



UCOR
an AECOM-led partnership with Jacobs

UCOR-5550

**Development of Fish Tissue and Surface Water
Preliminary Remediation Goals for
Radionuclides of Interest for the Proposed
Environmental Management Disposal Facility,
Oak Ridge, Tennessee**

This document is approved for public
release per review by:

Gerald B. Boroughs (signature on file)

UCOR Classification &
Information Control Office

04-28-22

Date

UCOR-5550

**Development of Fish Tissue and Surface Water
Preliminary Remediation Goals for
Radionuclides of Interest for the Proposed
Environmental Management Disposal Facility,
Oak Ridge, Tennessee**

Date Issued—April 2022

Prepared for the
U.S. Department of Energy
Oak Ridge Office of Environmental Management

UCOR LLC
under contract DE-SC-0004645

This page intentionally left blank.

APPROVALS

Development of Fish Tissue and Surface Water Preliminary Remediation Goals for Radionuclides of Interest for the Proposed Environmental Management Disposal Facility, Oak Ridge, Tennessee	UCOR-5550
	April 2022

<i>USQD Review Determination</i>	<input type="checkbox"/> USQD <input type="checkbox"/> UCD <input type="checkbox"/> CAT X <input type="checkbox"/> Exempt (Select Criteria 1-3 below.) USQD/UCD/CAT X No.: _____
<i>Exemption Criteria</i>	<input type="checkbox"/> (1) Non-Intent Change <input type="checkbox"/> (2) DOE-Approved Safety Basis Document <input type="checkbox"/> (3) Chief Accounting Officer, Internal Audit, Labor Relations, General Counsel, Outreach & Public Affairs, or Project Controls Services OR <input checked="" type="checkbox"/> (4) Document identified in USQD-MS-CX-REPORTS-1074
<i>USQD Preparer:</i>	MICHAEL NATZKE (Affiliate) <small>Digitally signed by MICHAEL NATZKE (Affiliate) Date: 2022.04.27 16:28:20 -04'00'</small> <hr style="width: 100%;"/> <div style="display: flex; justify-content: space-between;"> Name Date </div>
<i>Exhibit L Mandatory Contractor Document</i>	<input checked="" type="checkbox"/> No (No PCCB Reviewer Signature Required.) <input type="checkbox"/> Yes (Requires review by the Proforma Change Control Board.)
<i>PCCB Reviewer:</i>	<hr style="width: 100%;"/> <div style="display: flex; justify-content: space-between;"> Name Date </div>

Prepared by:  4/28/2022
 Fredrick Dolislager
 Human Health and Environmental Risk Assessor
 University of Tennessee
 Date

Concurred by: ERIC ABELQUIST (Affiliate) Digitally signed by ERIC ABELQUIST (Affiliate)
Date: 2022.04.27 16:46:50 -04'00'
 Eric Abelquist
 Technical Services, Deputy Director
 UCOR LLC
 Date

Approved by:  Digitally signed by JEFFREY FORTENBERRY (Affiliate)
Date: 2022.04.28 11:41:18 -04'00'
 Kent Fortenberry
 Technical Services and Regulatory Officer
 UCOR LLC
 Date

This page intentionally left blank.

REVISION LOG

Revision Number	Description of Changes	Revision Date	Pages Affected
0	Initial issue of document.	April 2022	

This page intentionally left blank.

CONTENTS

TABLES	ix
FIGURE	ix
ACRONYMS.....	xi
1. DEVELOPMENT OF FISH TISSUE AND INSTREAM SURFACE WATER PRELIMINARY REMEDATION GOALS	1
APPENDIX A SUPPORTING DOCUMENTATION FOR FISH TISSUE AND INSTREAM SURFACE WATER PRELIMINARY REMEDIATION GOALS	A-1

This page intentionally left blank.

TABLES

Table 1. Fish tissue and surface water PRGs.....	4
Table 2. Secular equilibrium and 160-year total fish tissue PRGs for Group 3 and 4 radionuclides	6
Table 3. Secular equilibrium and 160-year total surface water PRGs for Group 3 and 4 radionuclides	11

FIGURE

Fig. 1. Group 2 radionuclide Cs-137.....	16
Fig. 2. Group 2 radionuclide Sr-90.	16
Fig. 3. Group 2 radionuclide Ra-226.	17
Fig. 4. Group 2 radionuclide Th-228.	17
Fig. 5. Group 3 radionuclide Am-241.....	18
Fig. 6. Group 3 radionuclide Np-137.....	18
Fig. 7. Group 3 radionuclide Pu-238.....	19
Fig. 8. Group 3 radionuclide Pu-239.....	19
Fig. 9. Group 3 radionuclide Pu-240.....	20
Fig. 10. Group 3 radionuclide Ra-228.	20
Fig. 11. Group 3 radionuclide Th-230.	21
Fig. 12. Group 3 radionuclide Th-232.	21
Fig. 13. Group 3 radionuclide U-234.....	22
Fig. 14. Group 3 radionuclide U-236.....	22
Fig. 15. Group 3 radionuclide U-238.....	23
Fig. 16. Group 4 radionuclide U-233.....	23
Fig. 17. Group 4 radionuclide U-235.....	24

This page intentionally left blank.

ACRONYMS

EPA	U.S. Environmental Protection Agency
EMDF	Environmental Management Disposal Facility
FC	fractional contribution
ORR	Oak Ridge Reservation
PRG	preliminary remediation goal
SE	secular equilibrium

This page intentionally left blank.

1. DEVELOPMENT OF FISH TISSUE AND INSTREAM SURFACE WATER PRELIMINARY REMEDIATION GOALS

The Dispute Resolution Agreement Team, which is a joint working group comprised of members from the U.S. Environmental Protection Agency (EPA), the Tennessee Department of Environment and Conservation, and the U.S. Department of Energy, identified 21 radionuclides and associated progeny, which bioaccumulate and have the potential to be present in landfill wastewater at some time during the operational life of the Environmental Management Disposal Facility (EMDF). For the 21 radionuclides of interest, fish tissue and instream water column preliminary remediation goals (PRGs) have been developed to be protective of recreational use (human health), specifically fish ingestion. PRGs for fish tissue and instream surface water were established for these radionuclides of interest using EPA's PRG Calculator (June 2021 version) and are presented in Table 1. Tables 2 and 3 present calculation details of the fish tissue and surface water PRGs, respectively. EPA's PRG Calculator can be run in its Secular Equilibrium (SE) mode when developing PRGs, which assumes that all of a radionuclide's progeny are in SE. However, this approach is not appropriate for the EMDF landfill because the radionuclides being disposed at EMDF were received or generated during the Oak Ridge Reservation's (ORR's) operating lifetime, and some of the progeny of these radionuclides take tens of thousands of years to approach SE. This paper describes the derivation of PRGs and how EPA's PRG Calculator was used to appropriately account for progeny in calculating conservative PRGs that are representative of the radionuclides of interest at EMDF.

A summary of conditions/assumptions considered in developing the fish tissue and surface water PRGs for the EMDF include:

- The radionuclides of interest were either received or generated at the ORR without their progeny (e.g., uranium that was milled and refined, transuranics, and fission products produced from reactor operations).
- Considering the beginning of the Oak Ridge site (1942), the expected 26-year operational period of EMDF, and the possible lifespan of an exposed individual starting with the beginning of the EMDF operational period, a bounding timeframe for considering ingrowth of progeny radionuclides received or generated at the ORR is 160 years.
- Fish tissue and surface water PRGs are protective of recreation use, specifically fish ingestion, at a target risk of $1E-05$, an exposure duration of 26 years, an exposure frequency of 365 days/year, and a fish ingestion rate of 17.5 g/day. This equates to an annual fish ingestion rate for a recreational user of 6388 g/year.
- Appendix A provides additional documentation for fish tissue and surface water PRGs, including slope factors, fish bioconcentration factors, fish ingestion parameters, and equations used to calculate the PRGs.

The radionuclides of interest are grouped as follows:

1. Radionuclides that decay to a stable element (i.e., there are no progeny to account for).
2. Radionuclides that reach SE with their progeny within 160 years.
3. Radionuclides that have chains segmented for measurement purposes.
4. Radionuclides that do not reach SE within 160 years.

Use of EPA's PRG Calculator for each of these four groups of radionuclides is described below.

Radionuclides that decay to a stable element (no progeny)

Radionuclides in Group 1 decay directly to a stable isotope. For this group, the PRG Calculator is run in its SE mode and there are no progeny to account for. This group includes the following seven radionuclides:

- C-14
- Cl-36
- Co-60
- Eu-154
- H-3
- I-129
- Tc-99

Radionuclides that reach SE with their progeny within 160 years

For radionuclides in Group 2, their progeny build-in within 160 years and reach peak activity within the 160-year time period of interest. For this group, the PRG Calculator is run in its SE mode, and all of the progeny are accounted for at their most conservative activity. This group includes the following four radionuclides:

- Cs-137 (including Ba-137m)
- Sr-90 (Including Y-90)
- Ra-226 (including Rn-222, Po-218, At-218, Rn-218, Pb-214, Bi-214, Po-214, Tl-210, Pb-210, Bi-210, Po-210, Hg-206, and Tl-206)
- Th-228 (including Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, and Tl-208)

These radionuclides and their progeny in-growth are illustrated in Figs. 1 through 4.

Radionuclides that have chains segmented for measurement purposes

Group three radionuclides have their decay chains appropriately segmented to represent portions of a chain in equilibrium, with the remainder of the chain being tracked separately. For this group, the PRG Calculator is run in its SE mode, and progeny are accounted for at their most conservative activity. The parent and any progeny included are shaded in gray in Tables 2 and 3. If only the parent is included, the resulting PRG is the SE PRG contributed by the parent (as is the case for Am-241, Pu-238, Pu-240, Th-230, Th-232, U-234, and U-236). If there are progeny prior to reaching a radionuclide that is tracked separately (as is the case for Np-237, Pu-239, Ra-228, and U-238), then PRGs are calculated with the inverse sum of reciprocals process, and the last column in Tables 2 and 3 show the resulting partial chain SE PRG calculation. These radionuclides and their progeny in-growth are illustrated in Figs. 5 through 15. Appendix A offers an example calculation.

This third group includes the following eleven radionuclides:

- **Am-241** (432.5 y) → Np-237 (2.14 × 10⁶ y) → Pa-233 (26.98 d) → U-233 (159,200 y) → ...
— Only Am-241 is included since Np-237 is tracked separately.

- **Np-237** (2.14×10^6 y) → Pa-233 (26.98 d) → U-233 (159,200 y) → Th-229 (7,880 y) → Rn-225 (14.9 d) → ...
 - Np-237 and Pa-233 are calculated together. The next progeny, U-233, is tracked separately.
- **Pu-238** (87.8 y) → U-234 (245,500 y) → Th-230 (75,437 y) → Ra-226 (1,585.5 y) → Rn-222 (3.8 d) → ...
 - Only Pu-238 is included since U-234 is tracked separately.
- **Pu-239/Pu-240**

Pu-239/Pu-240 are reported together from the laboratory. Distinguishing the pairs is expensive and for ease of measurement the most protective PRG of the pairs is selected.

 - Pu-239 (24,110 y) → U-235m → U-235 (7.04×10^8) → Th-231 (1 d) → Pa-231 (32,760 y) → ...
 - Pu-239 and U-235m are calculated together. The next progeny, U-235, is tracked separately.
 - Pu-240 (6561 y) → U-236 (2.342×10^7 y) → Th-232 (1.4×10^{10} y) → ...
 - Only Pu-240 is included since U-236 is tracked separately.
- **Ra-228** (5.7 y) → Ac-228 (6.1 h) → Th-228 (1.9 y) → Ra-224 (3.6 d) → Rn-220 (55.6 s) → Po-216 (145 ms)
 - Ra-228 and Ac-228 are calculated together. Th-228 is tracked separately.
- **Th-230** (75,437 y) → Ra-226 (1585.5 y) → ...
 - Only Th-230 is included since Ra-226 is tracked separately.
- **Th-232** (1.4×10^{10} y) → Ra-228 (5.7 y) → ...
 - Only Th-232 is included since Ra-228 is tracked separately.
- **U-234** (245,500 y) → Th-230 (75,437 y) → ...
 - Only U-234 is included since Th-230 is tracked separately.
- **U-236** (2.342×10^7 y) → Th-232 (1.4×10^{10} y) → ...
 - Only U-236 is included since Th-232 is tracked separately.
- **U-238** (4.47×10^9 y) → Th-234 (24.1 d) → Pa-234 (6.67 h) → U-234 (245,500 y) → ...
 - U-238, Th-234, and Pa-234m/Pa-234 are calculated together. U-234 is tracked separately.

Radionuclides that do not reach SE within 160 years

Group 4 radionuclides require tens of thousands of years for all their progeny to build in and reach SE. Because the radionuclides of interest were received or generated at the ORR during the ORR's operating lifetime, a simple SE approach is not appropriate, and the 160-year period of interest must be considered. The following approach was taken to conservatively account for the contribution of all progeny during the 160-year period:

- First, the EPA PRG Calculator was run assuming all progeny are in SE (SE mode). This produced the total SE PRG for the radionuclide (Tables 2 and 3, Column 2) and for each progeny, the activity fraction (Tables 2 and 3, Column 3), and the fractional contribution to the total SE PRG (Tables 2 and 3, Column 4).

Many radionuclide decay chains include split-chain progeny, as indicated by an SE activity fraction less than 1.0 in Column 3 of Tables 2 and 3. Most of these split-chain progeny have no slope factor and so no contribution to the total PRG. But for the U-235 split-chain progeny that contributes to the total PRG, a corrected PRG had to be calculated assuming a fractional contribution (FC) of 1.0 (Tables 2 and 3, Column 5). Although the effect is very small, this correction was necessary to prevent redundant accounting of the FC when the 160-year fractional activity was calculated in the next step. Appendix A offers an example calculation.

- Second, the EPA Radionuclide Decay Chain Calculator was run for each radionuclide (with an initial activity of 1 pCi) and set to return the fractional activity of each progeny at 160 years (Tables 2 and 3, Column 6).
- Finally, the individual SE progeny PRGs were combined with the fractional activity of each progeny at 160 years, and the inverse sum of reciprocals method was used to calculate a 160-year Total PRG for the radionuclide of interest (Tables 2 and 3, Column 7). Appendix A offers an example calculation.

For the Group 4 radionuclides, their progeny are growing in during the 160-year period (see Figs. 16 and 17). As a result, the fractional activity for the progeny (Tables 2 and 3, Column 6) at 160 years is the bounding fractional activity for that progeny during the 160-year period. However, this is not the case for the parent, which decreases during the 160-year period. Again, the effect is very small, but to remain bounding, a parent activity fraction of 1.0 at 160 years was used in calculating the Total PRG.

The resulting Total PRG conservatively accounts for the contribution from all progeny during the 160-year period of interest. The progeny included are shaded in gray in Tables 2 and 3.

This fourth group includes the following two radionuclides:

- **U-233** (159,200 y) → Th-229 (7880 y) → Ra-225 (14.9 d) → Ac-225 (9.95 d) → Fr-221 (4.8 m) → ...
 - All progeny accounted for at their respective contribution in the 160-year period.
- **U-235** (7.04×10^8 y) → Th-231 (1.06 d) → Pa-231 (32,760 y) → Ac-227 (21.8 y) → ...
 - All progeny accounted for at their respective contribution in the 160-year period.

Similar to Pu-239/Pu-240, U-233/234 and U-235/236 are reported together from the laboratory. Distinguishing the pairs is expensive, and for ease of measurement, the most protective PRG of the pairs is selected.

The Group 4 radionuclides and their progeny in-growth are illustrated in Figs. 16 and 17.

Table 1. Fish tissue and surface water PRGs

Isotope	Fish tissue PRGs TR = 1E-05 (pCi/g)	Surface water PRGs TR = 1E-05 (pCi/L)
<i>Am-241</i>	4.51E-01	1.88E+00
<i>C-14</i>	3.01E+01	7.53E-02
<i>Cl-36</i>	1.36E+01	2.89E+02
<i>Co-60</i>	2.70E+00	3.55E+01
<i>Cs-137</i>	1.61E+00	6.45E-01
<i>Eu-154</i>	4.25E+00	3.27E+01

Table 1. Fish tissue and surface water PRGs (cont.)

Isotope	Fish tissue PRGs TR = 1E-05 (pCi/g)	Surface water PRGs TR = 1E-05 (pCi/L)
<i>H-3</i>	4.18E+02	4.65E+05
<i>I-129</i>	3.06E-01	1.02E+01
<i>Np-237</i>	6.56E-01	2.34E+01
<i>Pu-238</i>	3.55E-01	1.69E-02
<i>Pu-239/240</i>	3.46E-01	1.65E-02
<i>Ra-226</i>	1.52E-02	5.34E-01
<i>Ra-228</i>	4.22E-02	1.05E+01
<i>Sr-90</i>	6.32E-01	4.79E+01
<i>Tc-99</i>	1.51E+01	1.00E+03
<i>Th-228</i>	1.42E-01	2.19E+01
<i>Th-230</i>	5.05E-01	8.42E+01
<i>Th-232</i>	4.52E-01	7.53E+01
<i>U-233/234</i>	5.59E-01	3.17E+02
<i>U-235/236</i>	6.01E-01	4.55E+02
<i>U-238</i>	4.99E-01	2.10E+02

TR = target risk

**Table 2. Secular equilibrium and 160-year total fish tissue PRGs for Group 3 and 4 radionuclides
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/g)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/g)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/g)	Partial SE PRG TR = 1.0E-05 (pCi/g)
Am-241	5.80E-02	-					
Am-241		1.00E+00	4.51E-01				
Np-237		1.00E+00	7.27E-01				
Pa-233		1.00E+00	6.72E+00				
U-233		1.00E+00	6.21E-01				
Th-229		1.00E+00	2.07E-01				
Ra-225		1.00E+00	3.92E-01				
Ac-225		1.00E+00	2.22E-01				
Fr-221		1.00E+00	-				
At-217		1.00E+00	-				
Bi-213		1.00E+00	8.39E+01				
Po-213		9.79E-01	-				
Tl-209		2.09E-02	-				
Pb-209		1.00E+00	1.73E+02				
Np-237	6.65E-02	-					
Np-237		1.00E+00	7.27E-01				7.27E-01
Pa-233		1.00E+00	6.72E+00				6.56E-01
U-233		1.00E+00	6.21E-01				
Th-229		1.00E+00	2.07E-01				
Ra-225		1.00E+00	3.92E-01				
Ac-225		1.00E+00	2.22E-01				
Fr-221		1.00E+00	-				
At-217		1.00E+00	-				
Bi-213		1.00E+00	8.39E+01				
Po-213		9.79E-01	-				
Tl-209		2.09E-02	-				
Pb-209		1.00E+00	1.73E+02				
Pu-238	1.39E-02	-					
Pu-238		1.00E+00	3.55E-01				
U-234		1.00E+00	6.31E-01				
Th-230		1.00E+00	5.05E-01				
Ra-226		1.00E+00	1.17E-01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	1.24E+02				
Bi-214		1.00E+00	2.27E+02				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				
Pb-210		1.00E+00	5.12E-02				

**Table 2. Secular equilibrium and 160-year total fish tissue PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/g)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/g)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/g)	Partial SE PRG TR = 1.0E-05 (pCi/g)
Bi-210		1.00E+00	4.62E+00				
Po-210		1.00E+00	2.67E-02				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				
Pu-239	5.23E-02	-					
Pu-239		1.00E+00	3.46E-01				3.46E-01
U-235m		9.90E-01	5.67E+06				3.46E-01
U-235		1.00E+00	6.38E-01				
Th-231		1.00E+00	1.87E+01				
Pa-231		1.00E+00	2.67E-01				
Ac-227		1.00E+00	2.45E-01				
Th-227		9.86E-01	8.69E-01				
Fr-223		1.38E-02	4.32E+02				
Ra-223		1.00E+00	1.78E-01				
At-219		8.28E-07	-				
Rn-219		1.00E+00	-				
Bi-215		8.03E-07	-				
Po-215		1.00E+00	-				
Pb-211		1.00E+00	1.04E+02				
Bi-211		1.00E+00	-				
Po-211		2.76E-03	-				
Tl-207		9.97E-01	-				
Pu-240	2.68E-02	-					
Pu-240		1.00E+00	3.46E-01				
U-236		1.00E+00	6.70E-01				
Th-232		1.00E+00	4.52E-01				
Ra-228		1.00E+00	4.23E-02				
Ac-228		1.00E+00	2.20E+01				
Th-228		1.00E+00	4.07E-01				
Ra-224		1.00E+00	2.53E-01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				
Pb-212		1.00E+00	1.69E+00				
Bi-212		1.00E+00	5.96E+01				
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
Ra-228	3.25E-02	-					
Ra-228		1.00E+00	4.23E-02				4.23E-02
Ac-228		1.00E+00	2.20E+01				4.22E-02
Th-228		1.00E+00	4.07E-01				
Ra-224		1.00E+00	2.53E-01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				

**Table 2. Secular equilibrium and 160-year total fish tissue PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/g)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/g)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/g)	Partial SE PRG TR = 1.0E-05 (pCi/g)
Pb-212		1.00E+00	1.69E+00				
Bi-212		1.00E+00	5.96E+01				
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
Th-230	1.48E-02	-					
Th-230		1.00E+00	5.05E-01				
Ra-226		1.00E+00	1.17E-01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	1.24E+02				
Bi-214		1.00E+00	2.27E+02				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				
Pb-210		1.00E+00	5.12E-02				
Bi-210		1.00E+00	4.62E+00				
Po-210		1.00E+00	2.67E-02				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				
Th-232	3.04E-02	-					
Th-232		1.00E+00	4.52E-01				
Ra-228		1.00E+00	4.23E-02				
Ac-228		1.00E+00	2.20E+01				
Th-228		1.00E+00	4.07E-01				
Ra-224		1.00E+00	2.53E-01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				
Pb-212		1.00E+00	1.69E+00				
Bi-212		1.00E+00	5.96E+01				
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
U-233	7.40E-02	-					
U-233		1.00E+00	6.21E-01		1.00E+00	6.21E-01	
Th-229		1.00E+00	2.07E-01		1.50E-02	5.94E-01	
Ra-225		1.00E+00	3.92E-01		1.50E-02	5.81E-01	
Ac-225		1.00E+00	2.22E-01		1.50E-02	5.59E-01	
Fr-221		1.00E+00	-		1.50E-02		
At-217		1.00E+00	-		1.50E-02		
Bi-213		1.00E+00	8.39E+01		1.50E-02	5.59E-01	
Po-213		9.79E-01	-		1.47E-02		
Tl-209		2.09E-02	-		3.13E-04		
Pb-209		1.00E+00	1.73E+02		1.50E-02	5.59E-01	

**Table 2. Secular equilibrium and 160-year total fish tissue PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/g)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/g)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/g)	Partial SE PRG TR = 1.0E-05 (pCi/g)
U-234	1.44E-02	-					
U-234		1.00E+00	6.31E-01				
Th-230		1.00E+00	5.05E-01				
Ra-226		1.00E+00	1.17E-01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	1.24E+02				
Bi-214		1.00E+00	2.27E+02				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				
Pb-210		1.00E+00	5.12E-02				
Bi-210		1.00E+00	4.62E+00				
Po-210		1.00E+00	2.67E-02				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				
U-235	6.16E-02	-					
U-235		1.00E+00	6.38E-01		1.00E+00	6.38E-01	
Th-231		1.00E+00	1.87E+01		1.00E+00	6.17E-01	
Pa-231		1.00E+00	2.67E-01		3.38E-03	6.12E-01	
Ac-227		1.00E+00	2.45E-01		2.72E-03	6.08E-01	
Th-227		9.86E-01	8.69E-01	8.57E-01	2.68E-03	6.07E-01	
Fr-223		1.38E-02	4.32E+02	5.96E+00	3.75E-05	6.07E-01	
Ra-223		1.00E+00	1.78E-01		2.72E-03	6.01E-01	
At-219		8.28E-07	-		2.25E-09		
Rn-219		1.00E+00	-		2.72E-03		
Bi-215		8.03E-07	-		2.18E-09		
Po-215		1.00E+00	-		2.72E-03		
Pb-211		1.00E+00	1.04E+02		2.72E-03	6.01E-01	
Bi-211		1.00E+00	-		2.72E-03		
Po-211		2.76E-03	-		7.50E-06		
Tl-207		9.97E-01	-		2.71E-03		
U-236	2.90E-02	-					
U-236		1.00E+00	6.70E-01				
Th-232		1.00E+00	4.52E-01				
Ra-228		1.00E+00	4.23E-02				
Ac-228		1.00E+00	2.20E+01				
Th-228		1.00E+00	4.07E-01				
Ra-224		1.00E+00	2.53E-01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				
Pb-212		1.00E+00	1.69E+00				
Bi-212		1.00E+00	5.96E+01				

**Table 2. Secular equilibrium and 160-year total fish tissue PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/g)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/g)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/g)	Partial SE PRG TR = 1.0E-05 (pCi/g)
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
U-238	1.40E-02	-					
U-238		1.00E+00	6.95E-01				6.95E-01
Th-234		1.00E+00	1.77E+00				4.99E-01
Pa-234		1.60E-03	1.25E+04				4.99E-01
Pa-234m		1.00E+00	-				
U-234		1.00E+00	6.31E-01				
Th-230		1.00E+00	5.05E-01				
Ra-226		1.00E+00	1.17E-01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	1.24E+02				
Bi-214		1.00E+00	2.27E+02				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				
Pb-210		1.00E+00	5.12E-02				
Bi-210		1.00E+00	4.62E+00				
Po-210		1.00E+00	2.67E-02				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				

TR = target risk

Table 3. Secular equilibrium and 160-year total surface water PRGs for Group 3 and 4 radionuclides (final PRG shown in red)

Isotope	Total SE PRG TR = 1.0E-05 (pCi/L)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/L)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/L)	Partial SE PRG TR = 1.0E-05 (pCi/L)
Am-241	1.46E+00	-					
Am-241		1.00E+00	1.88E+00				
Np-237		1.00E+00	2.42E+01				
Pa-233		1.00E+00	6.72E+02				
U-233		1.00E+00	6.47E+02				
Th-229		1.00E+00	3.46E+01				
Ra-225		1.00E+00	9.80E+01				
Ac-225		1.00E+00	1.48E+01				
Fr-221		1.00E+00	-				
At-217		1.00E+00	-				
Bi-213		1.00E+00	5.59E+03				
Po-213		9.79E-01	-				
Tl-209		2.09E-02	-				
Pb-209		1.00E+00	6.91E+03				
Np-237	6.60E+00	-					
Np-237		1.00E+00	2.42E+01				2.42E+01
Pa-233		1.00E+00	6.72E+02				2.34E+01
U-233		1.00E+00	6.47E+02				
Th-229		1.00E+00	3.46E+01				
Ra-225		1.00E+00	9.80E+01				
Ac-225		1.00E+00	1.48E+01				
Fr-221		1.00E+00	-				
At-217		1.00E+00	-				
Bi-213		1.00E+00	5.59E+03				
Po-213		9.79E-01	-				
Tl-209		2.09E-02	-				
Pb-209		1.00E+00	6.91E+03				
Pu-238	1.64E-02	-					
Pu-238		1.00E+00	1.69E-02				
U-234		1.00E+00	6.57E+02				
Th-230		1.00E+00	8.42E+01				
Ra-226		1.00E+00	2.93E+01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	4.97E+03				
Bi-214		1.00E+00	1.51E+04				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				

**Table 3. Secular equilibrium and 160-year total surface water PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/L)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/L)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/L)	Partial SE PRG TR = 1.0E-05 (pCi/L)
Pb-210		1.00E+00	2.05E+00				
Bi-210		1.00E+00	3.08E+02				
Po-210		1.00E+00	7.42E-01				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				
Pu-239	1.64E-02	-					
Pu-239		1.00E+00	1.65E-02				1.65E-02
U-235m		9.90E-01	5.91E+09				1.65E-02
U-235		1.00E+00	6.65E+02				
Th-231		1.00E+00	3.12E+03				
Pa-231		1.00E+00	2.67E+01				
Ac-227		1.00E+00	1.64E+01				
Th-227		9.86E-01	1.45E+02				
Fr-223		1.38E-02	-				
Ra-223		1.00E+00	4.45E+01				
At-219		8.28E-07	-				
Rn-219		1.00E+00	-				
Bi-215		8.03E-07	-				
Po-215		1.00E+00	-				
Pb-211		1.00E+00	4.15E+03				
Bi-211		1.00E+00	-				
Po-211		2.76E-03	-				
Tl-207		9.97E-01	-				
Pu-240	1.64E-02	-					
Pu-240		1.00E+00	1.65E-02				
U-236		1.00E+00	6.98E+02				
Th-232		1.00E+00	7.53E+01				
Ra-228		1.00E+00	1.06E+01				
Ac-228		1.00E+00	1.47E+03				
Th-228		1.00E+00	6.78E+01				
Ra-224		1.00E+00	6.32E+01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				
Pb-212		1.00E+00	6.75E+01				
Bi-212		1.00E+00	3.97E+03				
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
Ra-228	7.09E+00	-					
Ra-228		1.00E+00	1.06E+01				1.06E+01
Ac-228		1.00E+00	1.47E+03				1.05E+01
Th-228		1.00E+00	6.78E+01				

**Table 3. Secular equilibrium and 160-year total surface water PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/L)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/L)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/L)	Partial SE PRG TR = 1.0E-05 (pCi/L)
Ra-224		1.00E+00	6.32E+01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				
Pb-212		1.00E+00	6.75E+01				
Bi-212		1.00E+00	3.97E+03				
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
Th-230	5.30E-01	-					
Th-230		1.00E+00	8.42E+01				
Ra-226		1.00E+00	2.93E+01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	4.97E+03				
Bi-214		1.00E+00	1.51E+04				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				
Pb-210		1.00E+00	2.05E+00				
Bi-210		1.00E+00	3.08E+02				
Po-210		1.00E+00	7.42E-01				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				
Th-232	6.48E+00	-					
Th-232		1.00E+00	7.53E+01				
Ra-228		1.00E+00	1.06E+01				
Ac-228		1.00E+00	1.47E+03				
Th-228		1.00E+00	6.78E+01				
Ra-224		1.00E+00	6.32E+01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				
Pb-212		1.00E+00	6.75E+01				
Bi-212		1.00E+00	3.97E+03				
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
U-233	9.20E+00	-					
U-233		1.00E+00	6.47E+02		1.00E+00	6.47E+02	
Th-229		1.00E+00	3.46E+01		1.50E-02	5.05E+02	
Ra-225		1.00E+00	9.80E+01		1.50E-02	4.69E+02	
Ac-225		1.00E+00	1.48E+01		1.50E-02	3.18E+02	
Fr-221		1.00E+00	-		1.50E-02		
At-217		1.00E+00	-		1.50E-02		

**Table 3. Secular equilibrium and 160-year total surface water PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/L)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/L)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/L)	Partial SE PRG TR = 1.0E-05 (pCi/L)
Bi-213		1.00E+00	5.59E+03		1.50E-02	3.18E+02	
Po-213		9.79E-01	-		1.47E-02		
Tl-209		2.09E-02	-		3.13E-04		
Pb-209		1.00E+00	6.91E+03		1.50E-02	3.17E+02	
U-234	5.30E-01	-					
U-234		1.00E+00	6.57E+02				
Th-230		1.00E+00	8.42E+01				
Ra-226		1.00E+00	2.93E+01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	4.97E+03				
Bi-214		1.00E+00	1.51E+04				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				
Pb-210		1.00E+00	2.05E+00				
Bi-210		1.00E+00	3.08E+02				
Po-210		1.00E+00	7.42E-01				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				
U-235	7.69E+00	-					
U-235		1.00E+00	6.65E+02		1.00E+00	6.65E+02	
Th-231		1.00E+00	3.12E+03		1.00E+00	5.48E+02	
Pa-231		1.00E+00	2.67E+01		3.38E-03	5.13E+02	
Ac-227		1.00E+00	1.64E+01		2.72E-03	4.72E+02	
Th-227		9.86E-01	1.45E+02	1.43E+02	2.68E-03	4.68E+02	
Fr-223		1.38E-02	-		3.75E-05		
Ra-223		1.00E+00	4.45E+01		2.72E-03	4.55E+02	
At-219		8.28E-07	-		2.25E-09		
Rn-219		1.00E+00	-		2.72E-03		
Bi-215		8.03E-07	-		2.18E-09		
Po-215		1.00E+00	-		2.72E-03		
Pb-211		1.00E+00	4.15E+03		2.72E-03	4.55E+02	
Bi-211		1.00E+00	-		2.72E-03		
Po-211		2.76E-03	-		7.50E-06		
Tl-207		9.97E-01	-		2.71E-03		
U-236	6.42E+00	-					
U-236		1.00E+00	6.98E+02				
Th-232		1.00E+00	7.53E+01				
Ra-228		1.00E+00	1.06E+01				
Ac-228		1.00E+00	1.47E+03				

**Table 3. Secular equilibrium and 160-year total surface water PRGs for Group 3 and 4 radionuclides (cont.)
(final PRG shown in red)**

Isotope	Total SE PRG TR = 1.0E-05 (pCi/L)	SE FC	Radionuclide contribution PRG TR = 1.0E-05 (pCi/L)	FC corrected PRG	Activity fraction at 160 Years	160-year total PRG TR = 1.0E-05 (pCi/L)	Partial SE PRG TR = 1.0E-05 (pCi/L)
Th-228		1.00E+00	6.78E+01				
Ra-224		1.00E+00	6.32E+01				
Rn-220		1.00E+00	-				
Po-216		1.00E+00	-				
Pb-212		1.00E+00	6.75E+01				
Bi-212		1.00E+00	3.97E+03				
Po-212		6.41E-01	-				
Tl-208		3.59E-01	-				
U-238	5.29E-01	-					
U-238		1.00E+00	7.24E+02				7.24E+02
Th-234		1.00E+00	2.96E+02				2.10E+02
Pa-234		1.60E-03	1.25E+06				2.10E+02
Pa-234m		1.00E+00	-				
U-234		1.00E+00	6.57E+02				
Th-230		1.00E+00	8.42E+01				
Ra-226		1.00E+00	2.93E+01				
Rn-222		1.00E+00	-				
Po-218		1.00E+00	-				
At-218		2.00E-04	-				
Rn-218		2.00E-07	-				
Pb-214		1.00E+00	4.97E+03				
Bi-214		1.00E+00	1.51E+04				
Po-214		1.00E+00	-				
Tl-210		2.10E-04	-				
Pb-210		1.00E+00	2.05E+00				
Bi-210		1.00E+00	3.08E+02				
Po-210		1.00E+00	7.42E-01				
Hg-206		1.90E-08	-				
Tl-206		1.34E-06	-				

TR = target risk

Decay over time for Cs-137
($A_0 = 1.00E+00$ pCi)

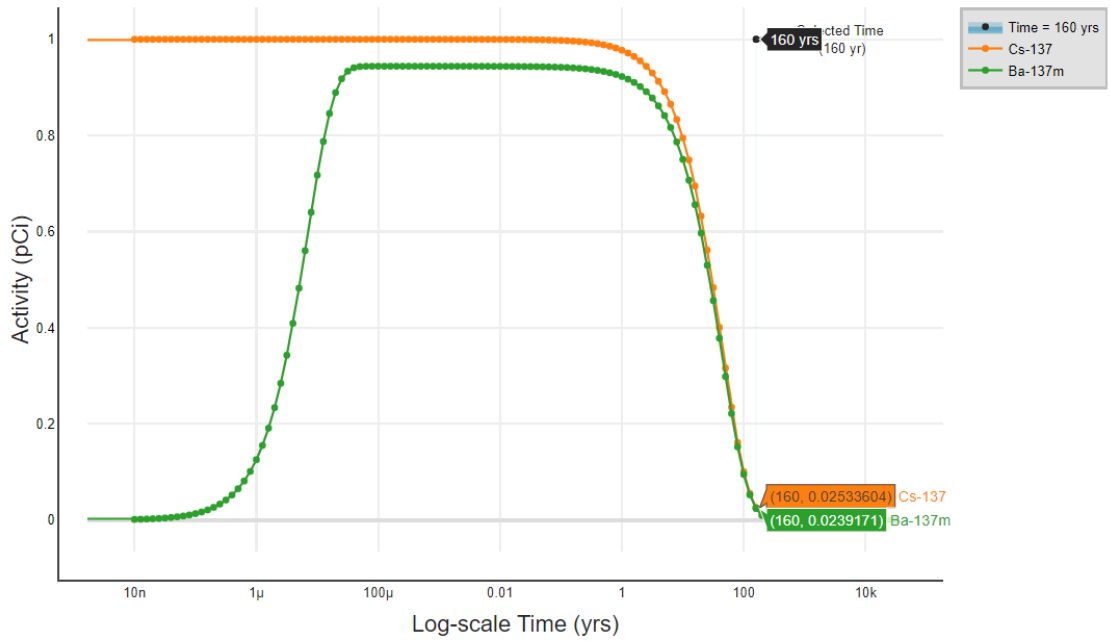


Fig. 1. Group 2 radionuclide Cs-137.

Decay over time for Sr-90
($A_0 = 1.00E+00$ pCi)

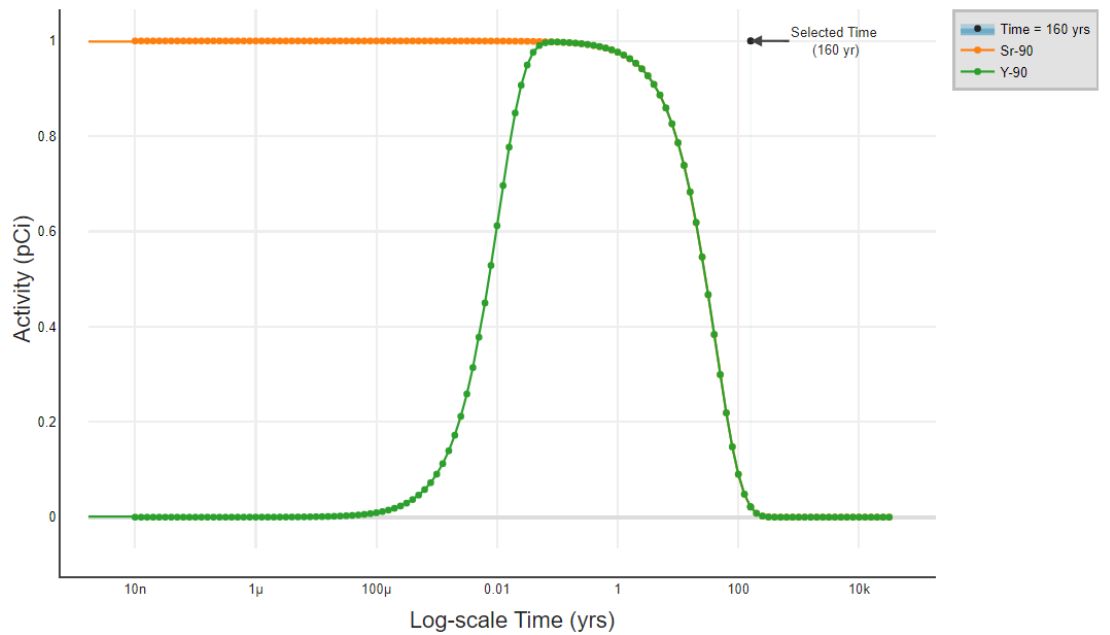


Fig. 2. Group 2 radionuclide Sr-90.

Decay over time for Ra-226
 ($A_0 = 1.00E+00$ pCi)

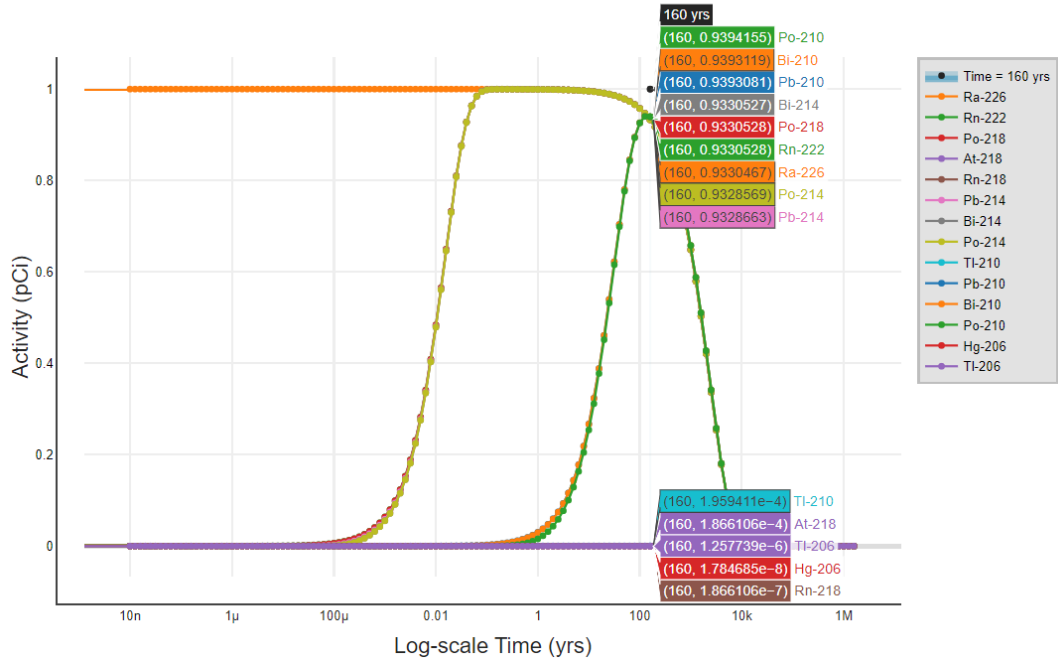


Fig. 3. Group 2 radionuclide Ra-226.

Decay over time for Th-228
 ($A_0 = 1.00E+00$ pCi)

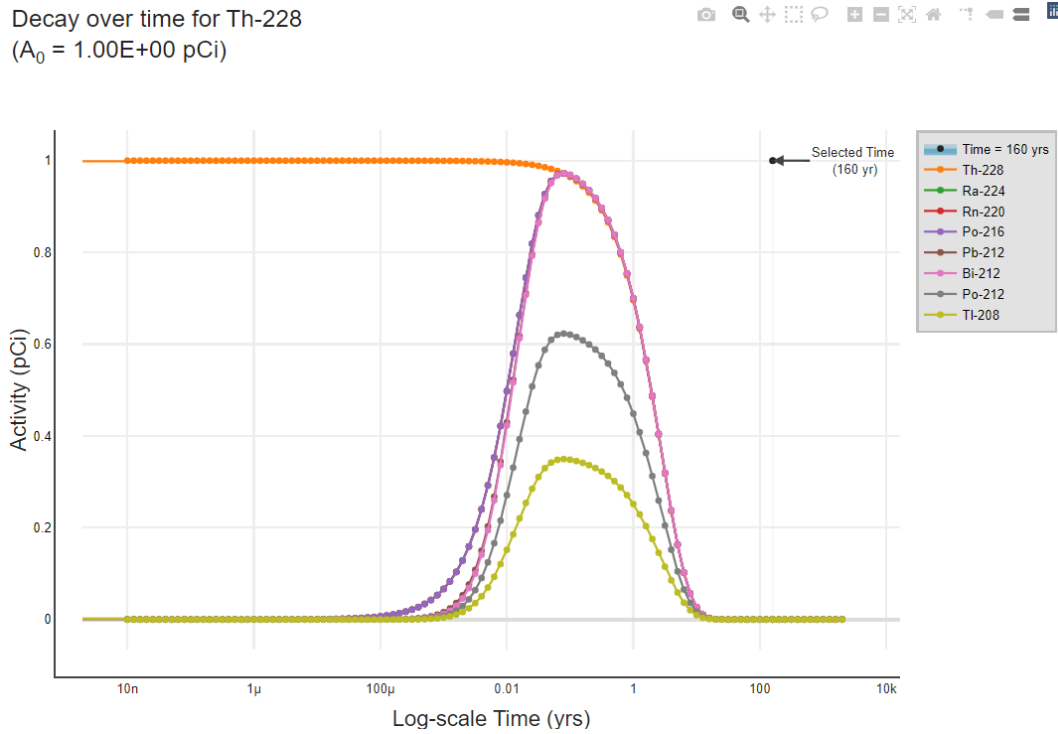


Fig. 4. Group 2 radionuclide Th-228.

Decay over time for Am-241
 ($A_0 = 1.00E+00$ pCi)

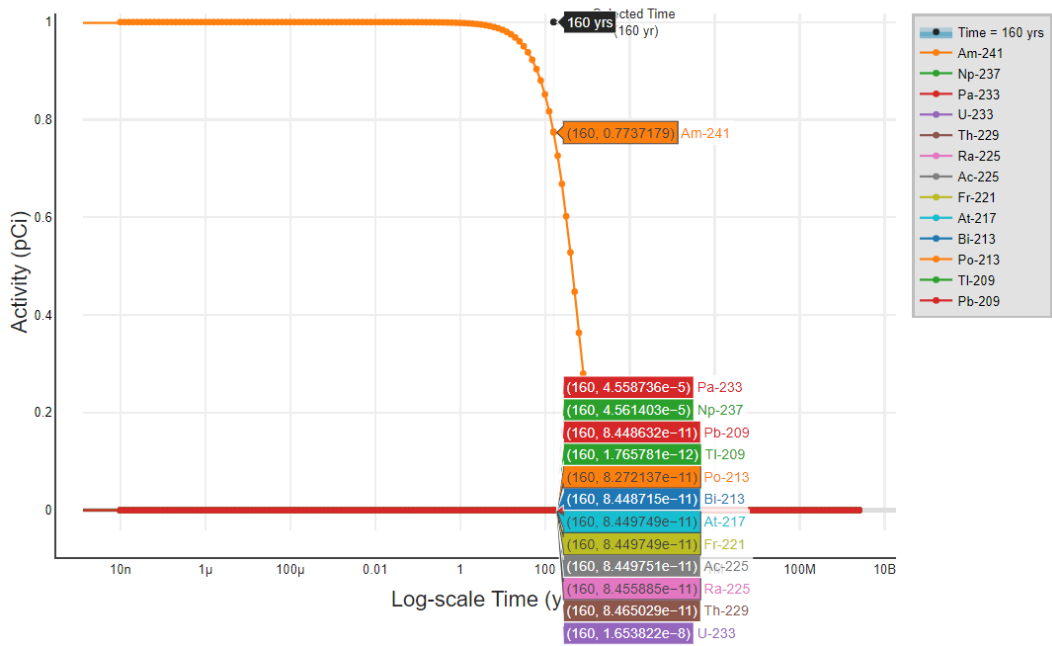


Fig. 5. Group 3 radionuclide Am-241.

Decay over time for Np-237
 ($A_0 = 1.00E+00$ pCi)

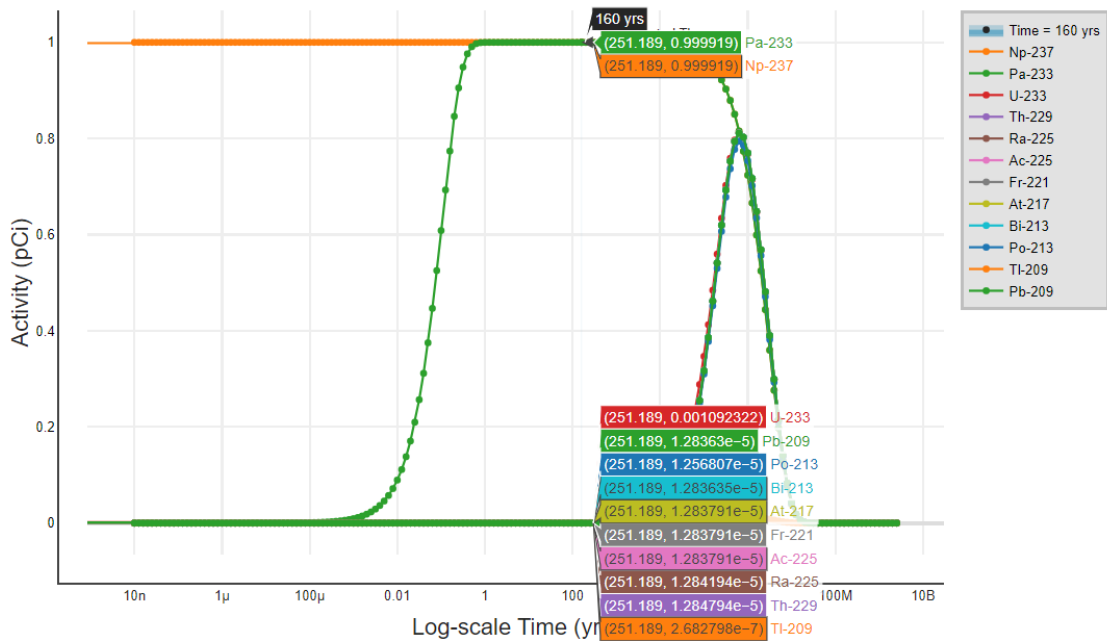


Fig. 6. Group 3 radionuclide Np-137.

Decay over time for Pu-238
 $(A_0 = 1.00E+00 \text{ pCi})$

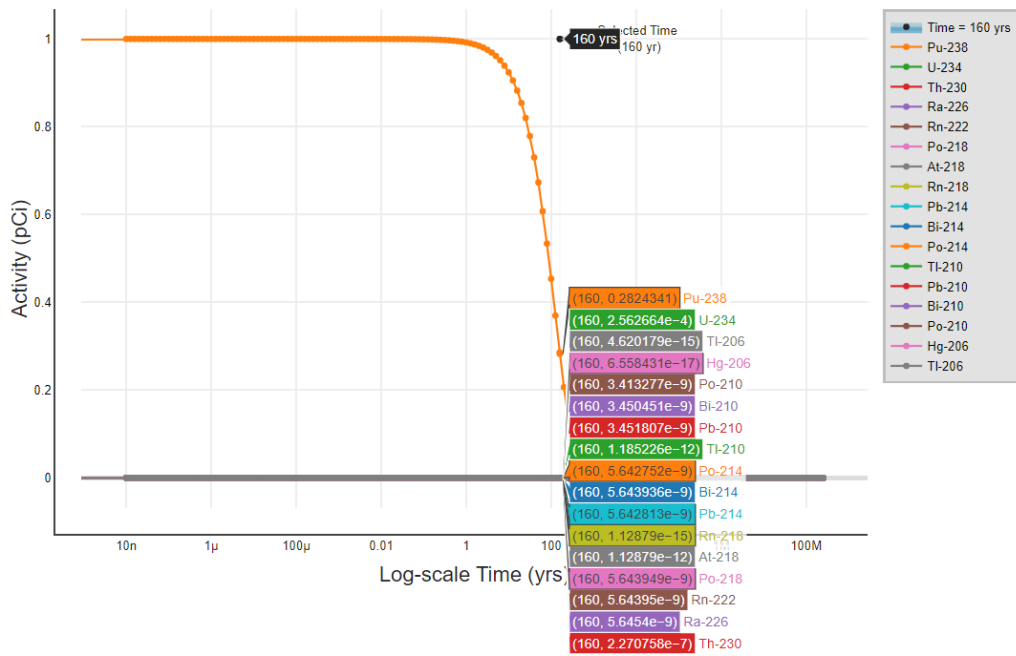


Fig. 7. Group 3 radionuclide Pu-238.

Decay over time for Pu-239
 $(A_0 = 1.00E+00 \text{ pCi})$

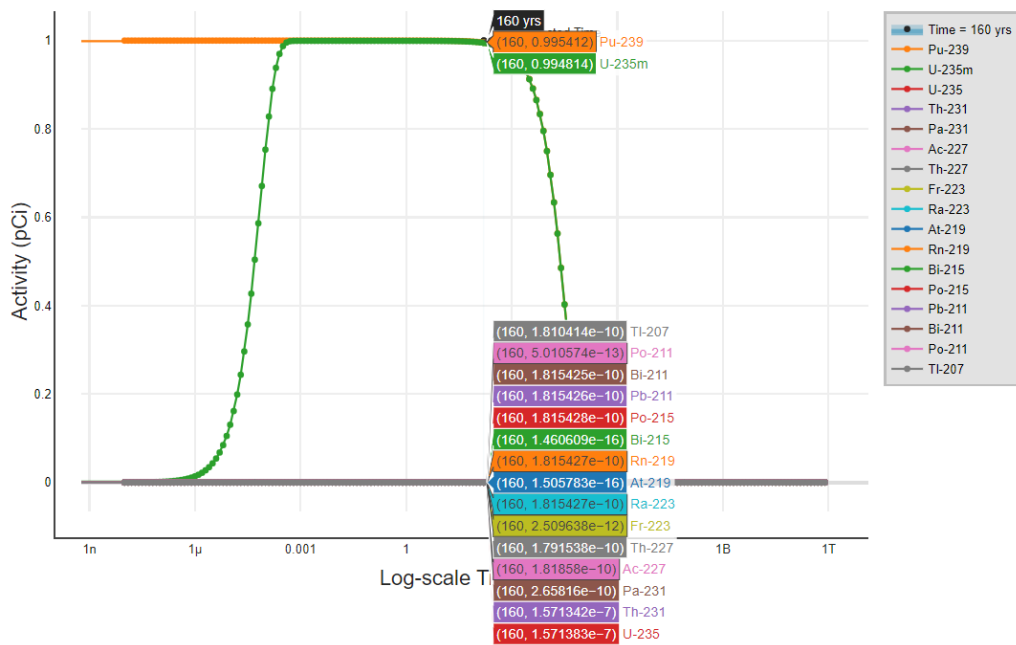


Fig. 8. Group 3 radionuclide Pu-239.

Decay over time for Pu-240
 ($A_0 = 1.00E+00$ pCi)

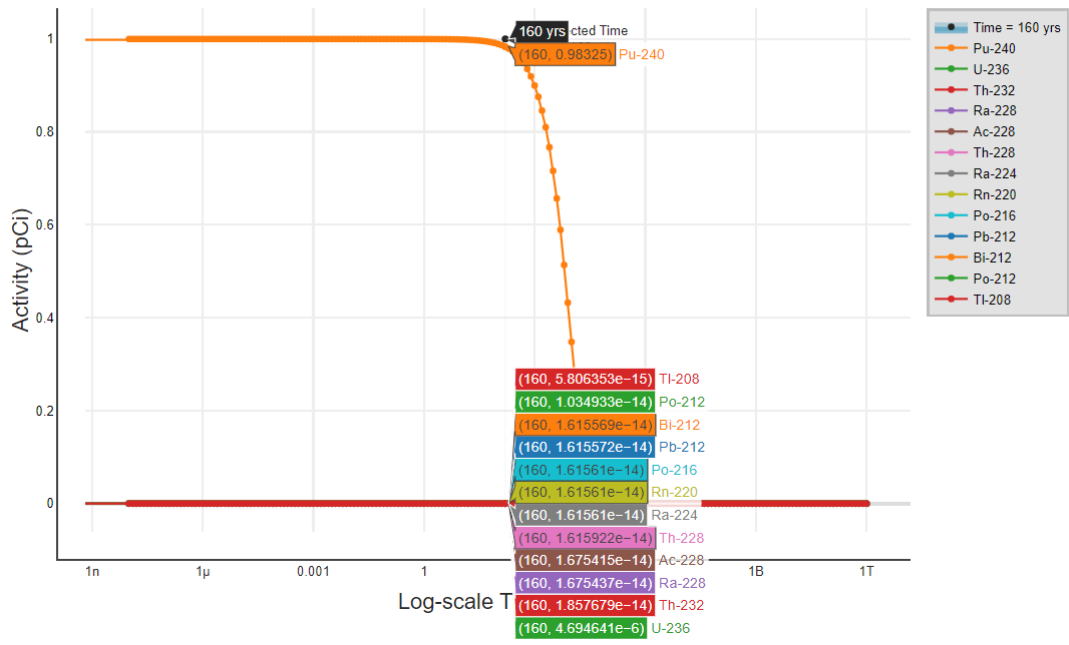


Fig. 9. Group 3 radionuclide Pu-240.

Decay over time for Ra-228
 ($A_0 = 1.00E+00$ pCi)

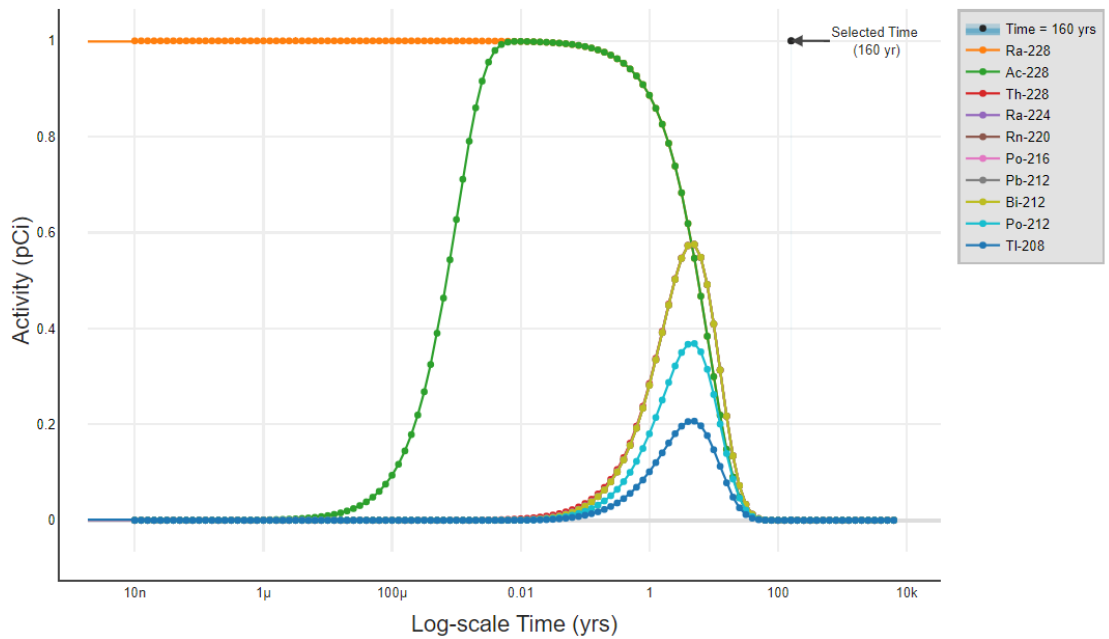


Fig. 10. Group 3 radionuclide Ra-228.

Decay over time for Th-230
 ($A_0 = 1.00E+00$ pCi)

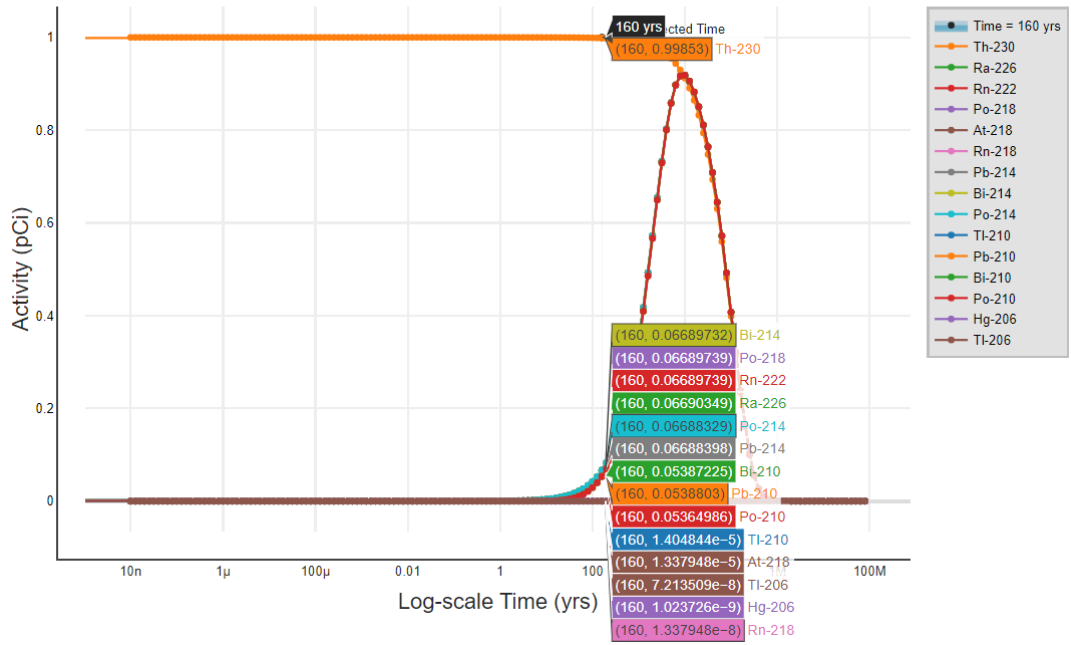


Fig. 11. Group 3 radionuclide Th-230.

Decay over time for Th-232
 ($A_0 = 1.00E+00$ pCi)

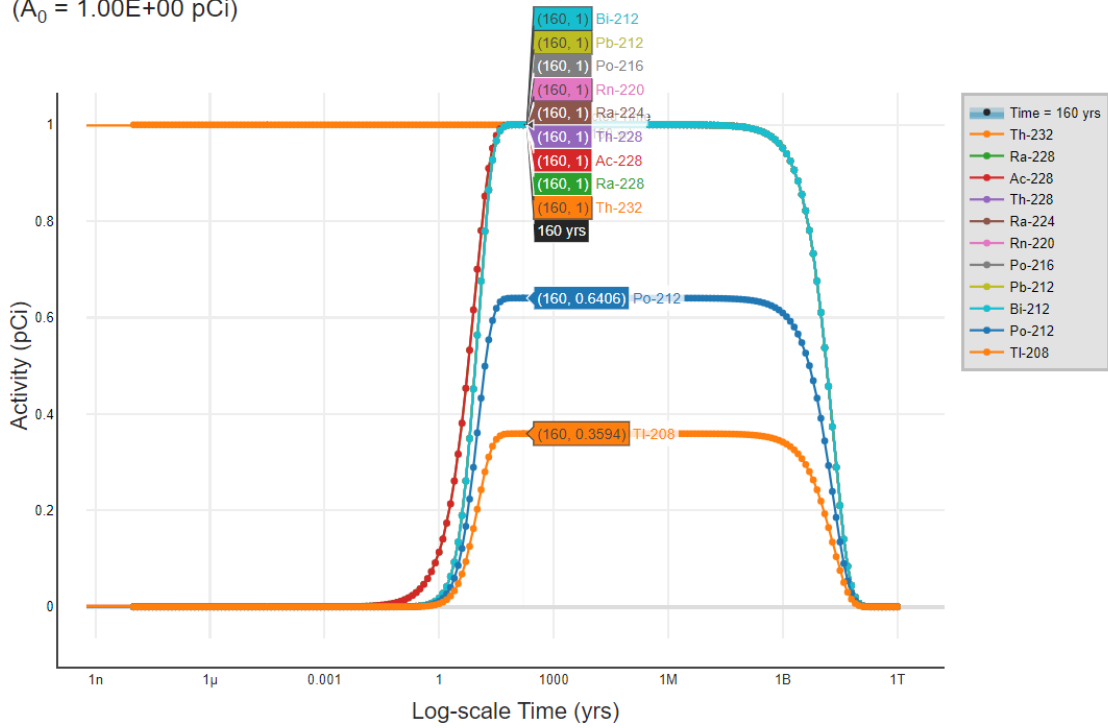


Fig. 12. Group 3 radionuclide Th-232.

Decay over time for U-234
 $(A_0 = 1.00E+00 \text{ pCi})$

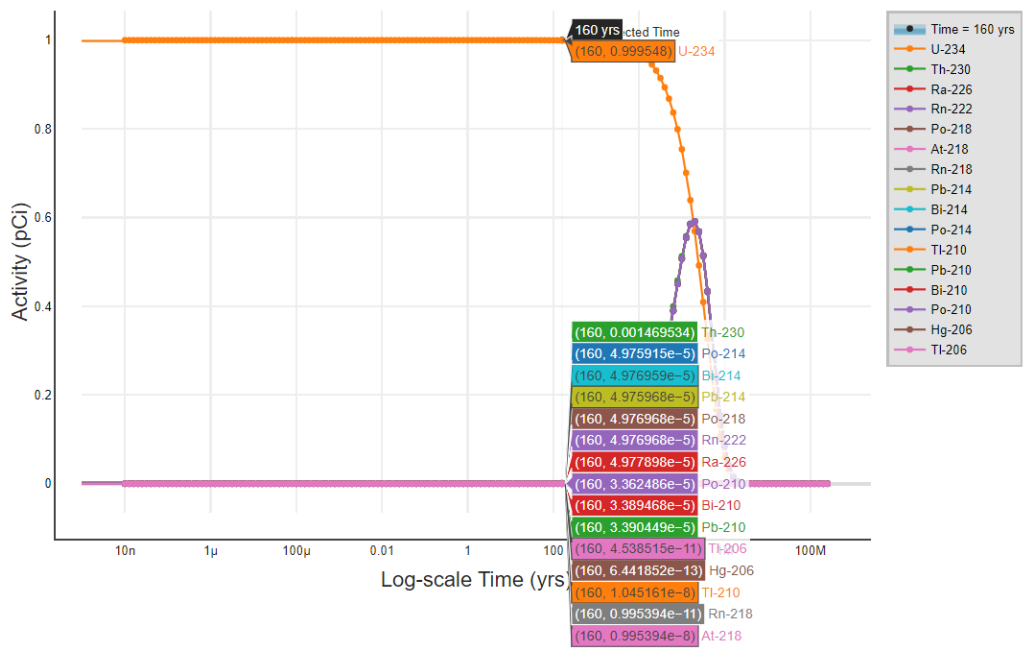


Fig. 13. Group 3 radionuclide U-234.

Decay over time for U-236
 $(A_0 = 1.00E+00 \text{ pCi})$

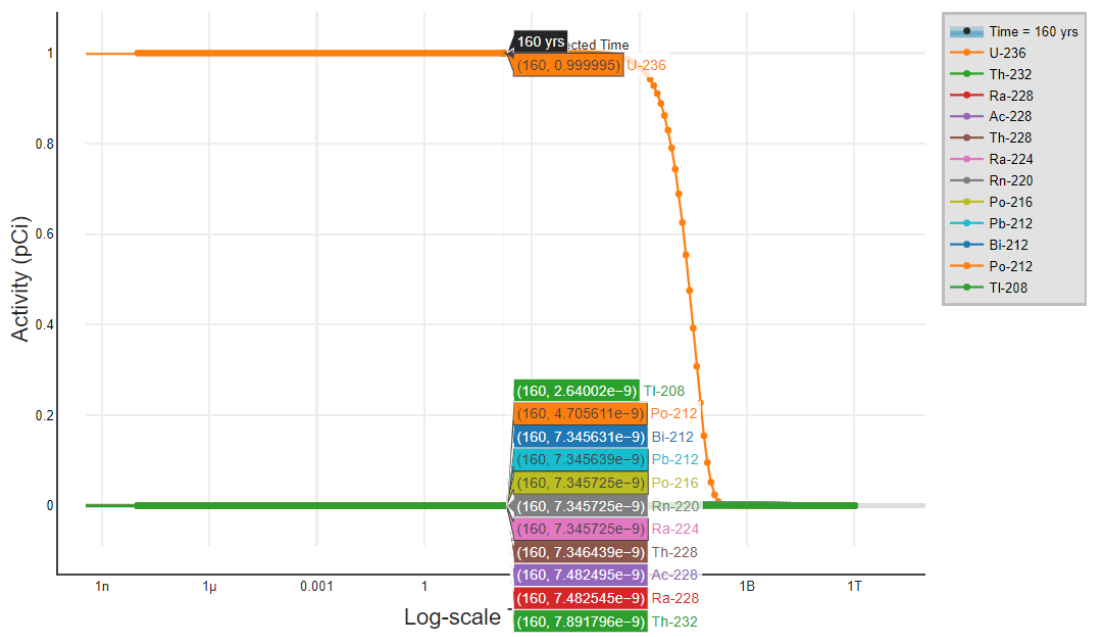


Fig. 14. Group 3 radionuclide U-236.

Decay over time for U-238
 ($A_0 = 1.00E+00$ pCi)

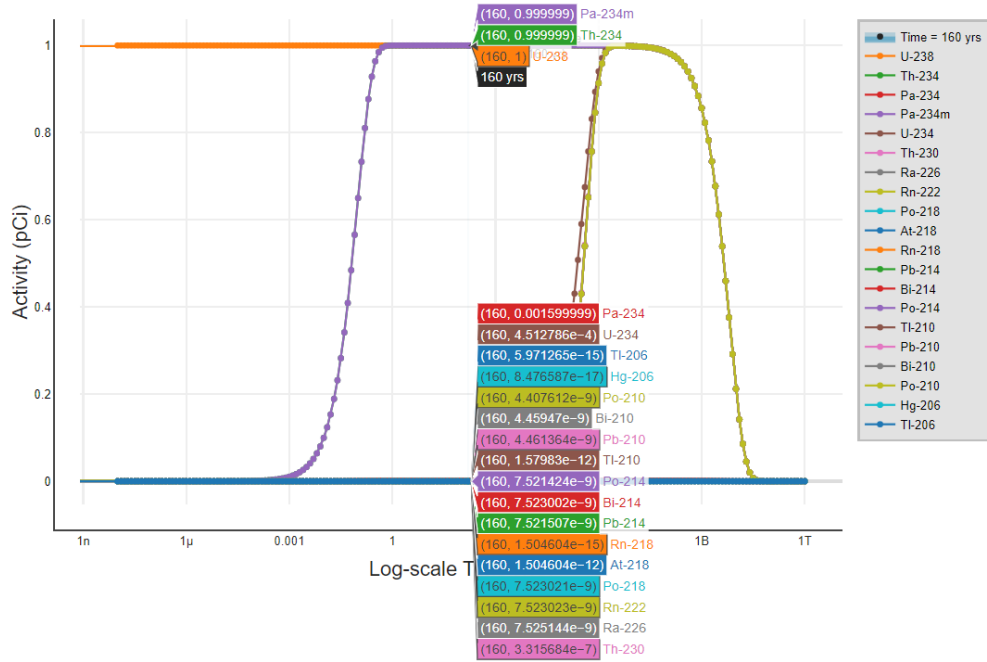


Fig. 15. Group 3 radionuclide U-238.

Decay over time for U-233
 ($A_0 = 1.00E+00$ pCi)

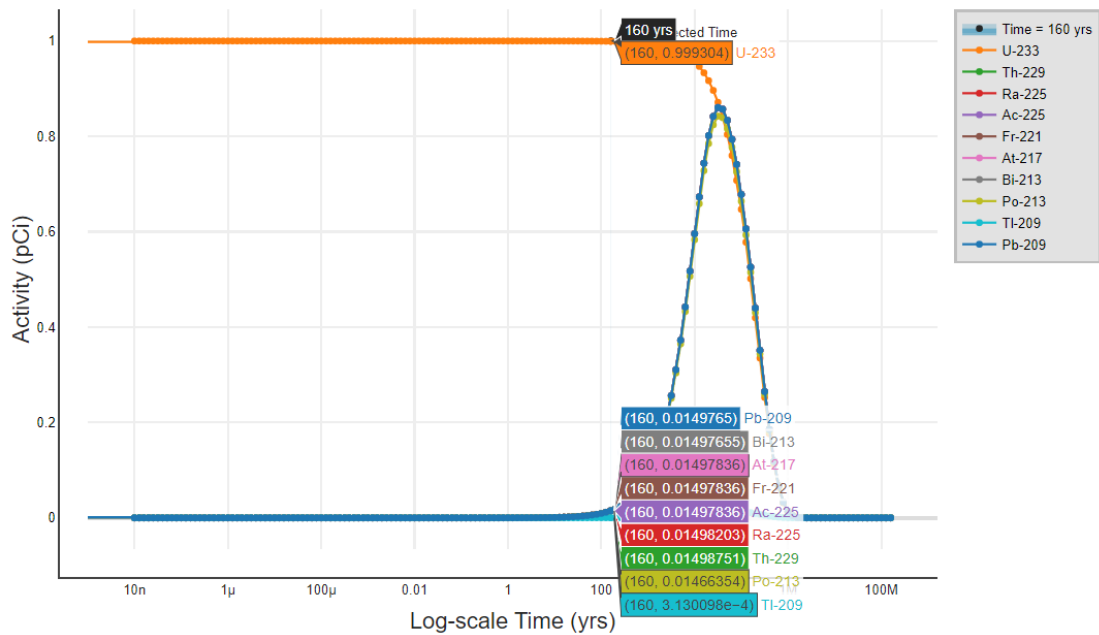


Fig. 16. Group 4 radionuclide U-233.

Decay over time for U-235
 ($A_0 = 1.00E+00$ pCi)

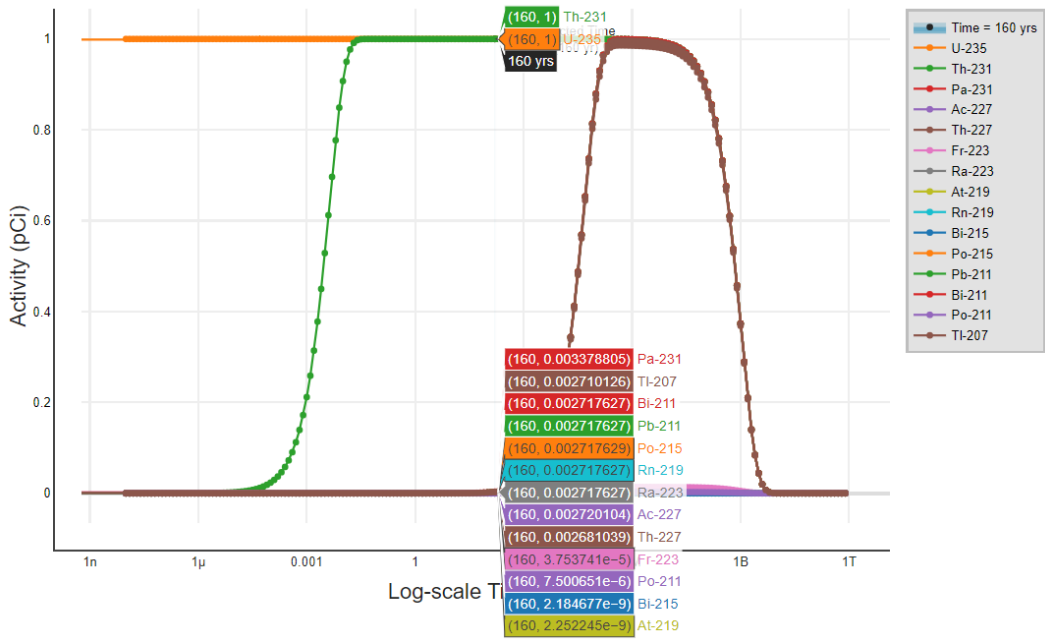


Fig. 17. Group 4 radionuclide U-235.

**APPENDIX A.
SUPPORTING DOCUMENTATION FOR
FISH TISSUE AND INSTREAM SURFACE WATER
PRELIMINARY REMEDIATION GOALS**

This page intentionally left blank.

This appendix provides details of the slope factors, fish bioconcentration factors (BCFs), fish ingestion parameters, and equations used to calculate the preliminary remediation goals (PRGs). Additionally, sample calculations for the fractional contribution (FC) correction, partial secular equilibrium (SE) PRGs, and 160-year PRGs are provided.

The U.S. Environmental Protection Agency (EPA) PRG Calculator (EPA 2022) farmer scenario was used to generate the PRGs. The media selected were “Biota Direct” for fish tissue, and “Combined Water and Biota” for the instream water column for surface water, only the PRG output option used was “Assumes secular equilibrium throughout chain (no decay).” Many of the PRGs presented by the PRG Calculator output of FinFish Consumption PRG. A few required some post-processing, as described in the main body of this report (i.e., Groups 3 and 4).

Slope Factors and Bioaccumulation factors

All the radionuclide toxicity values included in the PRG calculations were obtained from information drawn from <https://epa-prgs.ornl.gov/radionuclides/> (EPA 2022). This website is the Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites (EPA PRG) prepared by the Oak Ridge National Laboratory (ORNL) for EPA. For radionuclide isotopes, this site uses slope factors from “Calculation of Slope Factors and Dose Coefficients,” prepared by the Center for Radiation Protection Knowledge (ORNL 2014). These slope factors are updated values from the Federal Guidance Report 13 (EPA 1999), supplemented using International Commission on Radiological Protection (ICRP) 107 (ICRP 2008) decay data. All 24 parent isotopes and their progeny’s food ingestion slope factors are presented in Table A.1.

All the fish bioaccumulation factors included in the PRG calculations were obtained from information drawn from <https://epa-prgs.ornl.gov/radionuclides/>. The fish bioaccumulation factors were selected from a hierarchy of sources in the following order: International Atomic Energy Agency (IAEA 2010), United Kingdom Environmental Agency (EA 2009), RESidual RADioactive materials (RESRAD) (ANL 2001). All 24 parent isotopes and their progeny’s fish bioconcentration factors are presented in Table A.1.

Fish Ingestion Parameters

Table A.2. presents the fish ingestion exposure parameters used to calculate the PRGs and their references. Where site-specific values were used, the justification is presented.

Fish Ingestion Equations

Equation 1 Presents how the BCF is used to convert the fish tissue PRG to a water PRG.

$$PRG_{\text{far-water-finish-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-finish-ing}} (\text{pCi/g})}{BCF \left(\frac{\text{L}}{\text{kg}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

Equation 2 presents the default (i.e., using default parameters) fish tissue PRG equation and exposure parameters.

$$PRG_{\text{far-finish-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFFI_{\text{far-adj}} (1,931,020 \text{ g}) \times CF_{\text{far-finish}} (1)}$$

where:

$$IFFI_{\text{far-adj}} (1,931,020 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRFI_{\text{far-c}} \left(\frac{36.1 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRFI_{\text{far-a}} \left(\frac{155.9 \text{ g}}{\text{day}} \right) \right) \right)$$

Table A.1. Food ingestion slope factors and fish bioconcentration factors for all 24 parent isotopes and their progeny

Isotope	Food ingestion slope factor, SF _f (risk/pCi)	Finfish bioconcentration factor, BCF (pCi/kg per pCi/L)
<i>Am-241</i>	-	-
Am-241	1.34E-10	2.40E+02
Np-237	8.29E-11	3.00E+01
Pa-233	8.95E-12	1.00E+01
U-233	9.69E-11	9.60E-01
Th-229	2.90E-10	6.00E+00
Ra-225	1.54E-10	4.00E+00
Ac-225	2.72E-10	1.50E+01
Fr-221	0.00E+00	-
At-217	0.00E+00	-
Bi-213	7.18E-13	1.50E+01
Po-213	0.00E+00	3.60E+01
Tl-209	0.00E+00	9.00E+02
Pb-209	3.49E-13	2.50E+01
<i>C-14</i>	-	-
C-14	2.00E-12	4.00E+05
<i>Cl-36</i>	-	-
Cl-36	4.44E-12	4.70E+01
<i>Co-60</i>	-	-
Co-60	2.23E-11	7.60E+01
<i>Cs-137</i>	-	-
Cs-137	3.74E-11	2.50E+03
Ba-137m	0.00E+00	1.20E+00
<i>Eu-154</i>	-	-
Eu-154	1.42E-11	1.30E+02

Table A.1. Food ingestion slope factors and fish bioconcentration factors for all 24 parent isotopes and their progeny (cont.)

Isotope	Food ingestion slope factor, SF_f (risk/pCi)	Finfish bioconcentration factor, BCF (pCi/kg per pCi/L)
<i>H-3</i>	-	-
H-3	1.44E-13	9.00E-01
<i>I-129</i>	-	-
I-129	1.97E-10	3.00E+01
<i>Np-237</i>	-	-
Np-237	8.29E-11	3.00E+01
Pa-233	8.95E-12	1.00E+01
U-233	9.69E-11	9.60E-01
Th-229	2.90E-10	6.00E+00
Ra-225	1.54E-10	4.00E+00
Ac-225	2.72E-10	1.50E+01
Fr-221	0.00E+00	-
At-217	0.00E+00	-
Bi-213	7.18E-13	1.50E+01
Po-213	0.00E+00	3.60E+01
Tl-209	0.00E+00	9.00E+02
Pb-209	3.49E-13	2.50E+01
<i>Pu-238</i>	-	-
Pu-238	1.69E-10	2.10E+04
U-234	9.55E-11	9.60E-01
Th-230	1.19E-10	6.00E+00
Ra-226	5.14E-10	4.00E+00
Rn-222	0.00E+00	0.00E+00
Po-218	0.00E+00	3.60E+01
At-218	0.00E+00	-
Rn-218	0.00E+00	0.00E+00
Pb-214	4.85E-13	2.50E+01
Bi-214	2.65E-13	1.50E+01
Po-214	0.00E+00	3.60E+01
Tl-210	0.00E+00	9.00E+02
Pb-210	1.18E-09	2.50E+01
Bi-210	1.30E-11	1.50E+01
Po-210	2.25E-09	3.60E+01
Hg-206	0.00E+00	6.10E+03
Tl-206	0.00E+00	9.00E+02
<i>Pu-239</i>	-	-
Pu-239	1.74E-10	2.10E+04
U-235	9.44E-11	9.60E-01
U-235m	1.06E-17	9.60E-01
Th-231	3.22E-12	6.00E+00

Table A.1. Food ingestion slope factors and fish bioconcentration factors for all 24 parent isotopes and their progeny (cont.)

Isotope	Food ingestion slope factor, SF_f (risk/pCi)	Finfish bioconcentration factor, BCF (pCi/kg per pCi/L)
Pa-231	2.26E-10	1.00E+01
Ac-227	2.45E-10	1.50E+01
Th-227	7.03E-11	6.00E+00
Fr-223	1.01E-11	-
Ra-223	3.39E-10	4.00E+00
At-219	0.00E+00	-
Rn-219	0.00E+00	0.00E+00
Bi-215	0.00E+00	1.50E+01
Po-215	0.00E+00	3.60E+01
Pb-211	5.81E-13	2.50E+01
Bi-211	0.00E+00	1.50E+01
Po-211	0.00E+00	3.60E+01
Tl-207	0.00E+00	9.00E+02
<i>Pu-240</i>	-	-
Pu-240	1.74E-10	2.10E+04
U-236	8.99E-11	9.60E-01
Th-232	1.33E-10	6.00E+00
Ra-228	1.42E-09	4.00E+00
Ac-228	2.73E-12	1.50E+01
Th-228	1.48E-10	6.00E+00
Ra-224	2.38E-10	4.00E+00
Rn-220	0.00E+00	0.00E+00
Po-216	0.00E+00	3.60E+01
Pb-212	3.57E-11	2.50E+01
Bi-212	1.01E-12	1.50E+01
Po-212	0.00E+00	3.60E+01
Tl-208	0.00E+00	9.00E+02
<i>Ra-226</i>	-	-
Ra-226	5.14E-10	4.00E+00
Rn-222	0.00E+00	0.00E+00
Po-218	0.00E+00	3.60E+01
At-218	0.00E+00	-
Rn-218	0.00E+00	0.00E+00
Pb-214	4.85E-13	2.50E+01
Bi-214	2.65E-13	1.50E+01
Po-214	0.00E+00	3.60E+01
Tl-210	0.00E+00	9.00E+02
Pb-210	1.18E-09	2.50E+01
Bi-210	1.30E-11	1.50E+01
Po-210	2.25E-09	3.60E+01

Table A.1. Food ingestion slope factors and fish bioconcentration factors for all 24 parent isotopes and their progeny (cont.)

Hg-206	0.00E+00	6.10E+03
Tl-206	0.00E+00	9.00E+02
<i>Ra-228</i>	-	-
Ra-228	1.42E-09	4.00E+00
Ac-228	2.73E-12	1.50E+01
Th-228	1.48E-10	6.00E+00
Ra-224	2.38E-10	4.00E+00
Rn-220	0.00E+00	0.00E+00
Po-216	0.00E+00	3.60E+01
Pb-212	3.57E-11	2.50E+01
Bi-212	1.01E-12	1.50E+01
Po-212	0.00E+00	3.60E+01
Tl-208	0.00E+00	9.00E+02
<i>Sr-90</i>	-	-
Sr-90	6.88E-11	2.90E+00
Y-90	2.65E-11	4.00E+01
<i>Tc-99</i>	-	-
Tc-99	4.00E-12	1.50E+01
<i>Th-228</i>	-	-
Th-228	1.48E-10	6.00E+00
Ra-224	2.38E-10	4.00E+00
Rn-220	0.00E+00	0.00E+00
Po-216	0.00E+00	3.60E+01
Pb-212	3.57E-11	2.50E+01
Bi-212	1.01E-12	1.50E+01
Po-212	0.00E+00	3.60E+01
Tl-208	0.00E+00	9.00E+02
<i>Th-230</i>	-	-
Th-230	1.19E-10	6.00E+00
Ra-226	5.14E-10	4.00E+00
Rn-222	0.00E+00	0.00E+00
Po-218	0.00E+00	3.60E+01
At-218	0.00E+00	-
Rn-218	0.00E+00	0.00E+00
Pb-214	4.85E-13	2.50E+01
Bi-214	2.65E-13	1.50E+01
Po-214	0.00E+00	3.60E+01
Tl-210	0.00E+00	9.00E+02
Pb-210	1.18E-09	2.50E+01
Bi-210	1.30E-11	1.50E+01
Po-210	2.25E-09	3.60E+01

Table A.1. Food ingestion slope factors and fish bioconcentration factors for all 24 parent isotopes and their progeny (cont.)

Hg-206	0.00E+00	6.10E+03
Tl-206	0.00E+00	9.00E+02
<i>Th-232</i>	-	-
Th-232	1.33E-10	6.00E+00
Ra-228	1.42E-09	4.00E+00
Ac-228	2.73E-12	1.50E+01
Th-228	1.48E-10	6.00E+00
Ra-224	2.38E-10	4.00E+00
Rn-220	0.00E+00	0.00E+00
Po-216	0.00E+00	3.60E+01
Pb-212	3.57E-11	2.50E+01
Bi-212	1.01E-12	1.50E+01
Po-212	0.00E+00	3.60E+01
Tl-208	0.00E+00	9.00E+02
<i>U-233</i>	-	-
U-233	9.69E-11	9.60E-01
Th-229	2.90E-10	6.00E+00
Ra-225	1.54E-10	4.00E+00
Ac-225	2.72E-10	1.50E+01
Fr-221	0.00E+00	-
At-217	0.00E+00	-
Bi-213	7.18E-13	1.50E+01
Po-213	0.00E+00	3.60E+01
Tl-209	0.00E+00	9.00E+02
Pb-209	3.49E-13	2.50E+01
<i>U-234</i>	-	-
U-234	9.55E-11	9.60E-01
Th-230	1.19E-10	6.00E+00
Ra-226	5.14E-10	4.00E+00
Rn-222	0.00E+00	0.00E+00
Po-218	0.00E+00	3.60E+01
At-218	0.00E+00	-
Rn-218	0.00E+00	0.00E+00
Pb-214	4.85E-13	2.50E+01
Bi-214	2.65E-13	1.50E+01
Po-214	0.00E+00	3.60E+01
Tl-210	0.00E+00	9.00E+02
Pb-210	1.18E-09	2.50E+01
Bi-210	1.30E-11	1.50E+01
Po-210	2.25E-09	3.60E+01
Hg-206	0.00E+00	6.10E+03

Table A.1. Food ingestion slope factors and fish bioconcentration factors for all 24 parent isotopes and their progeny (cont.)

Tl-206	0.00E+00	9.00E+02
<i>U-235</i>	-	-
U-235	9.44E-11	9.60E-01
Th-231	3.22E-12	6.00E+00
Pa-231	2.26E-10	1.00E+01
Ac-227	2.45E-10	1.50E+01
Th-227	7.03E-11	6.00E+00
Fr-223	1.01E-11	-
Ra-223	3.39E-10	4.00E+00
At-219	0.00E+00	-
Rn-219	0.00E+00	0.00E+00
Bi-215	0.00E+00	1.50E+01
Po-215	0.00E+00	3.60E+01
Pb-211	5.81E-13	2.50E+01
Bi-211	0.00E+00	1.50E+01
Po-211	0.00E+00	3.60E+01
Tl-207	0.00E+00	9.00E+02
<i>U-236</i>	-	-
U-236	8.99E-11	9.60E-01
Th-232	1.33E-10	6.00E+00
Ra-228	1.42E-09	4.00E+00
Ac-228	2.73E-12	1.50E+01
Th-228	1.48E-10	6.00E+00
Ra-224	2.38E-10	4.00E+00
Rn-220	0.00E+00	0.00E+00
Po-216	0.00E+00	3.60E+01
Pb-212	3.57E-11	2.50E+01
Bi-212	1.01E-12	1.50E+01
Po-212	0.00E+00	3.60E+01
Tl-208	0.00E+00	9.00E+02
<i>U-238</i>	-	-
U-238	8.66E-11	9.60E-01
Th-234	3.39E-11	6.00E+00
Pa-234	3.00E-12	1.00E+01
Pa-234m	0.00E+00	1.00E+01
U-234	9.55E-11	9.60E-01
Th-230	1.19E-10	6.00E+00
Ra-226	5.14E-10	4.00E+00
Rn-222	0.00E+00	0.00E+00
Po-218	0.00E+00	3.60E+01
At-218	0.00E+00	-

Table A.1. Food ingestion slope factors and fish bioconcentration factors for all 24 parent isotopes and their progeny (cont.)

Rn-218	0.00E+00	0.00E+00
Pb-214	4.85E-13	2.50E+01
Bi-214	2.65E-13	1.50E+01
Po-214	0.00E+00	3.60E+01
Tl-210	0.00E+00	9.00E+02
Pb-210	1.18E-09	2.50E+01
Bi-210	1.30E-11	1.50E+01
Po-210	2.25E-09	3.60E+01
Hg-206	0.00E+00	6.10E+03
Tl-206	0.00E+00	9.00E+02

Output generated 01APR2022:09:58:02
 SF_f = food ingestion slope factor

Table A.2. Fish ingestion exposure parameters used to calculate the PRGs and their references.

Variable	Farmer food products default value	Site-specific value	Site-specific value source
CF _{far-finfish} (finfish contaminated fraction) unitless	1	1	Residential default for CERCLA risk assessment, and consistent with EMDF Operational Life.
ED _{far} (exposure duration - farmer) yr	40	26	Residential default for CERCLA risk assessment, and consistent with EMDF Operational Life.
ED _{far-a} (exposure duration - farmer adult) yr	34	26	Residential default for CERCLA risk assessment, and consistent with EMDF Operational Life.
ED _{far-c} (exposure duration - farmer child) yr	6	0	Risk to the adult is protective of child risk.
EF _{far-a} (exposure frequency - farmer adult) day/yr	350	365	EPA Office of Water value.
EF _{far-c} (exposure frequency - farmer child) day/yr	350	0	Risk to the adult is protective of child risk.
IFFI _{far-adj} (age-adjusted finfish ingestion fraction) g	1,931,020	166,075	Calculated based on current TN state guidance.
IRFI _{far-a} (finfish ingestion rate - farmer adult) g/day	155.9	17.5	TDEC instream value
IRFI _{far-c} (finfish ingestion rate - farmer child) g/day	36.1	0	Risk to the adult is protective of child risk.
t _{far} (time - farmer) yr	40	26	Residential default for CERCLA risk assessment, and consistent with EMDF Operational Life.
TR (target cancer risk) unitless	0.000001	0.00001	TN General Water Quality Criteria (per EPA Headquarters 12/31/2020 Dispute Resolution Letter).
Soil Type	Default	Default	

Output generated 01APR2022:09:58:02
 DOE = U.S. Department of Energy
 EMDF = Environmental Management Disposal Facility

Fractional Contribution Correction

Because the FC is applied in the SE PRGs and in the 160-year decay projections, it needs to be removed from one or the other to calculate an accurate PRG. In these PRGs, the FC was removed from the SE PRGs. For example, in the U-235 decay chain, Ac-227 decays 98.6 percent of the time to Th-227 and 1.38 percent of the time to Fr-223. The individual fish tissue PRGs for Th-227 and Fr-223 are 8.69E-01 pCi/g and 4.32E+2 pCi/g, respectively. The FC corrected PRGs are less than the original PRGs, which is as expected.

- To remove the FC from the Th-227 PRG, multiply the PRG by the FC, or $8.69\text{E-}01 \text{ pCi/g} \times 9.86\text{E-}01 = 8.57\text{E-}01 \text{ pCi/g}$.
- To remove the FC from the Fr-223 PRG, multiply the PRG by the FC, or $4.32\text{E+}02 \text{ pCi/g} \times 1.38\text{E-}02 = 5.96\text{E+}00 \text{ pCi/g}$.

Partial Secular Equilibrium PRGs

Some of the Group 3 PRGs are calculated at SE for a part of the chain. An example is Np-237, where it and Pa-233 are considered to be in equilibrium. The Np-237 and Pa-233 PRGs are 7.27E-01 pCi/g and 6.72E+02 pCi/g, respectively. The inverse sum of reciprocals approach is used to combine these PRGs. The partial SE PRG is smaller than both PRGs used in the calculation, as expected.

- To combine these PRGs, take $1/((1/7.27\text{E-}01 \text{ pCi/g})+(1/6.72\text{E+}00 \text{ pCi/g})) = 6.56\text{E-}01 \text{ pCi/g}$.

Therefore, the modified PRG for Np-237 that accounts for Pa-233 is 6.56E-01 pCi/g.

160-Year PRGs

Group 4 PRGs require combining the SE progeny PRGs with their activity decay fractions at 160 years. The FC correction process must be done first, if necessary. The inverse sum of reciprocals approach is used to combine these PRGs. The following is an example of the U-233 and the U-235 160-year fish tissue PRG calculations:

- For U-233 there is no need to apply an FC correction to the SE PRGs. The PRGs for U-233, Th-229, Ra-225, Ac-225, Bi-213, and Pb-209 are 6.21E-01, 2.07E-01, 3.92E-01, 2.22E-01, 8.39E+01, and 1.73E+02 pCi/g, respectively. The activity fractions at 160 years for U-233, Th-229, Ra-225, Ac-225, Bi-213, and Pb-209 are 1.00E+00, 1.50E-02, 1.50E-02, 1.50E-02, 1.50E-02, and 1.50E-02, respectively. To combine these PRGs, take the inverse sum of reciprocals of the activity fraction over the PRG, or $1/((1/6.21\text{E-}01)+(1.50\text{E-}02/2.07\text{E-}01)+(1.50\text{E-}02/3.92\text{E-}01)+(1.50\text{E-}02/2.22\text{E-}01)+(1.50\text{E-}02/8.39\text{E+}01)+(1.50\text{E-}02/1.73\text{E+}02)) = 5.59\text{E-}01 \text{ pCi/g}$.

The modified PRG for U-233 that incorporates the progeny present at 160 years is 5.59E-01 pCi/g.

- For U-235, there are two FC-corrected PRGs to use and they are presented in bold font. The PRGs for U-235, Th-231, Pa-231, Ac-227, Th-227, Fr-223, Ra-223, and Pb-211 are 6.38E-01, 1.87E+01, 2.67E-01, 2.45E-01, **8.57E-01**, **5.96E+00**, 1.78E-01, and 1.04E+02 pCi/g, respectively. The activity fractions at 160 years for U-235, Th-231, Pa-231, Ac-227, Th-227, Fr-223, Ra-223, and Pb-211 are 1.00E+00, 1.00E+00, 3.38E-03, 2.72E-03, 2.68E-03, 3.75E-05, 2.72E-03, and 2.72E-03, respectively. To combine these PRGs, take the inverse sum of reciprocals of the activity fraction over the PRG, or $1/((1/6.38\text{E-}01)+(1/1.87\text{E+}01)+(3.38\text{E-}03/2.67\text{E-}01)+(2.72\text{E-}03/2.45\text{E-}01)+(2.68\text{E-}03/**8.75\text{E-}01**)+(3.75\text{E-}05/**5.96\text{E+}00**)+(2.72\text{E-}03/1.78\text{E-}01)+(2.72\text{E-}03/1.04\text{E+}02)) = 6.01\text{E-}01 \text{ pCi/g}$.

The modified PRG for U-235 that incorporates the progeny present at 160 years is 6.01E-01 pCi/g.

REFERENCES

ANL 2001. *User's Manual for RESRAD Version 6*, Argonne National Laboratory, Argonne, IL. ANL/EAD-4.

Environment Agency (EA) (2006). *Initial radiological assessment methodology - part 2 methods and input data*, United Kingdom. SC030162/SR2.

IAEA 2010. *Technical Report Series No. 472: Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments*, International Atomic Energy Agency.

ICRP 2008. *Nuclear Decay Data for Dosimetric Calculations*, ICRP Publication 107. Ann. ICRP 38 (3).

ORNL 2014. Calculation of Slope Factors and Dose Coefficients and appendix. Center for Radiation Protection Knowledge. September 2014.

EPA 1999. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides. Federal Guidance Report No. 13. Office of Radiation and Indoor Air*, EPA 402-R-99-001. September 1999. <https://www.epa.gov/radiation/federal-guidance-radiation-protection>

EPA 2022. *Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites*, <https://epa-prgs.ornl.gov/radionuclides/>. Accessed April 2022.

UCOR-5550

RECORD COPY DISTRIBUTION

File—DMC—RC