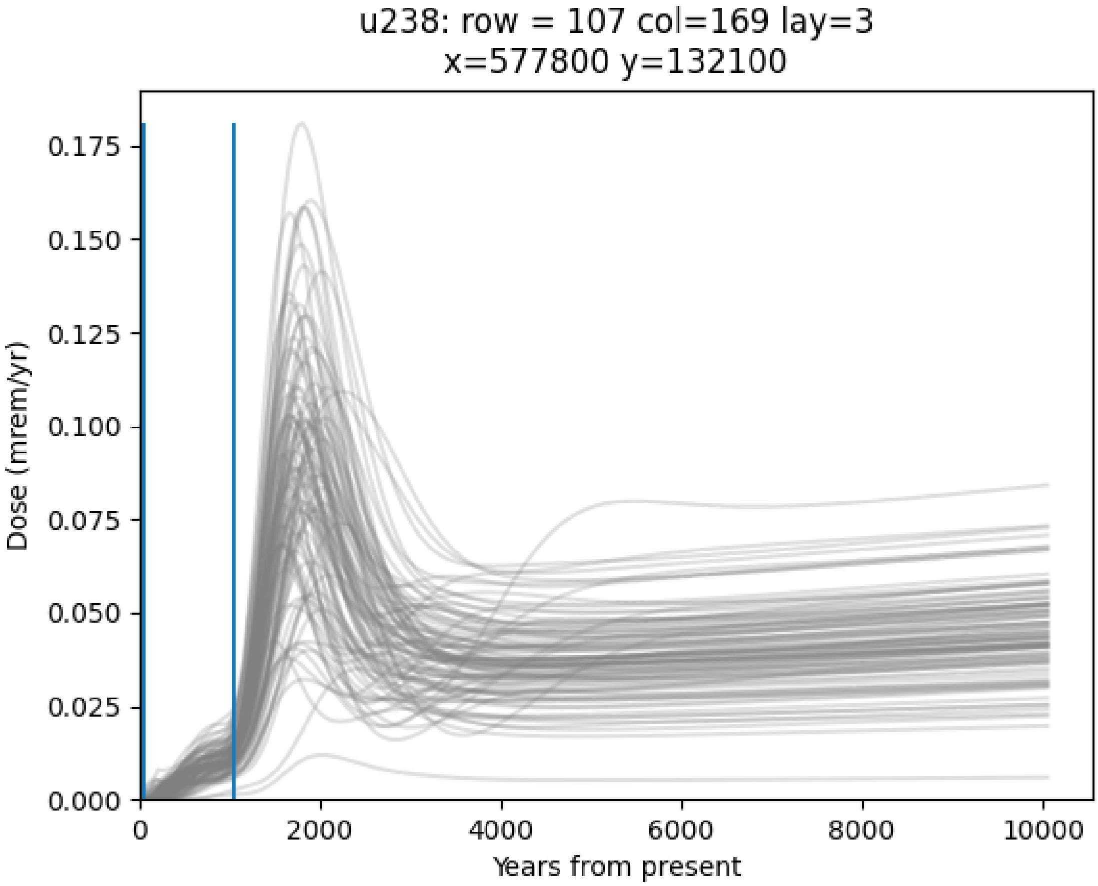
For this specific location along the southeastern corner of CA compliance boundary (x = 577800; y = 132100), Tc-99 had a maximum peak dose of 2.26 mrem/yr which was not reached until after the compliance period (CY 2070 to CY 3070) (Figure 17). The dose peaked approximately 200 years from the present and rapidly declined to a dose of less than 0.25 mrem/yr approximately 4,000 years from present (Figure 17). The maximum dose for Tc-99 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.

For this specific location along the southeastern corner of CA compliance boundary (x = 577800; y = 132100), U-238 had a maximum peak dose of 0.18 mrem/yr which was not reached until after the compliance period (CY 2070 to CY 3070). The U-238 dose slowly increased from 0 to less than 0.025 mrem/yr during the compliance period (Figure 18) and then the dose increased to a maximum peak dose of 0.18 mrem/yr approximately 2,000 years from present (Figure 19). The U-238 dose decreased until 4,000 years from present where the dose plateaued at approximately 0.05 to 0.075 mrem/yr (Figure 19). The maximum dose for U-238 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

Figure 18. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for U-238 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

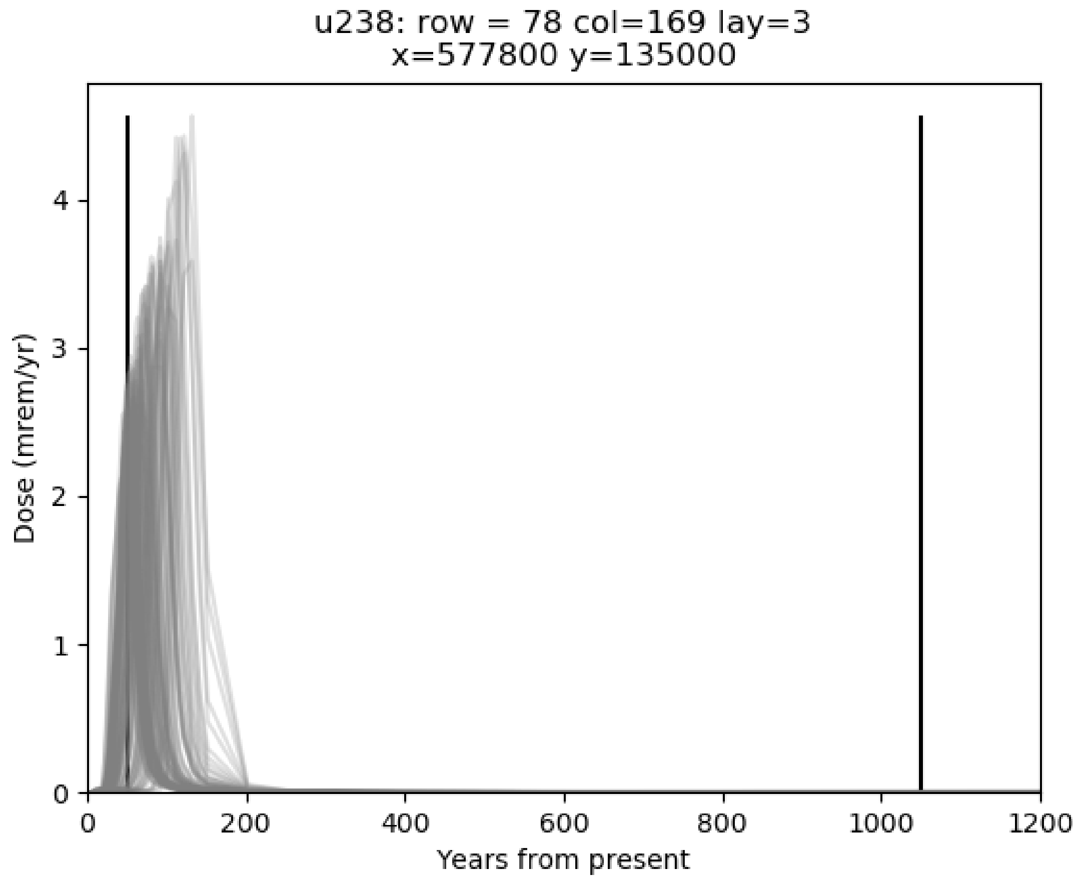


Note: Compliance period indicated by vertical lines.

Figure 19. Dose Realizations of the Null Space Monte Carlo Uncertainty Analysis for U-238 at the Selected Location for the Compliance (CY 2070 to CY 3070) and Postcompliance Periods (CY 3070 to CY 12070)

For this specific location along the southeastern corner of CA compliance boundary (x = 577800; y = 132100), U-238 had a maximum peak dose of 0.18 mrem/yr which was not reached until after the compliance period (CY 2070 to CY 3070) approximately 2,000 years from present (Figure 19). The U-238 dose decreased until 4,000 years from present where the dose plateaued at approximately 0.05 to 0.075 mrem/yr (Figure 19). The maximum dose for U-238 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.

For this specific location along the eastern edge of the CA compliance boundary (x = 577800; y = 135000), U-238 had a maximum peak dose of 4.56 mrem/yr which was reached approximately 70 years following the start compliance period (CY 2070 to CY 3070) (Figure 20). The U-238 dose rapidly decreased and reached zero by 200 years from present. The maximum dose for U-238 is below both the primary TED limit of 100 mrem/yr and the CA administrative TED limit of 30 mrem/yr.



Note: Compliance period indicated by vertical lines.

Figure 20. Dose Realizations from the Null Space Monte Carlo Uncertainty Analysis for U-238 at the Selected Location for the Compliance Period (CY 2070 to CY 3070)

8 References

CHRPC-04032, 2020, *Composite Analysis/Cumulative Impact Evaluation (CACIE) Utility Codes Integrated Software Management Plan*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.

CP-57037, 2020, *Model Package Report: Plateau to River Groundwater Model Version 8.3*, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: https://www.osti.gov/servlets/purl/1601635.

CP-64491, 2022, *Hanford Site Composite Analysis Data Package: Exposure Scenarios and Radionuclide Specific Dose Conversion Factors*, Rev. 1, Central Plateau Cleanup Company, Richland, Washington. Available at: https://www.osti.gov/servlets/purl/1845436.

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ECF-HANFORD-20-0079, 2022, *Calculation of Groundwater Pathway Radiological Dose for the Hanford Site Composite Analysis Base Case,* Rev. 1, Central Plateau Cleanup Company, Richland, Washington. Available at: https://www.osti.gov/servlets/purl/1855836.

Safe Drinking Water Act of 1974, 42 USC 300f et seq., Pub. L. 93-523 as amended, December 16, 1974. Available at: https://www.gpo.gov/fdsys/pkg/STATUTE-88/pdf/STATUTE-88-Pg1660-2.pdf.

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Appendix A

Software Installation and Checkout Form

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SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:
Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:
Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION

1. Software Name: CACIE-UTILS Version No.: v5.21

EXECUTABLE INFORMATION

2. Executable Name *(include path)*:
[redacted]

3. Executable Size *(bytes)*:

COMPILATION INFORMATION

4. Hardware System *(i.e., property number or ID)*:
N/A

5. Operating System *(include version number)*:
N/A

INSTALLATION AND CHECKOUT INFORMATION

6. Hardware System *(i.e., property number or ID)*:
Intera's Office Richland, Washington: property #859 (psc-iron)

7. Operating System *(include version number)*:
Windows 10 build 19043.1526

8. Open Problem Report? ☐ Yes ☒ No PR/CR No.:

TEST CASE INFORMATION

9. Directory/Path:
[redacted]

10. Procedures:
[redacted]

11. Libraries:
[redacted]

12. Input Files:
[redacted]

13. Output Files:
[redacted]

14. Test Cases:
[redacted]

15. Test Case Results:
[redacted]

16. Test Performed By: Eugene O Powers

17. Test Results: ☒ Satisfactory, Accepted for Use ☐ Unsatisfactory

18. Disposition *(include HISI update)*:
Accepted; Installation noted in HISI

SOFTWARE INSTALLATION AND CHECKOUT FORM (Continued)	
19. Prepared By *(Software Owner)*: Chris Farrow *Print First and Last Name*	CHRISTOPHER FARROW (Affiliate) Digitally signed by CHRISTOPHER FARROW (Affiliate) DN: C=US, O=U.S. Government, OU=Department of Energy, OID.0.9.2342.19200300.100.1.1=89001003727219 + CN=CHRISTOPHER FARROW (Affiliate) Reason: I have reviewed this document Location: your signing location here Date: 2022.03.14 13:04:29-05'00' Foxit PhantomPDF Version: 10.1.7 *Signature / Date*
20. Test Personnel: Title: Software Engineer Eugene O'Neil Powers *Print First and Last Name*	Eugene O. Powers Digitally signed by Eugene O. Powers DN: cn=Eugene O. Powers, o=Intera, ou, email=npowers@intera.com, c=US Date: 2022.03.14 10:55:23 -07'00' *Signature / Date*
Title: *Print First and Last Name*	*Signature / Date*
Title: *Print First and Last Name*	*Signature / Date*
21. Approved By *(Software SME)*: *Print First and Last Name*	*Signature / Date*

Appendix B

ICF Check-In Form

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ICF Submittal Data Form

<table>
<tr><td colspan="3">Title: Dose for Groundwater Pathway Base Case REV1 Sensitivity Case NSMC</td><td colspan="2">Date: 03/09/2022</td></tr>
<tr><td colspan="3">1. Data Name (for ICF database)
(to be filled in by QA Officer)</td><td colspan="2">Work Product Name: SDOSE</td></tr>
<tr><td>2. Data Version Number:</td><td colspan="4">v1.0</td></tr>
<tr><td colspan="5">This numbering system will be used in the ICF database to distinguish between previous revisions, particularly in the case of provisional data that is being tracked with various renditions/versions of the same provisional data.</td></tr>
<tr><td>3. Data Citation | Revision Number</td><td colspan="3">No.: ECF-HANFORD-20-0091</td><td>Rev.: 1</td></tr>
<tr><td colspan="5">Where possible, all data should be tied to a final number that corresponds with its final QA/QC'd designation. If the data is documented (or will be documented) with an ECF, then that ECF and revision number should be captured here.</td></tr>
<tr><td>4. QA/QC Flag (What is the QA/QC status of the product?)</td><td>Not-Checked:</td><td>Checked:☒</td><td colspan="2">Problem/Post-Check: ☐</td></tr>
<tr><td colspan="5">5. Disk Location of Data (Where is this information stored?)</td></tr>
<tr><td colspan="5">Path:[redacted]</td></tr>
<tr><td colspan="5">6. Description of Data (What is the general description of the data?)</td></tr>
<tr><td colspan="5">This is the Dose calc for specific cells based on the results of the NSMC groundwater flow and transport model provide 100 realizations of equally probable future predictions of radionuclide groundwater concentrations. The NSMC results are developed for 16 radionuclides evaluated in the CA at each time step of the groundwater flow and transport model from calendar year (CY) 2018 to CY 12070 at each of the active P2R/Modular Three-Dimensional Transport Multi-Species (MT3DMS) grid cells. At each MT3DMS model cell and model time step, the predicted radionuclide concentrations in the groundwater are multiplied by the unit dose factor to provide a radionuclide-specific dose.
The NSMC evaluates the impact of uncertainty in two aspects of the groundwater flow and transport model, namely the saturated zone hydraulic properties and groundwater recharge.</td></tr>
<tr><td colspan="5">7. Corresponding Project</td></tr>
<tr><td colspan="5">Composite Analysis</td></tr>
<tr><td colspan="5">8. Parent Data (Listing of pertinent parent data; if existing blockchain reference exists in the ICF, use this key and capture a snapshot from the ICF database)</td></tr>
<tr><td colspan="5">P2RNSU v2.0</td></tr>
<tr><td colspan="5">9. ICF Location (to be filled in by QA Officer):</td></tr>
<tr><td colspan="5">[redacted]</td></tr>
<tr><td colspan="5">10. Copy to Olive:N/A (Limited space on Olive, so check only if scripts expect this data to be there)</td></tr>
</table>

ICF Submittal Data Form

Data Provider: Eugene O Powers Position: Software Engineer	Eugene O. Powers — Digitally signed by Eugene O. Powers DN: cn=Eugene O. Powers, o=Intera, ou, email=npowers@intera.com, c=US Date: 2022.03.25 08:33:05 -07'00' *Signature* *Date*
Data Reviewer: Kimberly Ralston-Hooper Position: Ecotoxicologist	Kimberly Ralston-Hooper — Digitally signed by Kimberly Ralston-Hooper Date: 2022.03.25 08:37:09 -07'00' *Signature* *Date*
Data Reviewer: Trevor Budge Position: Senior Hydrogeologist	TREVOR BUDGE (Affiliate) — Digitally signed by TREVOR BUDGE (Affiliate) Date: 2022.03.25 08:38:17 -07'00' *Signature* *Date*