INL/MIS-23-74970-Revision-0

Impact to Groundwater All-Pathways Dose Estimates for the Remote-Handled Low-Level Waste Disposal Facility Performance Assessment Using Updated Dose Coefficients from DOE-STD-1196-2022

Changing the World's Energy Future

Arthur S. Rood

Idaho National Laboratory

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9. Objective / Purpose

The Performance Assessment (PA) for the Remote-Handled Low-Level Waste (RHLLW) Disposal Facility at Idaho National Laboratory (INL) was completed in 2018 (DOE-ID 2018) using dose coefficients from U.S. Department of Energy (DOE) Standard DOE-STD-1196-2011 (DOE 2011). Internal and external dosimetry was updated in 2021 and a new technical standard was published in 2022 (DOE-STD-1196-2022) (DOE 2022). This technical memorandum provides a comparison of the ingestion dose coefficients between those published in DOE (2011) and those published in DOE (2022). The dose coefficients in DOE (2022) were then used to calculate the all-pathways dose for the groundwater pathway and the results between the doses published in the 2018 PA and those calculated using the updated dose coefficients in DOE (2022) were compared. Several other issues in the 2018 RHLLW Disposal Facility PA were also addressed.

10. If revision, please state the reason and list sections and/or page being affected.

NA

11. Conclusion / Recommendations

Groundwater all-pathways doses calculated using DOE (2022) dose coefficients are generally lower compared to doses calculated using DOE (2011) dose coefficients. Other model changes incorporated into the dose calculation included using a concentration ratio/transfer coefficient model for C-14 and H-3, using per-capita ingestion rates for water and milk, and including the Nb-93m (progeny of Mo-93) doses in the Mo-93 all-pathways dose factor. However, inclusion of Nb-93m was insignificant in terms of dose contribution. The peak dose during the post-compliance period switched from the east receptor to the west receptor using dose coefficients from DOE (2022) and the other changes to the all-pathways dose model.

CONTENTS

1.0 PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name	Organization	Pages Covered (if applicable)
Performer	Arthur S. Rood	K-Spar Inc.	All
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Responsibilities:

a. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.
b. Concurrence of method or approach. See definition, LWP-10106.
c. Concurrence with the document’s markings in accordance with LWP-11202.
d. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.
e. Authorizes the commencement of work of the engineering deliverable.
f. Concurrence with the document’s assumptions and input information. See definition of Acceptance, LWP-10200.

2.0 INTRODUCTION AND PURPOSE

The Performance Assessment (PA) for the Remote-Handled Low-Level Waste (RHLLW) Disposal Facility at Idaho National Laboratory (INL) was completed in 2018 (DOE-ID 2018) using dose coefficients from U.S. Department of Energy (DOE) Standard DOE-STD-1196-2011 (DOE 2011). Internal and external dosimetry was updated in 2021 and a new technical standard was published in 2022 (DOE-STD-1196-2022) (DOE 2022). The all-pathways dose factors were recalculated using the dose coefficients in DOE (2022) and documented in ICP (2023). This technical memorandum provides a comparison of the ingestion dose coefficients between those published in DOE (2011) and those published in DOE (2022). The dose coefficients in DOE (2022) were then used to calculate all-pathways dose for the groundwater pathway and the results between the doses published in the 2018 PA and those calculated using the updated dose coefficients in DOE (2022) were compared. Several other issues in the 2018 RHLLW Disposal Facility PA were also addressed.

3.0 DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

Not applicable.

4.0 RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA

See Section 7.0, “Discussion/Analysis,” and Section 9.0, “References.”

5.0 ASSUMPTIONS

See Section 7.0, “Discussion/Analysis.”

6.0 COMPUTER CODE VALIDATIONS

A. Computer type: Macintosh.

B. Operating System and Version: Mac OS 11.7.9.

C. Computer program name and revision: GWSCREEN, Version 04/04/2008: MCMF Version 013118: MCMT Version 020321.

D. Inputs (may refer to an appendix): See electronic file distribution.

E. Outputs (may refer to an appendix): See electronic file distribution.

F. Evidence of, or reference to, computer program validation: See verification problems in Rood, 2003 for GWSCREEN and Rood 2021 for MCMF and MCMT.

G. Bases supporting application of the computer program to the specific physical problem: Vadose zone fate and transport modeling and aquifer modeling were performed using these two codes in the original PA.

7.0 DISCUSSION/ANALYSIS

7.1 DOSE QUANTITIES

The ingestion dose coefficients published in DOE (2022) represent the latest in internal dosimetry models and the most recently available census data for the United States. The dose quantities that are calculated are defined in the standard and reproduced below for completeness.

Absorbed dose. Absorbed dose, D, is the basic physical dose quantity used in protection of workers or members of the public from ionizing radiation. It is defined as the mean energy imparted to a volume of material, divided by the mass of the volume. The quantity is applicable to all types of ionizing radiation and to any material. The SI (Système Internationale or International System) unit is the gray (Gy) (J kg-1). The conventional unit of absorbed dose is the rad (1 Gy = 100 rad).

Equivalent dose. Equivalent dose, H_T, is a radiation protection quantity specific to an organ or tissue of the body. Equivalent dose is based on the mean absorbed dose in the volume of an organ or tissue, T, due to radiation of type R, modified by a radiation weighting factor (Table 1) for that radiation type, w_R. The w_R-modified absorbed dose due to each radiation type (e.g., alpha, beta, gamma) is summed and the resultant sum is called equivalent dose. The wR-weighting is intended to place the various types of radiation on a common scale. The radiation weighting factors used in this standard are those of International Commission on Radiological Protection (ICRP) Publication 103 (ICRP 2007). The SI unit of equivalent dose is the sievert (Sv) (J kg^{-1}). The conventional unit of equivalent dose is the rem (1 Sv = 100 rem).

Committed Equivalent Dose ($H_{T,50}$). The equivalent dose calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide by an adult or to age 70 years after intake by a pre-adult. It does not include contributions from radiation sources external to the body. Committed equivalent dose is expressed in the SI unit Sv (J kg^{-1}) or the conventional unit rem (1 rem = 0.01 Sv).

Effective dose. The effective dose, E, is the primary radiation protection quantity used by the ICRP. It is a weighted sum of equivalent doses to radiosensitive tissues, with the tissue weighting factors, w_T, representing the relative contribution of the different tissues to the total risk for the idealized case of uniform irradiation of the whole body. The weighting factors are normalized to sum to 1.0. The tissue weighting factors (Table 2 in DOE 2022) used in DOE-STD-1196-2022 are those recommended in ICRP Publication 103 (2007). The SI unit of effective dose is the Sv (J kg^{-1}). The conventional unit of effective dose is the rem (1 Sv = 100 rem).

Committed Effective Dose (E_{50}). The sum of the committed equivalent doses to various tissues or organs in the body ($H_{T,50}$), each multiplied by the appropriate tissue weighting factor (w_T) – that is, $E_{50} = \Sigma w_T H_{T,50} + w_{Remainder} \times H_{Remainder,50}$, where $w_{Remainder}$ is the tissue weighting factor assigned to the remainder organs and tissues and $H_{Remainder,50}$ is the committed equivalent dose to the remainder organs and tissues. Committed effective dose is expressed in the SI unit of Sv (J kg^{-1}) or the conventional unit rem (1 rem = 0.01 Sv).

Per-Capita Dose. Per-Capita dose, $E_{per\ capita}$, is the population weighted sum of age-specific effective dose coefficients, where the weight considers the fraction of each subgroup in the U.S. population represented by an age-specific effective dose coefficient and the level of exposure to the radionuclide for that age group. Per-capita dose is given by the expression:

$$E_{per\ capita} = \frac{1}{\sum\left(f_i^M U_i^M + f_i^F U_i^F\right)} \sum_i \left(f_i^M U_i^M + f_i^F U_i^F\right) e_i \tag{1}$$

where f_i^M and f_i^F are the fractions of the U.S. population in age group *i* for males and female, respectively; U_i^M and U_i^F are the daily intakes for age group *i* for males and females, respectively; and e_i is the effective dose coefficients (i.e., effective dose rate coefficient for external dose and committed effective dose coefficient for internal dose) for the i^{th} reference age group.

Groundwater all-pathways dose reported in the RHLLW Disposal Facility PA (DOE 2018) represents the committed effective dose, which is essentially the effective dose from internally deposited radionuclides integrated to age 70. For the adult, the integration time is 50 years, and for the newborn, the integration time is 70 years. The committed effective dose is referred to in the PA as the effective dose.

7.2 BASIS AND ASSUMPTION FOR DOSE COEFFICIENTS

The 2018 RHLLW Disposal Facility PA dose calculations used dose coefficients for the reference person from DOE (2011). The reference person dose coefficients represent the age and intake-weighted committed effective dose for water ingestion through all intakes (direction ingestion, vegetables, fruits, milk, etc.). Six age groups were considered (newborn, 1-y, 5-y, 10-y, 15-y, and adult).

In DOE (2022), dose coefficients were calculated for six age groups (newborn, 1-y, 5-y, 10-y, 15-y, and adult) and per-capita water and milk ingestion. The basis for the dose coefficients in DOE (2011) and DOE (2022) are summarized in DOE (2022) and repeated here for clarity.

7.2.1 Basis for Dose Coefficients in DOE-STD-1196-2011 (DOE 2011)

The exposure scenarios addressed in the previous version of the standard (DOE 2011) were external exposure to airborne radionuclides (submersion in air), ingestion of radionuclides in water, and inhalation of airborne radionuclides. The basis for the dose coefficients published in DOE (2011) are as follows:

1. Distribution of the U.S. population by age and sex as indicated by U.S. Census 2000 (U.S. Census Bureau, 2000).

2. Age-invariant effective dose coefficients for external exposure to airborne radionuclides tabulated in the Environmental Protection Agency (EPA) Federal Guidance Report (FGR) 12 (EPA, 1993).

3. Age-specific committed effective dose coefficients (previously known as Dose Conversion Factors) for internal emitters based on tissue weighting factors recommended in Publication 60 (1991) of the International Commission on Radiological Protection (ICRP) and the ICRP's biokinetic and dosimetric models applied in FGR 13 (EPA, 1999) on cancer risk coefficients.

4. Nuclear decay data from ICRP Publication 107 (ICRP 2008).

7.2.2 Basis for Dose Coefficients in DOE-STD-1196-2022 (DOE 2022)

The revised standard provides updated effective dose coefficients and per-capita dose coefficients that reflect the current state of knowledge and practice in radiation protection, as well as updated demographic data for the U.S. The exposure scenarios addressed are submersion in air, ingestion of water, ingestion of milk, and inhalation of air. The basis for the dose coefficients published in DOE (2022) are as follows:

1. Distribution of the U.S. population by age and sex as indicated by U.S. Census 2010 (U.S. Census Bureau, 2011).

2. Age-specific effective dose coefficients for external exposure to airborne radionuclides, from FGR 15 (EPA, 2019).

3. Age-specific committed effective dose coefficients for inhalation and ingestion of radionuclides based on updated biokinetic and dosimetric models of the ICRP and tissue weighting factors recommended in ICRP Publication 103 (2007) and calculated with the QCAL biokinetics and dosimetry code.

4. Separate per-capita dose coefficients for ingestion of radionuclides in water and milk.

5. Reference age- and sex-specific usage of environmental media by the U.S. population based on recent compilations.

6. Nuclear decay data from ICRP Publication 107 (ICRP 2008).

7.2.3 Differences in Dose Coefficient Methodology

Differences in the dose coefficients for the different age groups reside in biokinetic models and the tissue weighting factors. DOE (2022) also calculates per-capita weighted dose coefficients for ingestion of water and milk whereas DOE (2011) calculates dose coefficients for water ingestion for what was termed a reference person. Both calculations use Equation 1, but the reference person in DOE (2011) represents water ingestion from all sources of water including food products. For the RHLLW Disposal Facility PA calculations (DOE-ID 2018), the reference person dose coefficient was used for all ingestion pathways (water, milk, meat, and vegetables) for simplicity and conservatism because the reference person dose coefficient was generally higher than the adult dose coefficient. For these calculations using the dose coefficients in DOE (2022), the per-capita dose coefficient was applied to water ingestion and milk ingestion, and the adult dose coefficient was applied to meat and vegetable ingestion.

For the ingestion dose coefficients in DOE (2022), the *f1* value that is given in DOE (2011) is no longer presented. The *f1* value represents the gut absorption factor in DOE (2011). A gut absorption factor (termed *fA* in DOE 2022) is associated with each chemical type. In most cases, only a single type is listed (designated G for generic in this report) and uses the default *fA* value for the element. If the radionuclide is present in different chemical forms (organic, inorganic, tritiated water, organically bound tritium, etc.) then dose coefficients for each chemical form are listed.

7.3 COMPARISON OF DOSE COEFFICIENTS

Table 1 shows a side-by-side comparison of the ingestion dose coefficients from DOE (2011) and DOE (2022) for the base case radionuclides in the RHLLW Disposal Facility PA (DOE-ID 2018). In general, the dose coefficients are lower in DOE (2022) compared to DOE (2011). Direct comparison can be made between the 2022 per-capita water and 2011 reference person dose coefficient. The ratio of the DOE (2022) per-capita water and the DOE (2011) reference person dose coefficient ranged from 0.072 to 1.04. Except for Nb-94, all per-capita water dose coefficients in DOE (2022) were equal to or lower than the DOE (2011) reference persons dose coefficients. No direct comparison can be made for the per-capita milk dose coefficient in DOE (2022) because milk ingestion was not included in DOE (2011). The column labeled “+D” represents radionuclides with short-lived progeny that are assumed to be in secular equilibrium with the parent. In such cases, the dose coefficients of all progenies are summed with the parent. Radionuclides included in these +D values are presented in

Table 2.

Table 1. Comparison of ingestion dose coefficients[a] in DOE (2011) and DOE (2022) for the base case radionuclides in the RHLLW Disposal Facility PA.

Radionuclide	DOE (2011)		DOE (2022)						
	Reference Person (rem/Ci)	Reference Person +D (rem/Ci)	Adult (rem/Ci)	Per-Capita Water (rem/Ci)	Per-Capita Milk (rem/Ci)	Type[c]	Adult +D (rem/Ci)	Per-Capita Water +D (rem/Ci)	Per-Capita Milk +D (rem/Ci)
C-14	2.34E+03	—	5.88E+02	6.11E+02	7.84E+02	G	—	—	—
Cl-36	4.59E+03	—	3.67E+03	4.26E+03	7.88E+03	G	—	—	—
H-3	7.77E+01	—	7.22E+01	7.77E+01	1.14E+02	HTO	—	—	—
I-129	4.48E+05	—	3.47E+05	3.57E+05	4.03E+05	G	—	—	—
Mo-93	1.15E+04	—	7.47E+02	8.25E+02	1.34E+03	G	—	—	—
Nb-93m[b]	6.59E+02	—	9.99E+01	1.05E+02	1.44E+02	G	—	—	—
Nb-94	8.25E+03	—	8.55E+03	8.55E+03	9.21E+03	G	—	—	—
Ni-59	2.95E+02	—	4.26E+01	5.81E+01	1.71E+02	G	—	—	—
Tc-99	3.33E+03	—	4.03E+02	5.25E+02	1.38E+03	G	—	—	—
Np-237	4.63E+05	—	1.11E+05	1.47E+05	4.18E+05	G	1.11E+05	1.47E+05	4.19E+05
U-233	2.23E+05	—	1.31E+05	1.68E+05	3.92E+05	G	—	—	—
Th-229	2.25E+06	3.33E+06	7.77E+05	1.03E+06	2.90E+06	G	4.10E+06	6.19E+06	2.08E+07
PU-239	1.07E+06	—	4.48E+05	5.11E+05	1.00E+06	G	—	—	—
U-235	2.03E+05	2.05E+05	1.18E+05	1.51E+05	3.50E+05	G	2.35E+05	3.02E+05	7.00E+05

	DOE (2011)		DOE (2022)						
Radionuclide	Reference Person (rem/Ci)	Reference Person +D (rem/Ci)	Adult (rem/Ci)	Per-Capita Water (rem/Ci)	Per-Capita Milk (rem/Ci)	Type[c]	Adult +D (rem/Ci)	Per-Capita Water +D (rem/Ci)	Per-Capita Milk +D (rem/Ci)
Pa-231	2.07E+06	—	6.73E+05	7.92E+05	1.65E+06	G	—	—	—
Ac-227	1.45E+06	2.32E+06	6.40E+05	8.33E+05	2.28E+06	G	3.20E+06	4.70E+06	1.53E+07
Pu-240	1.07E+06	—	4.48E+05	5.11E+05	1.00E+06	G	—	—	—
U-236	2.02E+05	—	1.20E+05	1.54E+05	3.57E+05	G	—	—	—
Th-232	1.03E+06	—	2.61E+05	3.26E+05	7.99E+05	G	—	—	—
Ra-228	5.92E+06	5.92E+06	1.26E+06	2.78E+06	1.12E+07	G	2.52E+06	5.57E+06	2.25E+07
Th-228	4.29E+05	9.35E+05	1.15E+05	2.44E+05	1.20E+06	G	—	—	—
U-235	2.03E+05	2.05E+05	1.18E+05	1.51E+05	3.50E+05	G	2.35E+05	3.02E+05	7.00E+05
Pa-231	2.07e+06	—	6.73E+05	7.92E+05	1.65E+06	G	—	—	—
Ac-227	1.45E+06	2.32E+06	6.40E+05	8.33E+05	2.28E+06	G	3.20E+06	4.70E+06	1.53E+07
U-238	1.94E+05	2.13E+05	1.14E+05	1.46E+05	3.37E+05	G	3.49E+05	4.47E+05	1.03E+06
U-234	2.15E+05	—	1.28E+05	1.65E+05	3.85E+05	G	—	—	—
Th-230	9.36E+05	—	2.22E+05	2.82E+05	7.25E+05	G	—	—	—
Ra-226	1.68E+06	1.68E+06	4.70E+05	7.22E+05	2.01E+06	G	1.41E+06	2.17E+06	6.04E+06
Pb-210	3.77E+06	1.03E+07	1.31E+06	1.84E+06	4.81E+06	G	6.65E+06	9.69E+06	2.79E+07

a. Dose coefficient units were changed from Sv/Bq to rem/Ci using the conversion factor of 3.7×10^{12} rem/Ci per Sv/Bq.
b. Nb-93m was not a radionuclide of concern in the 2018 PA but is a daughter of Mo-93.
c. Type: G = generic form, HTO = tritiated water.

Table 2. Radionuclide decay chain members assumed to be in secular equilibrium with parent that are included in dose coefficients with the +D designation.

Parent	Progeny Included
U-238	Th-234
—	Pa-234
Ra-226	Pb-214
—	Bi-214
Pb-210	Bi-210
—	Po-210
Th-229	Ra-225
—	Ac-225
—	Bi-213
Np-237	Pa-233
U-235	Th-231

Parent	Progeny Included
Ac-227	Fr-223
—	Ra-223
—	Pb-211
—	Th-227
Ra-228	Ac-228
Th-228	Ra-224
—	Pb-212
—	Bi-212
U-232	Ra-224
—	Pb-212
—	Bi-212
—	U-232

7.3.1 All-Pathway Dose Factors

For the RHLLW Disposal Facility PA (DOE-ID 2018), the all-pathways receptor dose is equal to the groundwater all-pathways dose. The groundwater all-pathways dose factors were calculated using the model presented in DOE-ID (2018). The model includes the following pathways:

- Direct ingestion of water
- Ingestion of vegetables grown with well water
- Ingestion of beef cows that eat pasture irrigated with well water and drink well water directly
- Ingestion of milk from cows that eat pasture irrigated with well water and drink well water directly.

Three changes were made in the updated all-pathway dose calculation (ICP 2023). First, the original model for C-14 and H-3 was based on specific activity because plant concentration ratios and milk/meat transfer coefficients were not provided in Baes et al. (1984) for carbon (C) and hydrogen (H). All other radionuclides use the concentration ratio/transfer coefficient approach using values from Baes et al. (1984). For these calculations, a concentration ratio/transfer coefficient approach was used for C-14 and H-3 using concentration ratios and transfer coefficients from RESRAD (Yu et. al, 2016) and a dry-to-wet plant weight ratio of 0.23 (Table 3). This change was necessary so that per-capita milk and per-capita water dose coefficients could be utilized.

Table 3. Concentration ratios and transfer coefficients for C-14 and H-3 from RESRAD (Yu et al. 2016).

Parameter	C-14	H-3
Plant concentration ratio, wet weight	5.5	6.5
Plant concentration ratio, dry weight	23.6	27.9
Milk transfer coefficient (d/L)	0.012	0.01

Parameter	C-14	H-3
Meat transfer coefficient (d/Kg)	0.031	0.012

Second, the water and milk ingestion rates were changed from the current all-pathways dose model of 730 L/yr for water and 112 L/yr for milk to the per-capita consumption rates of 493 L/yr for water and 72.6 L/yr for milk. Milk and water consumption rates are given in DOE (2022) for each age category and gender (Table 4). Per-capita consumption rates are calculated using the denominator term in Equation (1). Note that for a dose calculation, the per-capita consumption cancels out and it is simply the summation of the product of the radionuclide concentration in water or milk, the age-specific dose coefficient, ingested amount, and fraction of the population for each age group. For beef, produce, and leafy vegetable ingestion, the PA all-pathways values of 85 kg/yr, 176 kg/yr, and 18 kg/yr, respectively, were retained and an adult dose coefficient was applied.

Table 4. Age and gender specific population fractions and water and milk consumption rates given in DOE (2022).

Age	Population Fraction		Water (L/d)		Milk (L/d)	
	Male	Female	Male	Female	Male	Female
Newborn	0.00652	0.00625	0.549	0.549	0.71	0.71
1	0.01335	0.0128	0.348	0.348	0.577	0.577
5	0.02698	0.02583	0.413	0.413	0.308	0.308
10	0.03395	0.03249	0.555	0.555	0.288	0.288
15	0.03477	0.03309	0.855	0.641	0.303	0.227
Adult	0.37604	0.39793	1.817	1.363	0.18	0.135

Third, Mo-93 has a daughter isotope (Nb-93m, 16.3-year half-life) that was originally not included in the dose calculations. Explicit modeling of the decay and ingrowth of Nb-93m from Mo-93 in the base-case source using the RHLLW Disposal Facility PA model and using all-pathway dose coefficients from DOE (2011) showed the dose increased by a factor of ~1.2. Molybdenum-93 was not a large-dose contributor, and the increase is negligible relative to the peak doses. Thus, the omission of Nb-93m in the 2018 RHLLW Disposal Facility PA made no difference. For these calculations, the dose coefficient for Nb-93m was added to Mo-93; thus, the assumption is implicitly made that Nb-93m is in secular equilibrium with Mo-93 and it transports at the same rate. These assumptions are conservative because niobium has a higher soil-water partitioning coefficient (K_d) compared to molybdenum; thus, Nb-93m would be slowed in the vadose zone resulting in lower fluxes to the groundwater compared to Mo-93.

A comparison the all-pathways dose factors using DOE (2011) and DOE (2022) (Table 5) shows that most all-pathways dose factors decreased except for Cl-36, H-3, and Nb-94. Tritium (H-3) increased because of the use of the concentration ratio/transfer coefficient model in the updated calculations. Chlorine-36 and Nb-94 went up because there was little change in dose coefficients and the use of per-capita milk ingestion dose coefficients for milk ingestion increases the overall dose for this pathway.

Table 5. Comparison of all-pathways dose factors reported in 2018 RHLLW Disposal Facility PA and those calculated with DOE 2022 and concentration ratios from RESRAD for C-14 and H-3.

Radionuclide	All-Pathways Dose Factors in 2018 PA using DOE (2011) (rem/Ci per Ci/m^3)	All-Pathways Dose Factors using DOE (2022) and C-14 and H-3 Concentration Ratio/Transfer Coefficient Model (rem/Ci per Ci/m^3)
C-14	5.86E+03	3.91E+03
Cl-36	1.04E+05	1.14E+05
H-3	1.74E+02	3.38E+02
I-129	6.92E+05	4.42E+05
Mo-93	1.24E+04	6.93E+02
Nb-93m[a]	5.60E+03	1.12E+03
Mo-93+D[b]	1.80E+04	1.81E+03
Nb-94	7.47E+04	9.28E+04
Ni-59	2.92E+02	4.70E+01
Tc-99	6.26E+03	1.32E+03
Np-237	3.53E+05	7.70E+04
U-233	1.78E+05	9.78E+04
Th-229+D	2.52E+06	8.30E+05
Pu-239	8.10E+05	2.67E+05
U-235+D	1.63E+05	8.77E+04
Pa-231	1.57E+06	4.14E+05
Ac-227+D	1.72E+06	6.24E+05
Pu-240	8.10E+05	2.67E+05
U-236	1.61E+05	8.92E+04
Th-232	7.81E+05	1.70E+05
Ra-228+D	4.51E+06	1.62E+06
Th-228	7.01E+05	1.25E+05
U-235+D	1.63E+05	8.77E+04
Pa-231	1.57E+06	4.14E+05
Ac-227+D	1.72E+06	6.24E+05
U-238+D	1.69E+05	8.62E+04
U-234	1.71E+05	9.59E+04

Radionuclide	All-Pathways Dose Factors in 2018 PA using DOE (2011) (rem/Ci per Ci/m^3)	All-Pathways Dose Factors using DOE (2022) and C-14 and H-3 Concentration Ratio/Transfer Coefficient Model (rem/Ci per Ci/m^3)
Th-230	7.11E+05	1.47E+05
Ra-226+D	1.30E+06	4.12E+05
Pb-210+D	7.91E+06	1.80E+06

a. Nb-93m was not a radionuclide of concern in the 2018 PA but is a daughter of Mo-93.
b. Includes contribution from Nb-93m assuming it is in secular equilibrium with Mo-93.

7.3.2 Groundwater All-Pathways Doses

Table 6 and Table 7 compare the groundwater all-pathways effective dose for the receptor 100-m downgradient of the east-side source zone in the PA (east-side vault arrays). Table 6 uses dose coefficients from DOE (2011) and the specific activity model for H-3 and C-14. These are the same doses in Table 4-3 of the RHLLW Disposal Facility PA (DOE-ID 2018). Table 7 uses dose coefficients and per-capita water and milk ingestion rates from DOE (2022). Table 7 also uses the concentration ratio/transfer coefficient model for C-14 and H-3 with ratios and coefficients from RESRAD (Yu et al. 2016), and includes Nb-93m as a daughter of Mo-93, which was not included in the original PA. A comparison of total peak doses between Table 6 and Table 7 shows the compliance period peak dose decreased from 4.38E-04 mrem/yr to 9.23E-5 mrem/yr, and the post-compliance period peak dose decreased from 0.642 mrem/yr to 0.141 mrem/yr when using DOE (2022). The peak dose also decreases for the institutional control period. Total peak doses were driven by Tc-99 in both cases.

Table 8 and Table 9 compare the groundwater all-pathways effective dose for the receptor 100-m downgradient of the west-side source zone in the PA (west-side vault arrays). Table 8 uses dose coefficients from DOE (2011) and the specific activity model for H-3 and C-14. These are the same doses in Table 4-4 of the RHLLW Disposal Facility PA (DOE-ID 2018). Table 9 uses dose coefficients from DOE (2022) and the other changes associated with Table 7 described in the previous paragraph. A comparison of total peak doses between Table 8 and Table 9 shows the peak dose during the post-compliance period decreased from 0.385 mrem/yr to 0.243 mrem/yr when using DOE (2022). A larger decrease in peak dose was observed during both the institutional control period and compliance period. Peak dose during the post-compliance period was driven by I-129 and dose coefficients for I-129 decreased only slightly between DOE (2011) and DOE (2022).

Table 6. Groundwater all-pathways effective dose 100-m downgradient from the east-side source zone as reported in the 2018 RHLLW Disposal Facility PA and calculated with dose coefficients from DOE (2011) and specific activity model for C-14 and H-3.

		Institutional Control		Compliance Period		Post-Compliance Period	
		(2040–2139)		(2140–3039)		(Greater than 3039)	
Radionuclide	Progeny	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)
C-14	—	6.13E-27	2139	1.05E-13	3039	4.96E-02	24,789
Cl-36	—	1.21E-25	2139	7.54E-11	3039	4.82E-03	21,539
H-3	—	4.32E-23	2139	9.76E-22	3039	2.57E-29	3,040
I-129	—	1.52E-32	2139	4.78E-20	3039	2.95E-03	30,789
Mo-93	—	2.41E-42	2139	3.09E-29	3039	3.15E-07	46,789
Nb-94	—	1.60E-53	2139	9.62E-43	3039	4.82E-09	284,039
Ni-59	—	7.06E-54	2139	2.41E-40	3039	2.85E-04	312,039
Tc-99	—	2.10E-16	2139	4.38E-04	3039	6.33E-01	21,739
Np-237	—	2.04E-43	2139	7.72E-33	3039	2.54E-04	100,039
—	U-233	3.27E-41	2139	1.07E-30	3039	5.28E-05	78,789
—	Th-229	6.67E-43	2139	2.69E-32	3039	1.48E-05	92,039
Total, Np-237		3.36E-41	2139	1.10E-30	3039	3.06E-04	96,039
Pu-239	—	5.21E-61	2139	2.17E-50	3039	5.16E-18	312,039
—	U-235	3.00E-41	2139	1.07E-30	3039	2.42E-06	68,789
—	Pa-231	9.30E-44	2139	4.03E-33	3039	2.13E-07	96,039
—	Ac-227	2.18E-44	2139	1.43E-33	3039	3.37E-07	96,039
Total, Pu-239		3.01E-41	2139	1.07E-30	3039	2.76E-06	70,789
Pu-240	—	5.17E-61	2139	2.01E-50	3039	2.08E-27	140,039
—	U-236	2.96E-41	2139	9.77E-31	3039	2.63E-07	66,789
—	Th-232	1.08E-49	2139	4.41E-39	3039	4.42E-14	276,039
—	Ra-228	3.27E-49	2139	1.51E-38	3039	2.43E-13	272,039
—	Th-228	3.47E-50	2139	1.73E-39	3039	3.41E-14	260,039

Radionuclide	Progeny	Institutional Control (2040–2139) ED (mrem/yr)	Institutional Control (2040–2139) Time (year)	Compliance Period (2140–3039) ED (mrem/yr)	Compliance Period (2140–3039) Time (year)	Post-Compliance Period (Greater than 3039) ED (mrem/yr)	Post-Compliance Period (Greater than 3039) Time (year)
Total, Pu-240		2.96E-41	2139	9.77E-31	3039	2.63E-07	66,789
U-235	—	3.14E-41	2139	3.72E-29	3039	1.35E-03	64,789
—	Pa-231	9.74E-44	2139	1.32E-31	3039	1.00E-04	80,789
—	Ac-227	2.28E-44	2139	3.92E-32	3039	1.58E-04	80,789
Total, U-235	—	3.15E-41	2139	3.74E-29	3039	1.51E-03	65,789
U-238	—	3.16E-41	2139	1.93E-29	3039	2.81E-04	65,789
—	U-234	9.84E-41	2139	2.37E-27	3039	1.16E-04	68,789
—	Th-230	5.69E-44	2139	1.59E-30	3039	2.76E-06	92,039
—	Ra-226	3.58E-46	2139	1.46E-32	3039	4.99E-06	96,039
—	Pb-210	3.30E-46	2139	3.24E-32	3039	4.52E-05	96,039
Total, U-238		1.30E-40	2139	2.39E-27	3039	4.23E-04	66,789
Total		2.10E-16	2139	4.38E-04	3039	6.42E-01	21,739

Table 7. Groundwater all-pathways effective dose 100-m downgradient from the east-side source zone calculated with dose coefficients from DOE (2022), concentration ratio/transfer coefficient model for C-14 and H-3, and Nb-93m doses included in the Mo-93 dose.

Radionuclide	Progeny	Institutional Control (2040–2139) ED (mrem/yr)	Institutional Control (2040–2139) Time (year)	Compliance Period (2140–3039) ED (mrem/yr)	Compliance Period (2140–3039) Time (year)	Post-Compliance (Greater than 3039) ED (mrem/yr)	Post-Compliance (Greater than 3039) Time (year)
C-14	—	4.09E-27	2139	7.00E-14	3039	3.31E-02	24,789
Cl-36	—	1.33E-25	2139	8.26E-11	3039	5.29E-03	21,539
H-3	—	8.39E-23	2139	1.90E-21	2239	4.99E-29	3,040
I-129	—	9.68E-33	2139	3.05E-20	3039	1.89E-03	30,789
Mo-93	—	3.52E-43	2139	4.51E-30	3039	4.60E-08	46,789
Nb-94	—	1.98E-53	2139	1.20E-42	3039	5.99E-09	284,039
Ni-59	—	1.14E-54	2139	3.87E-41	3039	4.59E-05	312,039
Tc-99	—	4.43E-17	2139	9.23E-05	3039	1.34E-01	21,739

		Institutional Control (2040–2139)		Compliance Period (2140–3039)		Post-Compliance (Greater than 3039)	
Radionuclide	Progeny	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)
Np-237	—	4.46E-44	2139	1.68E-33	3039	5.54E-05	100,039
—	U-233	1.80E-41	2139	5.86E-31	3039	2.90E-05	78,789
—	Th-229	2.20E-43	2139	8.85E-33	3039	4.88E-06	92,039
Total, Np-237		1.82E-41	2139	5.97E-31	3039	8.21E-05	96,039
Pu-239	—	1.72E-61	2139	7.15E-51	3039	1.71E-18	312,039
—	U-235	1.61E-41	2139	5.74E-31	3039	1.30E-06	68,789
—	Pa-231	2.45E-44	2139	1.06E-33	3039	5.63E-08	96,039
—	Ac-227	7.90E-45	2139	5.19E-34	3039	1.23E-07	96,039
Total, Pu-239		1.61E-41	2139	5.75E-31	3039	1.41E-06	70,789
Pu-240	—	1.70E-61	2139	6.62E-51	3039	9.41E-28	140,039
—	U-236	1.64E-41	2139	5.41E-31	3039	1.70E-07	66,789
—	Th-232	2.35E-50	2139	9.59E-40	3039	1.14E-14	276,039
—	Ra-228	1.17E-49	2139	5.41E-39	3039	1.04E-13	272,039
—	Th-228	6.19E-51	2139	3.08E-40	3039	7.23E-15	260,039
Total, Pu-240		1.64E-41	2139	5.41E-31	3039	1.70E-07	66,789
U-235	—	1.69E-41	2139	2.00E-29	3039	7.26E-04	64,789
—	Pa-231	2.57E-44	2139	3.49E-32	3039	2.64E-05	80,789
—	Ac-227	8.26E-45	2139	1.42E-32	3039	5.73E-05	80,789
Total, U-235	—	1.69E-41	2139	2.01E-29	3039	7.79E-04	65,789
U-238	—	1.61E-41	2139	9.86E-30	3039	1.43E-04	65,789
—	U-234	5.52E-41	2139	1.33E-27	3039	6.53E-05	68,789
—	Th-230	1.18E-44	2139	3.28E-31	3039	5.71E-07	92,039
—	Ra-226	1.14E-46	2139	4.63E-33	3039	1.58E-06	96,039
—	Pb-210	7.51E-47	2139	7.36E-33	3039	1.03E-05	96,039
Total, U-238		7.13E-41	2139	1.34E-27	3039	2.14E-04	66,789
Total		4.43E-17	2139	9.23E-05	3039	1.41E-01	21,739

Table 8. Groundwater all-pathways effective dose 100-m downgradient from the west-side source zone as reported in the 2018 RHLLW Disposal Facility PA and calculated with dose coefficients from DOE (2011) and specific activity model for C-14 and H-3.

		Institutional Control		Compliance Period		Post-Compliance Period	
		(2040–2139)		(2140–3039)		(Greater than 3039)	
Radionuclide	Progeny	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)
C-14	—	1.28E-27	2139	2.77E-15	3039	1.38E-02	24,789
Cl-36	—	2.04E-25	2139	1.71E-12	3039	2.03E-03	21,539
H-3	—	1.28E-24	2139	2.65E-23	2239	5.84E-31	3,040
I-129	—	1.99E-33	2139	4.62E-21	3039	3.78E-01	38,789
Mo-93	—	3.77E-42	2139	8.03E-31	3039	9.02E-09	47,789
Nb-94	—	2.69E-53	2139	1.10E-42	3039	3.67E-09	284,039
Ni-59	—	1.15E-53	2139	6.04E-42	3039	2.22E-04	308,039
Tc-99	—	4.74E-18	2139	9.95E-06	3039	1.77E-01	28,789
Np-237	—	3.44E-43	2139	1.27E-32	3039	7.53E-05	108,039
—	U-233	5.51E-41	2139	1.79E-30	3039	1.65E-05	80,789
—	Th-229	1.12E-42	2139	4.52E-32	3039	4.73E-06	96,039
Total, Np-237		5.66E-41	2139	1.85E-30	3039	9.12E-05	104,039
Pu-239	—	8.78E-61	2139	3.65E-50	3039	6.33E-19	308,039
—	U-235	5.05E-41	2139	1.65E-30	3039	4.66E-07	75,789
—	Pa-231	1.57E-43	2139	6.27E-33	3039	3.99E-08	100,039
—	Ac-227	3.67E-44	2139	2.26E-33	3039	6.33E-08	100,039
Total, Pu-239		5.07E-41	2139	1.66E-30	3039	5.32E-07	77,789
Pu-240	—	8.71E-61	2139	3.38E-50	3039	1.35E-27	148,039
—	U-236	4.99E-41	2139	1.63E-30	3039	3.47E-07	72,789
—	Th-232	1.82E-49	2139	7.35E-39	3039	5.84E-14	200,039
—	Ra-228	5.51E-49	2139	2.52E-38	3039	3.21E-13	248,039
—	Th-228	5.87E-50	2139	2.89E-39	3039	4.52E-14	264,039
Total, Pu-240		4.99E-41	2139	1.63E-30	3039	3.47E-07	72,789

		Institutional Control (2040–2139)		Compliance Period (2140–3039)		Post-Compliance Period (Greater than 3039)	
Radionuclide	Progeny	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)
U-235	—	5.05E-41	2139	2.47E-30	3039	3.34E-05	65,789
—	Pa-231	1.57E-43	2139	9.19E-33	3039	2.50E-06	80,789
—	Ac-227	3.67E-44	2139	3.12E-33	3039	3.93E-06	80,789
Total, U-235		5.07E-41	2139	2.48E-30	3039	3.76E-05	66,789
U-238	—	5.23E-41	2139	2.12E-30	3039	6.78E-06	65,789
—	U-234	5.45E-41	2139	5.56E-29	3039	9.10E-05	72,789
—	Th-230	3.18E-44	2139	3.73E-32	3039	1.80E-06	96,039
—	Ra-226	2.02E-46	2139	3.51E-34	3039	3.26E-06	100,039
—	Pb-210	1.88E-46	2139	8.14E-34	3039	2.95E-05	100,039
Total, U-238		1.07E-40	2139	5.77E-29	3039	1.14E-04	74,789
Total		4.74E-18	2139	9.95E-06	3039	3.85E-01	38,789

Table 9. Groundwater all-pathways effective dose 100-m downgradient from west-side source zone calculated with dose coefficients from DOE (2022), concentration ratio/transfer coefficient model for C-14 and H-3, and Nb-93m doses included in the Mo-93 dose.

		Institutional Control (2040–2139)		Compliance Period (2140–3039)		Post-Compliance Period (Greater than 3039)	
Radionuclide	Progeny	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)
C-14	—	8.52E-28	2139	1.85E-15	3039	9.18E-03	24,789
Cl-36	—	2.24E-25	2139	1.88E-12	3039	2.22E-03	21,539
H-3	—	2.48E-24	2139	5.16E-23	2239	1.13E-30	3,040
I-129	—	1.27E-33	2139	2.95E-21	3039	2.42E-01	38,789
Mo-93	—	5.51E-43	2139	1.17E-31	3039	1.32E-09	47,789
Nb-94	—	3.34E-53	2139	1.37E-42	3039	4.56E-09	284,039
Ni-59	—	1.85E-54	2139	9.72E-43	3039	3.57E-05	308,039
Tc-99	—	1.00E-18	2139	2.10E-06	3039	3.73E-02	28,789
Np-237	—	7.51E-44	2139	2.76E-33	3039	1.64E-05	108,039
—	U-233	3.03E-41	2139	9.85E-31	3039	9.09E-06	80,789

		Institutional Control		Compliance Period		Post-Compliance Period	
		(2040–2139)		(2140–3039)		(Greater than 3039)	
Radionuclide	Progeny	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)	ED (mrem/yr)	Time (year)
—	Th-229	3.70E-43	2139	1.49E-32	3039	1.56E-06	96,039
Total, Np-237		3.07E-41	2139	1.00E-30	3039	2.46E-05	104,039
Pu-239	—	2.89E-61	2139	1.20E-50	3039	2.14E-19	308,039
—	U-235	2.72E-41	2139	8.87E-31	3039	2.54E-07	75,789
—	Pa-231	4.13E-44	2139	1.65E-33	3039	1.07E-08	100,039
—	Ac-227	1.33E-44	2139	8.21E-34	3039	2.33E-08	100,039
Total, Pu-239		2.72E-41	2139	8.90E-31	3039	2.75E-07	77,789
Pu-240	—	2.87E-61	2139	1.12E-50	3039	6.66E-28	148,039
—	U-236	2.76E-41	2139	9.02E-31	3039	2.12E-07	72,789
—	Th-232	3.97E-50	2139	1.60E-39	3039	1.42E-14	200,039
—	Ra-228	1.98E-49	2139	9.04E-39	3039	1.29E-13	248,039
—	Th-228	1.05E-50	2139	5.15E-40	3039	9.02E-15	264,039
Total, Pu-240		2.76E-41	2139	9.02E-31	3039	2.12E-07	72,789
U-235	—	2.72E-41	2139	1.33E-30	3039	1.80E-05	65,789
—	Pa-231	4.13E-44	2139	2.42E-33	3039	6.60E-07	80,789
—	Ac-227	1.33E-44	2139	1.13E-33	3039	1.43E-06	80,789
Total, U-235		2.72E-41	2139	1.33E-30	3039	1.93E-05	66,789
U-238	—	2.67E-41	2139	1.08E-30	3039	3.46E-06	65,789
—	U-234	3.05E-41	2139	3.12E-29	3039	5.11E-05	72,789
—	Th-230	6.57E-45	2139	7.71E-33	3039	3.72E-07	96,039
—	Ra-226	6.40E-47	2139	1.11E-34	3039	1.03E-06	100,039
—	Pb-210	4.28E-47	2139	1.85E-34	3039	6.71E-06	100,039
Total, U-238		5.73E-41	2139	3.22E-029	3039	5.78E-05	74,789
Total		1.00E-18	2139	2.10E-06	3039	2.43E-01	38,789

A side-by-side comparison of the all-pathways doses for the east-side and west-side source zones (Table 10 and Table 11) shows the dose from H-3 and Cl-36 increased using DOE (2022) while all other doses decreased. The increase in the H-3 dose was due to using the concentration ratio/transfer coefficient model instead of the specific activity model. The dose coefficients for H-3 did not change appreciably from DOE (2011) and DOE (2022) whereas C-14 dose coefficient for water ingestion in DOE (2022) was 26% of the dose coefficient in DOE (2011). The dose coefficients for Cl-36 decreased slightly in DOE (2022) but the per-capita milk ingestion dose coefficient was substantially higher than the adult or the per-capita water ingestion dose coefficient.

Peak doses downgradient of the east-side source zone during the institutional, compliance, and post-compliance periods were driven by Tc-99 and the overall peak dose (post-compliance period) calculated with DOE (2022) (0.141 mrem/yr) was ~22% of the value calculated with DOE (2011) (0.642 mrem/yr). Peak doses downgradient of the west-side source zone during the institutional and compliance period were driven by Tc-99. Peak dose for the west-side source zone during the post-compliance period was driven by I-129 and the dose calculated with DOE (2022) (0.243 mrem/yr) was 63% of the value calculated with DOE (2011) (0.385 mrem/yr).

It is noteworthy that the peak dose during the post-compliance period switched from the east receptor to the west receptor using DOE (2022) dose coefficients and the other model changes. This is due primarily to the difference in dose coefficients for Tc-99 and I-129 between DOE (2011) and DOE (2022). For example, the DOE (2022) per-capita water dose coefficient for Tc-99 is 84% less than the reference person water ingestion dose coefficient for Tc-99 from DOE (2011). In contrast, the DOE (2022) per-capita water dose coefficient for I-129 is only 20% less than the reference person water ingestion dose coefficient for I-129 from DOE (2011). Because the dose from the west-side source is dominated by I-129 during the post-compliance period, and the dose from the east-side source is dominated by Tc-99, the west-side receptor dose decreased by a smaller amount than the east-side receptor dose.

Table 10. Comparison of groundwater all-pathways effective dose 100m downgradient of the east-side source zone calculated with DOE (2011) dose coefficients and DOE (2022) dose coefficients.

		Institutional Control Period		Compliance Period		Post-Compliance Period	
		DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]
Radionuclide	Progeny	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)
C-14	—	6.13E-27	4.09E-27	1.05E-13	7.00E-14	4.96E-02	3.31E-02
Cl-36	—	1.21E-25	1.33E-25	7.54E-11	8.26E-11	4.82E-03	5.29E-03
H-3	—	4.32E-23	8.39E-23	9.76E-22	1.90E-21	2.57E-29	4.99E-29
I-129	—	1.52E-32	9.68E-33	4.78E-20	3.05E-20	2.95E-03	1.89E-03
Mo-93	—	2.41E-42	3.52E-43	3.09E-29	4.51E-30	3.15E-07	4.60E-08
Nb-94	—	1.60E-53	1.98E-53	9.62E-43	1.20E-42	4.82E-09	5.99E-09
Ni-59	—	7.06E-54	1.14E-54	2.41E-40	3.87E-41	2.85E-04	4.59E-05

		Institutional Control Period		Compliance Period		Post-Compliance Period	
		DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]
Radionuclide	Progeny	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)
Tc-99	—	2.10E-16	4.43E-17	4.38E-04	9.23E-05	6.33E-01	1.34E-01
Np-237	—	2.04E-43	4.46E-44	7.72E-33	1.68E-33	2.54E-04	5.54E-05
—	U-233	3.27E-41	1.80E-41	1.07E-30	5.86E-31	5.28E-05	2.90E-05
—	Th-229	6.67E-43	2.20E-43	2.69E-32	8.85E-33	1.48E-05	4.88E-06
Total, Np-237		3.36E-41	1.82E-41	1.10E-30	5.97E-31	3.06E-04	8.21E-05
Pu-239	—	5.21E-61	1.72E-61	2.17E-50	7.15E-51	5.16E-18	1.71E-18
—	U-235	3.00E-41	1.61E-41	1.07E-30	5.74E-31	2.42E-06	1.30E-06
—	Pa-231	9.30E-44	2.45E-44	4.03E-33	1.06E-33	2.13E-07	5.63E-08
—	Ac-227	2.18E-44	7.90E-45	1.43E-33	5.19E-34	3.37E-07	1.23E-07
Total, Pu-239		3.01E-41	1.61E-41	1.07E-30	5.75E-31	2.76E-06	1.41E-06
Pu-240	—	5.17E-61	1.70E-61	2.01E-50	6.62E-51	2.08E-27	9.41E-28
—	U-236	2.96E-41	1.64E-41	9.77E-31	5.41E-31	2.63E-07	1.70E-07
—	Th-232	1.08E-49	2.35E-50	4.41E-39	9.59E-40	4.42E-14	1.14E-14
—	Ra-228	3.27E-49	1.17E-49	1.51E-38	5.41E-39	2.43E-13	1.04E-13
—	Th-228	3.47E-50	6.19E-51	1.73E-39	3.08E-40	3.41E-14	7.23E-15
Total, Pu-240		2.96E-41	1.64E-41	9.77E-31	5.41E-31	2.63E-07	1.70E-07
U-235	—	3.14E-41	1.69E-41	3.72E-29	2.00E-29	1.35E-03	7.26E-04
—	Pa-231	9.74E-44	2.57E-44	1.32E-31	3.49E-32	1.00E-04	2.64E-05
—	Ac-227	2.28E-44	8.26E-45	3.92E-32	1.42E-32	1.58E-04	5.73E-05
Total, U-235		3.15E-41	1.69E-41	3.74E-29	2.01E-29	1.51E-03	7.79E-04
U-238	—	3.16E-41	1.61E-41	1.93E-29	9.86E-30	2.81E-04	1.43E-04
—	U-234	9.84E-41	5.52E-41	2.37E-27	1.33E-27	1.16E-04	6.53E-05
—	Th-230	5.69E-44	1.18E-44	1.59E-30	3.28E-31	2.76E-06	5.71E-07
—	Ra-226	3.58E-46	1.14E-46	1.46E-32	4.63E-33	4.99E-06	1.58E-06
—	Pb-210	3.30E-46	7.51E-47	3.24E-32	7.36E-33	4.52E-05	1.03E-05
Total, U-238		1.30E-40	7.13E-41	2.39E-27	1.34E-27	4.23E-04	2.14E-04
Total		2.10E-16	4.43E-17	4.38E-04	9.23E-05	6.42E-01	1.41E-01

a. DOE-STD-1196-2011 (DOE 2011)
b. DOE-STD-1196-2022 (DOE 2022)

Table 11. Comparison of groundwater all-pathways effective dose 100m downgradient of the west-side source zone calculated with DOE 2011 dose coefficients and DOE 2022 dose coefficients.

		Institutional Control Period		Compliance Period		Post-Compliance Period	
		DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]
Radionuclide	Progeny	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)
C-14	—	1.28E-27	8.52E-28	2.77E-15	1.85E-15	1.38E-02	9.18E-03
Cl-36	—	2.04E-25	2.24E-25	1.71E-12	1.88E-12	2.03E-03	2.22E-03
H-3	—	1.28E-24	2.48E-24	2.65E-23	5.16E-23	5.84E-31	1.13E-30
I-129	—	1.99E-33	1.27E-33	4.62E-21	2.95E-21	3.78E-01	2.42E-01
Mo-93	—	3.77E-42	5.51E-43	8.03E-31	1.17E-31	9.02E-09	1.32E-09
Nb-94	—	2.69E-53	3.34E-53	1.10E-42	1.37E-42	3.67E-09	4.56E-09
Ni-59	—	1.15E-53	1.85E-54	6.04E-42	9.72E-43	2.22E-04	3.57E-05
Tc-99	—	4.74E-18	1.00E-18	9.95E-06	2.10E-06	1.77E-01	3.73E-02
Np-237	—	3.44E-43	7.51E-44	1.27E-32	2.76E-33	7.53E-05	1.64E-05
—	U-233	5.51E-41	3.03E-41	1.79E-30	9.85E-31	1.65E-05	9.09E-06
—	Th-229	1.12E-42	3.70E-43	4.52E-32	1.49E-32	4.73E-06	1.56E-06
Total, Np-237		5.66E-41	3.07E-41	1.85E-30	1.00E-30	9.12E-05	2.46E-05
Pu-239	—	8.78E-61	2.89E-61	3.65E-50	1.20E-50	6.33E-19	2.14E-19
—	U-235	5.05E-41	2.72E-41	1.65E-30	8.87E-31	4.66E-07	2.54E-07
—	Pa-231	1.57E-43	4.13E-44	6.27E-33	1.65E-33	3.99E-08	1.07E-08
—	Ac-227	3.67E-44	1.33E-44	2.26E-33	8.21E-34	6.33E-08	2.33E-08
Total, Pu-239		5.07E-41	2.72E-41	1.66E-30	8.90E-31	5.32E-07	2.75E-07
Pu-240	—	8.71E-61	2.87E-61	3.38E-50	1.12E-50	1.35E-27	6.66E-28
—	U-236	4.99E-41	2.76-41	1.63E-30	9.02E-31	3.47E-07	2.12E-07
—	Th-232	1.82E-49	3.97E-50	7.35E-39	1.60E-39	5.84E-14	1.42E-14
—	Ra-228	5.51E-49	1.98E-49	2.52E-38	9.04E-39	3.21E-13	1.29E-13
—	Th-228	5.87E-50	1.05E-50	2.89E-39	5.15E-40	4.52E-14	9.02E-15
Total, Pu-240		4.99E-41	2.76E-41	1.63E-30	9.02E-31	3.47E-07	2.12E-07
U-235	—	5.05E-41	2.72E-41	2.47E-30	1.33E-30	3.34E-05	1.80E-05
—	Pa-231	1.57E-43	4.13E-44	9.19E-33	2.42E-33	2.50E-06	6.60E-07
—	Ac-227	3.67E-44	1.33E-44	3.12E-33	1.13E-33	3.93E-06	1.43E-06
Total, U-235		5.07E-41	2.72E-41	2.48E-30	1.33-30	3.76E-05	1.93E-05

		Institutional Control Period		Compliance Period		Post-Compliance Period	
		DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]	DOE (2011)[a]	DOE (2022)[b]
Radionuclide	Progeny	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)	ED (mrem/yr)
U-238	—	5.23E-41	2.67E-41	2.12E-30	1.08E-30	6.78E-06	3.46E-06
—	U-234	5.45E-41	3.05E-41	5.56E-29	3.12E-29	9.10E-05	5.11E-05
—	Th-230	3.18E-44	6.57E-45	3.73E-32	7.71E-33	1.80E-06	3.72E-07
—	Ra-226	2.02E-46	6.40E-47	3.51E-34	1.11E-34	3.26E-06	1.03E-06
—	Pb-210	1.88E-46	4.28E-47	8.14E-34	1.85E-34	2.95E-05	6.71E-06
Total, U-238		1.07E-40	5.73E-41	5.77E-29	3.22E-29	1.14E-04	5.78E-05
Total		4.74E-18	1.00E-18	9.95E-06	2.10E-06	3.85E-01	2.43E-01

a. DOE-STD-1196-2011 (DOE 2011)
b. DOE-STD-1196-2022 (DOE 2022)

8.0 CONCLUSIONS

Groundwater all-pathways doses calculated using DOE (2022) dose coefficients are generally lower compared to doses calculated using DOE (2011) dose coefficients. Other model changes incorporated into the dose calculation included using a concentration ratio/transfer coefficient model for C-14 and H-3, using per-capita ingestion rates for water and milk, and including the Nb-93m (progeny of Mo-93) doses in the Mo-93 all-pathways dose factor. However, inclusion of Nb-93m was insignificant in terms of dose contribution. The peak dose during the post-compliance period switched from the east receptor to the west receptor using dose coefficients from DOE (2022) and the other changes to the all-pathways dose model.

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