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SPECIAL ANALYSIS: REVISION OF INTERMEDIATE LEVEL VAULT DISPOSAL LIMITS (U)

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EXECUTIVE SUMMARY

New disposal limits have been computed for the IL vaults based on several revisions to the PA. The most important changes are implementation of a 1,000 year time for compliance, rather than 10,000 years, and consideration of additional radon precursors. Other revisions include refinement of the aquifer mesh to more accurately model the footprint of two IL vaults, a new Pu chemistry model accounting for the different transport properties of oxidation states III/IV and V/VI, and implementation of a timed sum-of-fractions approach to setting limits. A significant decrease in the groundwater pathway limits for I-129 was speculated in the FY2003 interim measures assessment, in response to refinement of the aquifer mesh and source node definition. In fact, the new limits for these nuclides are only slightly lower. Based on the IL vault inventory as of 7/2/04 and disposal limits developed herein, the largest inventory fractions are 30% for Ra-226 and the radon analysis, 11% for I-129 (generic) and the groundwater pathway, and 9% for C-14 and the air pathway. For comparison the volume-filled fraction is at about 36%. Continued operation of the IL vault should not challenge performance objectives, assuming future disposal patterns are similar to historic use of the facility.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

ACRONYMS

DOE	Department of Energy
EPA	Environmental Protection Agency
FACT	Subsurface Flow and Contaminant Transport code
GSA	General Separations Area
HELP	Hydrologic Evaluation of Landfill Performance code
IL	Intermediate Level
ILV	Intermediate Level Vault
ILNTV	Intermediate Level Non-Tritium Vault
ILTV	Intermediate Level Tritium Vault
LLC	Limited Liability Company
MCL	Maximum Contaminant Level
PA	Performance Assessment
SOF	Sum-Of-Fractions
SRS	Savannah River Site

ABBREVIATIONS

Ci	Curie
cm	centimeter
d	day
ft	feet
g	gram
in	inch
m	meter
mL	milliliter
mrem	millirem
s	second
yr	year

1.0 INTRODUCTION

This Special Analysis report describes a general revision to disposal limits for the Intermediate Level Vault in E-Area, that supersedes limits defined by the E-Area Performance Assessment (McDowell-Boyer et al. 2000) and subsequent Special Analyses cited below. Relative to the PA, the analysis incorporates the following revisions

- implementation of a 1,000 year time for compliance (Wilhite 2003) and timed sum-of-fractions approach (Collard 2003)
- additional radionuclides based on a recent updated screening analysis (Cook 2004)
- special waste forms: high-concentration activated-carbon I-129 vessels (Collard 2000), and K and L Basin resins containing radionuclides of interest C-14, Tc-99 and I-129 (Collard 2003)
- a revised treatment of Pu chemistry in the groundwater pathway, in which Pu(III/IV) and Pu(V/VI) are modeled separately with differing geochemical properties (Cook 2002b, Kaplan 2004)
- updated soil-solute distribution coefficients (K_d's) for various elements and soil/waste types (Kaplan 2004)
- a more extensive investigation of solubility controls on U and Pu groundwater migration
- a revised infiltration transient to reflect the present E-Area closure plan and a cover degradation analysis (Phifer 2004a, b)
- refinement of the aquifer model computational mesh to allow a more accurate representation of the IL vault footprint (Wilhite and Butcher 2003)
- optimal selection of aquifer source cells receiving the flux computed by the vadose zone transport model (Flach and Collard 2003)
- groundwater flow field results from a new GSA/PORFLOW model that replaces the previous GSA/FACT model (Flach 2004)
- an expanded radon analysis considering Ra-226, Th-230, U-238 and Pu-238 as ancestors of Rn-222 in addition to U-234, which was the only precursor considered in the PA
- updated meteorology parameters and dose factors (Simpkins 2004) in the air pathway analysis
- a consideration of decay-only in a new automated intruder analysis that uses updated Federal Guidance Report 11 and 12 dose conversion factors (Koffman 2004).

Disposal limits are computed based on analyses of groundwater, inadvertent intruder, radon, and air pathways for potential exposure. Each pathway analysis is discussed in subsequent sections of the report, followed by presentation of disposal limits based on all pathways, and conclusions and recommendations.

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2.0 GROUNDWATER ANALYSIS

The groundwater pathway analysis for each radionuclide involves a vadose zone flow and transport simulation to estimate flux to the water table for a disposed parent and any subsequent progeny, followed by saturated zone flow and transport modeling to estimate the groundwater concentration(s) at a hypothetical well placed 100 meters down-gradient from the disposal unit.

2.1 Revisions

The vadose zone flow model was revised to reflect the current E-Area closure plan (Phifer 2004a), which calls for a geosynthetic cover system instead of a kaolin cap as assumed in the PA. An initial analysis of cover degradation and performance over time (Phifer 2004b) indicates infiltration through the vault roof will be nearly zero during a 25 year operational period and 100 years of institutional control (Figure 2-1). Infiltration over the adjacent native soil and backfill is about 40 cm/yr during the same period. After institutional control and placement of the cover system, infiltration is predicted to gradually increase over time due to cover degradation, such as intrusion of deep-rooted plants (e.g. trees) and silting of drainage layers. At 1,050 years after operational closure, the vault roof is assumed to fail and infiltration is predicted to abruptly rise to about 40 cm/yr (McDowell-Boyer et al. 2000, Section C.1.1.2).

In the PA a cap comprised of low-permeability kaolin and high-permeability drainage layers was explicitly included in the PORFLOW computational model. For the present analysis, the upper layers of the model representing the now obsolete cap were removed, in favor of direct specification of flux through the bottom of an implied cover system (Figure 2-2). Pre-closure (0-125 yrs), the infiltration flux is effectively applied to the vault roof and adjacent soil at the same elevation. Post-closure, infiltration is specified at the top of structural backfill (included in the model) at the bottom of the geosynthetic clay liner (omitted).

Preliminary flow simulations using the infiltration estimate from Phifer (2004b) indicated that the low-permeability vault roof would backup water into overlying layers between about 300 years and roof/cap failure. The preliminary infiltration analysis using HELP (USEPA 1994a, b) did not consider potential effects of a low permeability layer underlying the cover system. Infiltration over the ILV was thus reduced to a sufficiently low level to avoid ponding, in recognition of the fact that the drainage layer overlying the ILV roof would remove excess water. No change to infiltration over the backfill and native soil portion of the model was required. Figure 2-1 illustrates the infiltration rates used in the final PORFLOW model. The vadose zone flow simulation was performed as a sequence of steady-state runs approximating average conditions during the time intervals of 0-25, 25-125, 125-325, 325-575, 575-1075, and 1075+ years, as indicated by the stair-step variation shown in Figure 2-1. Time zero is the start of disposal unit operation, assumed to precede operational closure by 25 years. Material properties used in the PA were retained. The material property variations include a “degraded” vault condition from 575 – 1,075 years, and a “failed” state after year 1,075 (1,050 years after roof construction and operational closure). The saturation and velocity fields produced in each time period are plotted in Appendix A.

In the vadose transport model, the concentrations of U and Pu isotopes may be solubility-limited in the waste zone depending on the inventory disposed. In the PA, a single transport simulation was performed for each parent. Generally, the modeled inventory was sufficiently large to create solubility-limited conditions. For the present analysis, multiple simulations using much lower inventories in the range of 0.001 to 1 Ci per 2 disposal units (vaults) were performed (0.001 – 10 Ci for Pu-238). This range was chosen to bracket realistic disposal quantities of U and Pu isotopes. Table 2-1 shows the waste zone concentration that would be produced for a uniform distribution of parent and no solubility limit. Partitioning between the solid and liquid phases is controlled by the soil-solute distribution coefficient K_d (mL/g), or equivalently the retardation factor $R = 1 + \rho_b K_d / \theta$ (unitless) (cf. Fetter 1993). The highlighted entries exceed the solubility limit. Within this range of inventories, U-232, U-233, U-234 and Pu-238 are never solubility-limited, while Pu-244 is always solubility-limited. For the remaining nuclides, the inventory range straddles the point of initial solubility control. Solubility limits can complicate interpretation of inventory limits as presently calculated for any chain containing U or Pu, as discussed later in the report.

The new plutonium chemistry implemented for the trench disposal units (Cook 2002b, Kaplan 2004) has been included in the present special analysis. The Pu(III/IV) oxidation state is far more abundant than Pu(V/VI), but the latter is significantly more mobile in sediments: a soil-solute distribution coefficient of K_d = 370 mL/g is assumed for Pu(III/IV) versus K_d = 15 mL/g for Pu(V/VI). Although present in trace amounts, the relatively high mobility of Pu(V/VI) could potentially lead to a significant contribution to the sum-of-fractions at the 100 meter well. The two pairs of oxidation states are tracked separately in the vadose zone transport simulations to accommodate the difference in mobility. Implementation of the new Pu chemistry in terms of decay and regeneration rates is presented in Appendix A.

In addition to the geochemistry modifications described above, some distribution coefficients were updated to reflect current knowledge. Of particular note, the K_d for U in soil was raised from 35 mL/g to 800 mL/g (Cook 2000, Kaplan 2004). Appendix A provides a complete listing of K_d values used in the groundwater analysis and other key input data such as, parents analyzed, half-lives, atomic mass, concentration limits, solubility limits, and assumed decay chains. Based on an updated screening analysis (Cook 2004), K-40, Zr-95, Nb-94, Nb-95, Nb-95m, Bi-210, Ra-226, Th-230, Cm-242 were added to the groundwater pathway analysis.

The FACT code model of the General Separations Area was recently superseded by an equivalent model using the PORFLOW code, in order to consolidate PA subsurface flow and transport modeling to a single software product (Flach 2004). The flow field computed by GSA/PORFLOW is used in the present study. GSA/PORFLOW is a regional scale model with a mesh resolution in the horizontal plane of 200 ft, compared to a width of about 50 ft for the IL vault. In order to more accurately represent the physical width of an IL vault, higher resolution velocity and saturation fields in the vicinity of the IL vaults were created by interpolating values from GSA/FACT onto a 50 ft by 50 ft grid. Interpolation onto the finer-scale grid was done in a mass-conserving manner.

Figure 2-3 illustrates locations of the two IL vaults being modeled and aquifer model mesh. Under current plans a second IL vault will be constructed at footprint #5, 150 ft away from the existing vault (cf. drawing W2017860 and Appendix B). However, adjoining IL footprints are modeled as a conservatism. Figure 2-3 also shows the extent of the aquifer flow and transport model (blue border) and the mesh resolution in the horizontal plane (light gray dashes). Particle tracking results starting from the four corners of the combined facility indicate the groundwater flow direction. Time markers (red dots) are shown every 10 years of travel. At the 50 ft square grid resolution, the physical area of an IL vault (50 ft × 279 ft) can be well approximated by 6 grid blocks. The depth of aquifer source cells was optimally selected following Flach and Collard (2003).

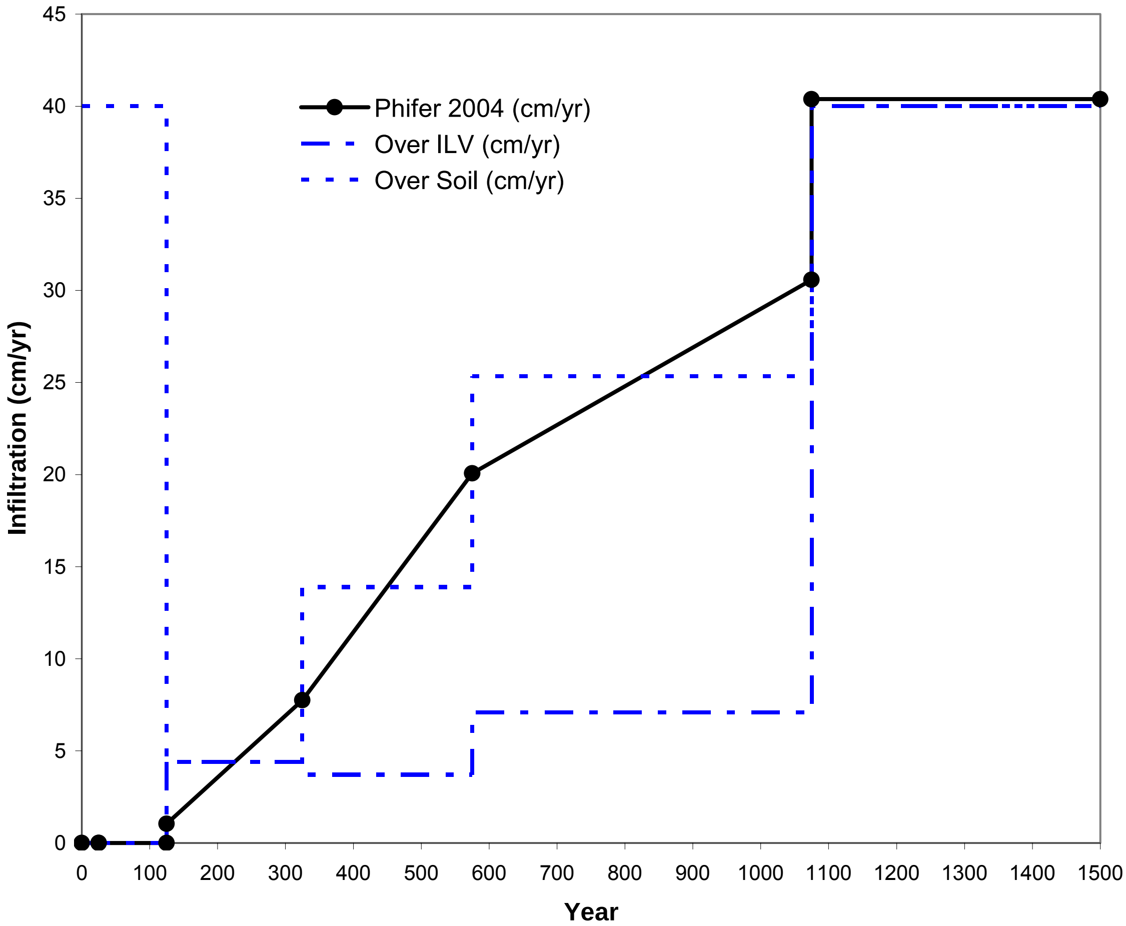

Figure 2-1. Infiltration estimate for IL vault cover system.

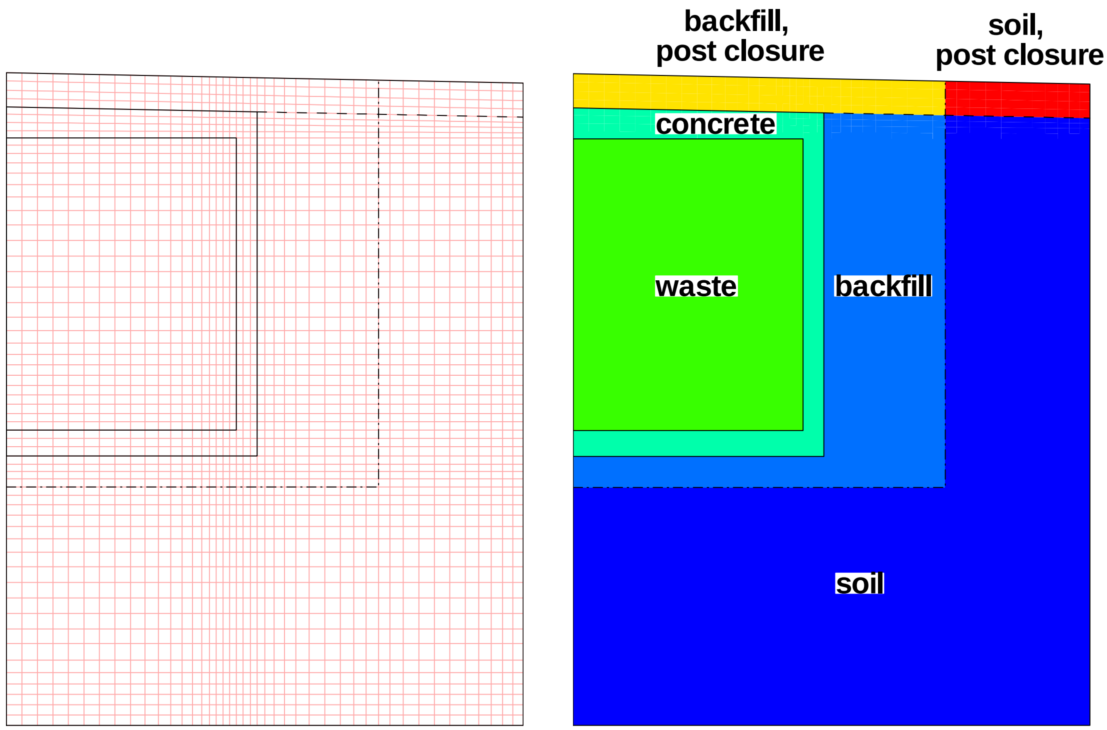

Figure 2-2. Computational mesh and material zones for PORFLOW vadose flow and transport model.

Table 2-1. Initial U and Pu concentrations in the waste zone for various inventories.

			inventory for 2 disposal units: activity (Ci)	0.001	0.01	0.1	1
			activity per unit length per half width (pCi/cm)	2.94E+04	2.94E+05	2.94E+06	2.94E+07
parent	sol limit (pCi/mL)	Kd (mL/g)	R	conc (pCi/mL)	conc (pCi/mL)	conc (pCi/mL)	conc (pCi/mL)
U-232	1.56E+03	2000	24145	1.16E-05	1.16E-04	1.16E-03	1.16E-02
U-233	6.74E-01	2000	24145	1.16E-05	1.16E-04	1.16E-03	1.16E-02
U-234	4.37E-01	2000	24145	1.16E-05	1.16E-04	1.16E-03	1.16E-02
U-235	1.52E-04	2000	24145	1.16E-05	1.16E-04	**1.16E-03**	**1.16E-02**
U-236	4.58E-03	2000	24145	1.16E-05	1.16E-04	1.16E-03	**1.16E-02**
U-238	2.40E-05	2000	24145	1.16E-05	**1.16E-04**	**1.16E-03**	**1.16E-02**
Pu-238	1.79E+00	100	1208	2.32E-04	2.32E-03	2.32E-02	2.32E-01
Pu-239	6.52E-03	100	1208	2.32E-04	2.32E-03	**2.32E-02**	**2.32E-01**
Pu-240	2.40E-02	100	1208	2.32E-04	2.32E-03	2.32E-02	**2.32E-01**
Pu-241	1.10E+01	100	1208	2.32E-04	2.32E-03	2.32E-02	2.32E-01
Pu-242	4.21E-04	100	1208	2.32E-04	**2.32E-03**	**2.32E-02**	**2.32E-01**
Pu-244	1.97E-06	100	1208	**2.32E-04**	**2.32E-03**	**2.32E-02**	**2.32E-01**

bold = solubility limit is exceeded

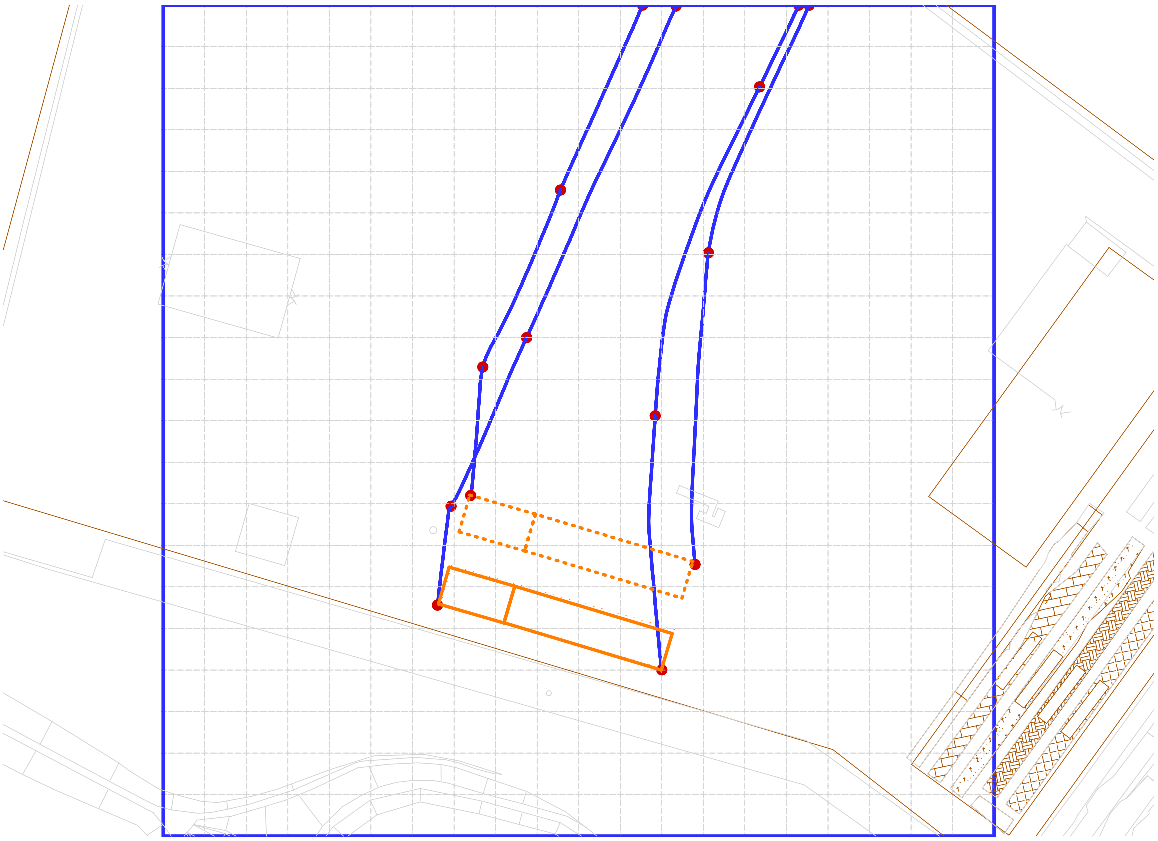

Figure 2-3. Plan view of computational mesh used for aquifer transport simulations, with particle tracking results.

2.2 Results

The EPA and DOE have defined limits on radionuclide concentrations required to safeguard human health. The lower of the EPA MCL and the concentration corresponding to a 25 mrem/yr dose is taken as the concentration limit for the groundwater pathway in this analysis (Appendix A). Disposal limits are based on a sum-of-fractions concept defined by

$$SOF = \sum_{j}^{parents} \sum_{i}^{chain} \frac{c_{ij}(A_j)}{c_{MCL,i}} \leq 1 \tag{2-1}$$

where $c_{ij}(A_j)$ is groundwater concentration computed for the i^{th} member of a chain starting with the j^{th} parent for a disposal unit inventory of A_j, and $c_{MCL,i}$ is the concentration limit for the i^{th} nuclide set by either an MCL or the 25 mrem/yr dose limit. For reference, the sum-of-fractions approach is used by the EPA to assess compliance with the MCL for beta and photon radioactivity (10 CFR 141.66(d)) and the NRC for classification of waste for near surface disposal when mixtures are involved (10 CFR 61.55). The groundwater concentration c_{ij} is chosen as the concentration occurring at the time and location where the sum-of-fractions computed for the j^{th} chain is maximized. Equation (2-1) can be abbreviated as

$$SOF = \sum_{j}^{parents} \sum_{i}^{chain} f_{ij}(A_j) \leq 1 \tag{2-2}$$

where f_{ij} denotes the concentration ratio (unitless). Equation (2-2) is more conveniently written as

$$SOF = \sum_{j}^{parents} A_j \sum_{i}^{chain} \frac{f_{ij}(A_j)}{A_j} = \sum_{j}^{parents} A_j \sum_{i}^{chain} F_{ij}(A_j) \le 1 \tag{2-3}$$

where F_{ij} is the concentration ratio or fraction per unit inventory of parent (1/Ci). For many radionuclides, specifically those with constant K_d and no solubility limits, concentration and concentration ratio are proportional to the inventory of parent. That is, F_{ij} is a constant that can be computed from a single PORFLOW transport simulation. In the present analysis, U and Pu have solubility limits and the fraction per unit inventory varies with the amount disposed.

An example involving Pu-239 in the 1,000-10,000 year time frame is shown in Table 2-2, where "Pu-239" denotes Pu-239(III/IV) and "Pu-239_56" denotes Pu-239(V/VI). As indicated in Table 2-1, the initial concentration of Pu-239 is below the solubility limit for disposal unit inventories of 0.0005 and 0.005 Ci. At the higher inventories of 0.05 and 0.5 Ci, concentration is limited by solubility in the waste zone to 6.52 pCi/L = 4.4e-13 mol/L (McDowell-Boyer et al. 2000, Table 4.1-5). Progeny U-235 is well below its solubility limit in all cases. At the two lower inventories, the peak Pu concentrations and concentration ratios are proportional to the initial inventory, and the Pu fractions on a per unit inventory basis are the same. The last column of Table 2-2 gives the limit based on the sum-of-fractions for the chain on the line denoted "SOF-chain". The other values in the column indicate the percentage contribution to the sum-of-fractions from each member of the chain.

Pu-239(III/IV) is observed to be the dominant contributor to the sum-of-fractions on a per unit inventory basis (99.96%), and thus the inventory "limit" ($1/SOF$) is the same for each case. At the two higher inventories, the peak Pu concentrations and ratios are fixed, and the fractions per unit inventory are inversely proportional to inventory. The inventory "limit" is proportional to inventory. For this time frame, none of the inventory "limits" have the conventional meaning as the maximum inventory that can be disposed without exceeding a groundwater concentration limit. Were U-235 not present in the chain, the inventory limit would effectively be infinite because the sum of concentration ratios for the chain has leveled off at 1.5×10^{-5}.

From an implementation perspective, a disposal limit can be conservatively defined by $1/SOF$ from a simulation with an assumed inventory below the actual inventory. Solubility controls can potentially be used to increase disposal limits, depending on the relationship between concentration and solubility limits.

In general, the time for compliance in this study is taken to be 1,000 years after disposal unit closure, following Wilhite (2003). An operational period of 25 years followed by 100 years of institutional control and interim closure is assumed to precede the 1,000 year time for compliance (Phifer 2004a). The groundwater analysis should therefore extend at least 1,125 years from the start of operations, for the purpose of defining limits. In this study, groundwater results through year 1,350 are used to define limits, to account for uncertainty in the vault failure time. A 1,000 year time for compliance is retained for the other pathways. Vault failure is assumed to occur at year 1,075, or 50 years before the end of the compliance period. The longer time for compliance allows ample time for relatively mobile nuclides to migrate from the IL vault to the 100 meter well following vault failure, and ensures that limits will not be highly sensitive to the assumed time of vault failure. Although the present limits are based on a 1,350 year window, PORFLOW simulations for most nuclides are run to 10,000 years for comparison to previous limits.

Plots of fractional flux, concentration, fractions and sum-of-fractions for each radionuclide and inventory modeled with PORFLOW are presented in Appendix A. Table 2-3 summarizes $1/SOF$ "limits" from the groundwater pathway analysis. Results are segregated into three time intervals for input to a timed sum-of-fractions approach to setting disposal limits. The time for compliance for the groundwater pathway is chosen as 1,350 years, so only the first two periods impact the present limits. Results from the 1,350-10,000 year period are included for comparison to previous limits, which are often based on results past 1,350 years. For chains containing U and/or Pu, four simulations were run at disposal unit inventories of 0.0005, 0.005, 0.05 and 0.5 Ci (0.001, 0.01, 0.1 and 1 Ci for two disposal units in the model). For Pu-238, a 5 Ci inventory was also run because the current inventory for the nuclide on 7/2/04 was 1.34 Ci. Otherwise, a single simulation corresponding to 0.5 Ci in a single disposal unit was run. The limits are generally based directly on a PORFLOW simulation starting from the parent. In the case of a relatively short-lived parent, namely Nb-95m, Bi-210, Pu-241, Am-241, Cm-242, Cm-244, Cf-252, the parent is instantly decayed to a sufficiently long-lived daughter. The limit for the parent is computed from

$$A_p = \frac{\lambda_p}{\lambda_d} A_d = \frac{\tau_d}{\tau_p} A_d \qquad (2\text{-}4)$$

where A denotes activity (Ci), λ decay rate (1/yr), τ half-life (yr), and the subscripts "parent" and "daughter". More comprehensive groundwater pathway results are included in Appendix A.

A significant decrease in the limits for I-129 (generic) and I-129_ETF-Carbon was speculated in the FY2003 interim measures assessment, in response to refinement of the aquifer mesh and source node definition (Wilhite and Butcher 2003). The limits for these nuclides are only slightly lower (Table E-1). Because several changes were made to the groundwater analysis, a rigorous explanation for the present outcome is not possible without performing a detailed sensitivity analysis. Apparently the impact of mesh and source node refinement was less than speculated and/or other model changes compensated. Mitigating factors probably include a decrease in vertical mesh resolution and slower groundwater travel introduced in switching from the GSA/FACT model to the GSA/PORFLOW model.

For the IL vault inventory and volume-filled (36%) as of 7/2/04, only I-129 (generic) and I-129_ETF-Carbon produce a fraction of the groundwater pathway limit exceeding 1%. Thus the conservative approach to defining limits as the minimum $1/SOF$ value among inventories modeled in the PORFLOW transport simulations for solubility-limited radionuclides should be adequate, assuming future disposal patterns are similar to historic use of the facility. Fractions for the groundwater pathway and current inventory are presented in Chapter 6.0, where this topic is further discussed.

Table 2-2. Sum-of-fraction results for Pu-239 and four inventories in the 1,000-10,000 year period.

nuclide	model inventory (Ci)	disposal unit inventory (Ci)	groundwater concentration (at peak SOF) (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
1000-10000 yrs							
Pu-239	0.001	0.0005	6.5E-06	8.1E+00	8.0E-07	1.6E-03	99.963
Pu-239_56			2.4E-09	8.1E+00	2.9E-10	5.8E-07	0.036
U-235			3.2E-12	6.5E+01	5.0E-14	9.9E-11	0
SOF-chain						1.6E-03	6.3E+02
Pu-239	0.01	0.005	6.5E-05	8.1E+00	8.0E-06	1.6E-03	99.963
Pu-239_56			2.4E-08	8.1E+00	2.9E-09	5.8E-07	0.036
U-235			3.2E-11	6.5E+01	5.0E-13	9.9E-11	0
SOF-chain						1.6E-03	6.3E+02
Pu-239	0.1	0.05	1.2E-04	8.1E+00	1.5E-05	3.0E-04	99.963
Pu-239_56			4.4E-08	8.1E+00	5.5E-09	1.1E-07	0.036
U-235			6.1E-11	6.5E+01	9.3E-13	1.9E-11	0
SOF-chain						3.0E-04	3.3E+03
Pu-239	1	0.5	1.2E-04	8.1E+00	1.5E-05	3.0E-05	99.963
Pu-239_56			4.4E-08	8.1E+00	5.5E-09	1.1E-08	0.036
U-235			6.1E-11	6.5E+01	9.3E-13	1.9E-12	0
SOF-chain					**1.5E-05**	3.0E-05	3.3E+04

notes: Pu concentration limit is based on DOE 25 mrem/yr dose limit (Cook 2002a)
U concentration limit is based on EPA MCL (Cook 2002a)

Table 2-3. Inventory limits (Ci) for groundwater pathway for three time periods (current time of compliance is 1,350 years for this pathway).

Nuclide	Activity (Ci/unit)	Limit (Ci) 0-100 yrs	Limit (Ci) 100-1,350 yrs	Limit (Ci) 1,350-10,000 yrs
H-3	0.5	5.32E+09	5.48E+09	6.50E+39
C-14	0.5	2.06E+31	9.07E+07	1.69E+04
C-14_KB	0.5	5.77E+29	2.55E+06	6.72E+02
K-40	0.5	2.34E+19	1.98E-01	2.33E+01
Ni-59	0.5	7.17E+82	3.87E+39	1.64E+02
Se-79	0.5	6.18E+40	1.17E+06	3.29E+00
Sr-90	0.5	1.60E+28	6.12E+11	1.83E+12
Zr-93	0.5	6.09E+76	7.30E+37	5.69E+08
Zr-95	0.5	1.00E+99	1.00E+99	1.00E+99
Nb-94	0.5	9.51E+73	1.40E+31	1.51E+02
Nb-95m	0.5	9.70E+99	9.70E+99	9.70E+99
Tc-99	0.5	4.04E+19	1.32E+02	1.87E+01
Tc-99_KB	0.5	3.02E+22	2.41E+04	1.30E+02
Sn-126	0.5	8.25E+71	1.74E+29	7.26E+01
I-129	0.5	4.33E+10	4.55E-04	3.54E+01
I-129_ETF-Carbon	0.5	1.25E+13	9.67E-02	1.03E-01
I-129_KB	0.5	4.28E+23	6.24E+03	1.20E+00
Cs-135	0.5	9.38E+77	1.20E+35	4.60E+01
Bi-210	0.5	2.76E+100	2.76E+100	2.76E+100

Nuclide	Activity (Ci/unit)	Limit (Ci) 0-100 yrs	Limit (Ci) 100-1,350 yrs	Limit (Ci) 1,350-10,000 yrs
Ra-226	0.5	5.76E+75	7.88E+34	9.60E+01
Th-228	0.5	1.00E+99	1.00E+99	1.00E+99
Th-230	0.5	4.10E+78	2.18E+35	8.81E+01
Th-232	0.5	4.62E+88	1.84E+55	2.11E+23
U-232	0.0005	1.89E+96	1.29E+58	3.65E+38
U-232	0.005	1.89E+96	1.29E+58	2.87E+38
U-232	0.05	1.89E+96	1.29E+58	2.82E+38
U-232	0.5	1.89E+96	1.29E+58	2.82E+38
U-233	0.0005	9.54E+96	2.77E+53	1.68E+09
U-233	0.005	9.55E+96	2.77E+53	1.68E+09
U-233	0.05	9.56E+96	2.77E+53	1.68E+09
U-233	0.5	9.57E+96	2.77E+53	1.68E+09
U-234	0.0005	1.40E+83	6.06E+37	8.53E+03
U-234	0.005	1.40E+83	6.06E+37	8.53E+03
U-234	0.05	1.40E+83	6.06E+37	8.53E+03
U-234	0.5	1.40E+83	6.06E+37	8.53E+03
U-235	0.0005	1.26E+92	1.86E+48	4.68E+05
U-235	0.005	1.26E+92	1.86E+48	5.60E+05
U-235	0.05	9.03E+92	9.48E+48	4.22E+06
U-235	0.5	5.46E+93	1.70E+49	1.23E+07
U-236	0.0005	1.03E+97	3.03E+53	2.82E+09
U-236	0.005	1.03E+97	3.03E+53	2.81E+09
U-236	0.05	1.03E+97	3.02E+53	2.81E+09
U-236	0.5	2.60E+97	9.40E+53	1.12E+10
U-238	0.0005	7.42E+95	2.17E+52	2.02E+08
U-238	0.005	3.56E+96	1.29E+53	1.53E+09
U-238	0.05	3.56E+97	1.28E+54	1.50E+10
U-238	0.5	3.55E+98	1.19E+55	1.25E+11
Np-237	0.5	1.83E+35	1.53E+06	2.30E+01
Pu-238	0.0005	5.56E+85	5.08E+46	7.48E+12
Pu-238	0.005	5.56E+85	5.08E+46	7.49E+12
Pu-238	0.05	5.56E+85	5.08E+46	7.50E+12
Pu-238	0.5	5.56E+85	5.08E+46	7.51E+12
Pu-238	5	7.00E+85	5.08E+46	7.51E+12
Pu-239	0.0005	2.14E+85	1.04E+42	6.26E+02
Pu-239	0.005	2.12E+85	1.04E+42	6.26E+02
Pu-239	0.05	7.52E+85	4.43E+42	3.34E+03
Pu-239	0.5	7.52E+86	4.43E+43	3.34E+04
Pu-240	0.0005	2.15E+85	1.16E+42	1.35E+03
Pu-240	0.005	2.15E+85	1.15E+42	1.35E+03
Pu-240	0.05	2.15E+85	1.28E+42	1.74E+03
Pu-240	0.5	2.07E+86	1.28E+43	1.73E+04
Pu-241	0.5	2.74E+40	2.29E+11	3.46E+06
Pu-242	0.0005	2.18E+85	1.03E+42	4.89E+02
Pu-242	0.005	1.19E+86	6.90E+42	4.22E+03
Pu-242	0.05	1.19E+87	6.89E+43	4.22E+04
Pu-242	0.5	1.18E+88	6.83E+44	4.17E+05
Pu-244	0.0005	2.64E+87	1.53E+44	9.23E+04
Pu-244	0.005	2.61E+88	1.50E+45	9.00E+05
Pu-244	0.05	2.27E+89	1.26E+46	7.22E+06
Pu-244	0.5	1.35E+90	7.67E+46	4.62E+07
Am-241	0.5	9.05E+38	7.57E+09	1.14E+05
Am-243	0.0005	1.03E+89	5.55E+43	1.40E+04
Am-243	0.005	1.03E+89	5.55E+43	1.40E+04
Am-243	0.05	1.03E+89	5.55E+43	1.40E+04
Am-243	0.5	1.03E+89	5.63E+43	3.17E+04
Cm-242	0.0005	1.09E+88	9.99E+48	1.47E+15

Nuclide	Activity (Ci/unit)	Limit (Ci) 0-100 yrs	Limit (Ci) 100-1,350 yrs	Limit (Ci) 1,350-10,000 yrs
Cm-242	0.005	1.09E+88	9.99E+48	1.47E+15
Cm-242	0.05	1.09E+88	9.99E+48	1.48E+15
Cm-242	0.5	1.09E+88	9.99E+48	1.48E+15
Cm-242	5	1.38E+88	9.99E+48	1.48E+15
Cm-244	0.0005	7.79E+87	4.19E+44	4.90E+05
Cm-244	0.005	7.80E+87	4.19E+44	4.90E+05
Cm-244	0.05	7.81E+87	4.63E+44	6.30E+05
Cm-244	0.5	7.50E+88	4.62E+45	6.29E+06
Cm-245	0.0005	1.88E+41	4.84E+09	8.28E+03
Cm-245	0.005	1.88E+41	4.84E+09	8.28E+03
Cm-245	0.05	1.88E+41	4.84E+09	8.28E+03
Cm-245	0.5	3.46E+41	4.84E+09	8.28E+03
Cm-246	0.5	1.00E+99	2.40E+75	8.32E+27
Cm-247	0.0005	1.85E+48	6.81E+18	1.50E+05
Cm-247	0.005	1.85E+48	6.81E+18	1.50E+05
Cm-247	0.05	1.85E+48	6.81E+18	1.50E+05
Cm-247	0.5	1.85E+48	6.81E+18	1.50E+05
Cm-248	0.0005	3.63E+92	1.84E+47	3.49E+07
Cm-248	0.005	3.63E+92	1.84E+47	3.49E+07
Cm-248	0.05	3.63E+92	1.84E+47	3.49E+07
Cm-248	0.5	3.63E+92	1.88E+47	8.68E+07
Cf-249	0.0005	1.03E+45	1.88E+11	2.05E+05
Cf-249	0.005	1.03E+45	1.88E+11	2.05E+05
Cf-249	0.05	1.03E+45	1.88E+11	2.05E+05
Cf-249	0.5	1.03E+45	1.88E+11	2.05E+05
Cf-252	0.0005	4.77E+97	2.42E+52	4.60E+12
Cf-252	0.005	4.77E+97	2.42E+52	4.60E+12
Cf-252	0.05	4.77E+97	2.42E+52	4.60E+12
Cf-252	0.5	4.77E+97	2.47E+52	1.14E+13

3.0 INADVERTENT INTRUDER ANALYSIS

The inadvertent intruder analysis considers the radiological impacts to hypothetical persons who are assumed to intrude into the E-Area LLWF after institutional control ceases 100 years after facility closure.

3.1 Revisions

The intruder analysis was performed with a newly completed software tool for automated analyses (Koffman 2004). The tool eliminates the historical use of extensive spreadsheets that require extensive design checks.

The first major change in the method of analysis was to decouple the intruder analyses from the groundwater pathway analysis by neglecting leaching and only considering decay for the amount of contaminant remaining at the time of intrusion. The groundwater pathway typically used a distribution coefficient (K_d) that was conservative for its own pathway by enhancing the release slightly. However, that value was typically slightly non-conservative for the intruder pathways, because too much release meant that less contaminant remained for the intruder to encounter. This non-conservatism has been removed with the revised method.

The second major change in the method of analysis was to introduce a transient analysis for each type of intrusion, rather than selecting a fixed time. The decay process continually changes the amount of contaminant present in the waste zone that the intruder can encounter. While the amount of parent monotonically decreases, the amount of each progeny initially increases and ultimately decreases. At the same time as the decay process, sediments and engineered materials can erode and degrade. Determining the time when the most conservative impact on the intruder will occur is impossible, unless a rigorous examination is conducted with calculus or a transient analysis is performed. The new method selected a transient analysis that is valid across the spectrum of disposal units and does not require extensive calculations by the analyst; rather it requires the analyst to define geometry and process inputs, and then relies on the computer model to perform pathways calculations at a specified time increment that is nominally 10 years.

The first change in the implementation was selection of a new geometry that includes a 12 inch thick erosion barrier near the top of the cap (Phifer 2004a). Because the erosion barrier is assumed to never erode and all the layers between the waste and the erosion barrier always remain in place at their design thickness, about 10.4 ft of material always exists above the waste. That thickness is greater than the depth of a typical basement (3 m or 9.8 ft) and the agriculture scenario can never occur, because the agriculture scenario relies on a basement extending into the waste zone. Additionally, the concrete roof of the vault will prevent excavation through it for more than 1,000 years.

For the resident scenario, the erosion barrier greatly increases the amount of material above the waste that serves to shield the residential intruder. For the post-drilling scenario, the erosion barrier does not prevent drilling through the waste. However, the grout was assumed to prevent drilling through the waste, thus the post-drilling scenario was not considered for the ILV.

The second change in the implementation was selection of a consistent volume for the ILV. The ILV consists of 9 cells, where 2 were designed to contain tritiated waste, while the other 7 were designed for non-tritium waste. The PA intruder analysis was based on the volume of the non-tritium, “ILNTV”, portion of the facility, or 5,700 m^3 (McDowell-Boyer et al. 2000, Section 3.3.2.3). Presently, no distinction is made between the ILNTV and tritium (ILTV) portions of the facility in setting limits, and a second facility will not have separate tritium and non-tritium compartments. Therefore, in the present analysis considering two disposal units, an IL vault volume of 7,300 m^3 is assumed in the intruder analysis. The larger facility volume includes 1,600 m^3 reported in the PA for the ILTV (McDowell-Boyer et al. 2000, Section 3.3.2.3).

The PA states "the geometrical correction factor, G, in Eq. 6.3-1 takes into account that a large-scale excavation into disposal units, as assumed in the agriculture and resident scenarios, would involve exposure to uncontaminated material between individual disposal units as well as disposed waste itself." "Therefore, the geometrical correction factor is given by the fraction of the land area encompassed by the disposal units of a particular type that contains waste." (McDowell-Boyer et al. 2000, page 6-20). The PA provides a geometrical reduction factor, G, in Table 6-3-4 of McDowell-Boyer et al. (2000) for the ILV of 0.4 for IL vaults. This setting is consistent with current plans to locate a second IL vault at footprint #5 (cf. drawing W2017860). The resulting spacing between IL vaults would be 150 ft.

Soil/cover layers overlying the IL vault roof were adjusted to be consistent with the current closure plan (Phifer 2004a, b). Appendix B provides additional information on disposal unit specific inputs to the automated intruder analysis.

3.2 Results

Because the agriculture scenario was eliminated based on using an erosion barrier, the PA agriculture scenario table (Table 6.3-5) was eliminated. Results of the resident intruder analyses are provided in Table 3-1 (that replaces Table 6.3-11 and Table 6.3-12 in the PA). Additional detail is provided in Appendix B. The PA tables were for 100 years and 10,000 years. Because the new method applies a transient analysis, it provides the lowest inventory for the entire time period, regardless of when it occurs. The new analysis stopped at 1,000 years, which is the new time for compliance.

The vault roof and upper layer of clean grout provide more than a meter of shielding throughout the resident scenario transient. Consequently, exposure levels are relatively low compared to other disposal units (e.g. slit and engineered trenches). Limits are correspondingly high. For the IL vault inventory and volume-filled (36%) as of 7/2/04, none of the radionuclides produce a significantly large fraction of the intruder limit, as discussed later in Chapter 6.0.

Table 3-1. Inventory limits for the intruder resident scenario; transient calculation for 1,000 years (--- denotes limit exceeding 1E+20 Ci).

Radionuclide	Time of Maximum Dose (Years)	Concentration Limit (mCi/m^3)	Inventory Limit (Ci/unit)
H-3	---	---	---
C-14	---	---	---
Na-22	100	1.48E+17	1.08E+15
Al-26	100	9.08E+04	6.62E+02
S-35	---	---	---
Cl-36	---	---	---
Ar-39	---	---	---
K-40	100	2.10E+06	1.53E+04
Ca-41	---	---	---
Sc-46	100	---	---
Co-60	100	1.09E+11	7.98E+08
Ni-59	---	---	---
Ni-63	---	---	---
Se-79	---	---	---
Kr-85	100	5.20E+12	3.79E+10
Rb-87	---	---	---

Radionuclide	Time of Maximum Dose (Years)	Concentration Limit (mCi/m^3)	Inventory Limit (Ci/unit)
Sr-90	---	---	---
Zr-93	---	---	---
Nb-93m	---	---	---
Nb-94	100	1.81E+06	1.32E+04
Mo-93	---	---	---
Tc-99	100	---	7.66E+17
Pd-107	---	---	---
Ag-108m	100	5.35E+06	3.91E+04
Cd-113m	---	---	---
Sn-121m	---	---	---
Sn-126	100	2.92E+06	2.13E+04
Sb-125	100	2.69E+18	1.96E+16
I-129	100	---	---
Cs-134	100	---	5.72E+18
Cs-135	---	---	---
Cs-137	100	1.14E+08	8.33E+05
Ba-133	100	2.29E+11	1.68E+09
Sm-151	---	---	---
Eu-152	100	1.22E+08	8.92E+05
Eu-154	100	2.19E+09	1.60E+07
Eu-155	100	---	1.55E+18
W-181	100	---	---
W-185	100	---	---
W-188	100	---	---
Pb-210	100	7.49E+12	5.47E+10
Bi-207	100	5.87E+06	4.28E+04
Ra-226	100	1.94E+05	1.42E+03
Ra-228	100	7.07E+09	5.16E+07
Ac-227	100	1.67E+09	1.22E+07
Th-228	100	---	2.61E+18
Th-229	100	7.20E+06	5.25E+04
Th-230	1000	5.32E+05	3.88E+03
Th-232	180	6.05E+04	4.42E+02
Pa-231	230	6.93E+07	5.06E+05
U-232	100	1.71E+05	1.25E+03
U-233	1000	7.93E+07	5.79E+05
U-234	1000	1.08E+08	7.87E+05
U-235	1000	3.30E+09	2.41E+07
U-236	1000	1.24E+12	9.05E+09
U-238	1000	1.06E+08	7.74E+05
Np-237	1000	8.82E+08	6.44E+06
Pu-238	1000	3.82E+11	2.79E+09
Pu-239	1000	4.55E+15	3.32E+13
Pu-240	1000	8.77E+16	6.40E+14
Pu-241	1000	1.69E+14	1.24E+12
Pu-242	1000	6.84E+14	5.00E+12
Pu-244	100	5.01E+06	3.66E+04
Am-241	1000	5.55E+12	4.05E+10
Am-242m	100	7.84E+08	5.72E+06
Am-243	100	6.02E+09	4.39E+07
Cm-242	1000	7.53E+13	5.49E+11
Cm-243	100	1.33E+11	9.73E+08
Cm-244	1000	3.35E+19	2.45E+17
Cm-245	1000	1.13E+12	8.24E+09

Radionuclide	Time of Maximum Dose (Years)	Concentration Limit (mCi/m^3)	Inventory Limit (Ci/unit)
Cm-246	1000	7.74E+17	5.65E+15
Cm-247	1000	1.96E+08	1.43E+06
Cm-248	1000	6.31E+11	4.60E+09
Bk-249	100	1.10E+11	8.06E+08
Cf-249	100	2.85E+08	2.08E+06
Cf-250	1000	---	2.13E+18
Cf-251	100	5.10E+10	3.72E+08
Cf-252	1000	8.60E+16	6.27E+14

4.0 AIR ANALYSIS

The air analysis considers diffusion of volatile radionuclides from the waste zone through overlying soil layers to the ground surface. The specific radionuclides analyzed are H-3 and C-14; radon is assessed separately in Chapter 5.0.

4.1 Revisions

The present analysis uses updated dose factors based on average meterological conditions for the period 1997-2001 measured near H-Area (Simpkins 2004), but retains the calculation method used in the PA. In computing dose-release factors, an atmospheric plume was assumed to result from a point release at ground level, and be depleted by radioactive decay and deposition. Dose to a maximally exposed individual was calculated for six pathways: plume shine, ground shine, inhalation, vegetable consumption, milk consumption, and meat consumption. Parameters were chosen to maximize the dose. The release fractions (Ci/yr annual release per Ci of inventory) computed in the PA were retained in the present analysis. Among the waste forms considered in the PA for the IL vault, job control waste is most limiting and the focus of the present analysis.

4.2 Results

Table 4-1 summarizes inputs and results for the air pathway analysis, following the calculation method described in the PA (McDowell-Boyer et al. 2000, Sections 4.1.2, 4.2.2 and 5.2). Appendix C provides additional detail. The current inventory of C-14 in the IL vaults corresponds to about 9% of the air pathway limit, while the contribution of H-3 to the sum-of-fractions is negligible.

Table 4-1. Summary of air pathway analysis for H-3 and C-14.

H-3		**C-14**		**ILV**
100m	*Boundary*	*100m*	*Boundary*	*Parameter*
10	10	10	10	Dose limit (mrem/yr)
6.6E-03	2.4E-06	2.4	1.1E-03	Dose factor (mrem/Ci)
3.2E-04	3.2E-04	1	1	Release fraction (Ci/yr per Ci inventory)
2.1E-06	7.7E-10	2.4E+00	1.1E-03	Dose fraction (mrem/yr per Ci inventory)
100	0	100	0	Lag time (yrs)
12.33	12.33	5730	5730	Halflife (yrs)
276	1	1	1	Decay factor
1.3E+09	1.3E+10	4.2	9.1E+03	Limit (Ci inventory)

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5.0 RADON ANALYSIS

DOE Order 435.1 sets a performance objective of 20 pCi/m^2/s or less for the average surface flux of radon gas emanating from a disposal facility (USDOE 1999a). Disposal unit performance against this objective is assessed through a separate analysis for radon.

5.1 Revisions

In the PA, radon is assumed to be released through the ground surface from decay of disposed U-234. In the present analysis, additional ancesters of Rn-222 are considered, namely Ra-226, Th-230, U-238 and Pu-238. Radionuclides that create Rn-222 are illustrated in Figure 5-1. The diagram shows the specific decay chains that lead to the formation of Rn-222, as well as the half-lives for each nuclide. The extremely long half-lives of Pu-242 and U-238 (375,500 and 4,500,000 years respectively) cause the other radioisotopes higher up in the chain of parents to be of little concern with regard to their potential to contribute significantly to the Rn-222 flux at the land surface over the period of interest.

A conservative approach to estimating radon flux from the waste zone to ground surface was taken in the PA. In the present Special Analysis, a more realistic conceptual model of radon transport was developed, as described in detail in Appendix D. The revised analysis incorporates a radon emanation coefficient, and waste zone layering and properties (e.g. porosity) more consistent with anticipated conditions.

5.2 Results

Table 5-1 summarizes the limits resulting from the radon analysis. The inventory of Ra-226 in the IL vaults as 7/2/04 corresponds to about 30% of the radon limit, while the contribution of other nuclides in Table 5-1 to the sum-of-fractions is negligible. For comparison the volume-filled is approximately 36%.

Table 5-1 Simulated peak instantaneous Rn-222 flux over 1,000-years at the land surface and associated disposal limits for parent isotopes.

Parent Source (1 Ci)	Peak Instantaneous Rn-222 Flux at land surface (pCi/m^2-s)	Unit Disposal Limit of parent isotope (Ci/m^2)	Disposal Limit of parent per ILV (75 m x 15 m = 1125 m^2) (Ci/ILV)
Pu-238	5.38E-03	3.72E+03	4.18E+06
U-238	2.05E-02	9.74E+02	1.10E+06
U-234	1.86E+01	1.08E+00	1.21E+03
Th-230	3.31E+03	6.04E-03	6.79E+00
Ra-226	8.72E+03	2.29E-03	2.58E+00

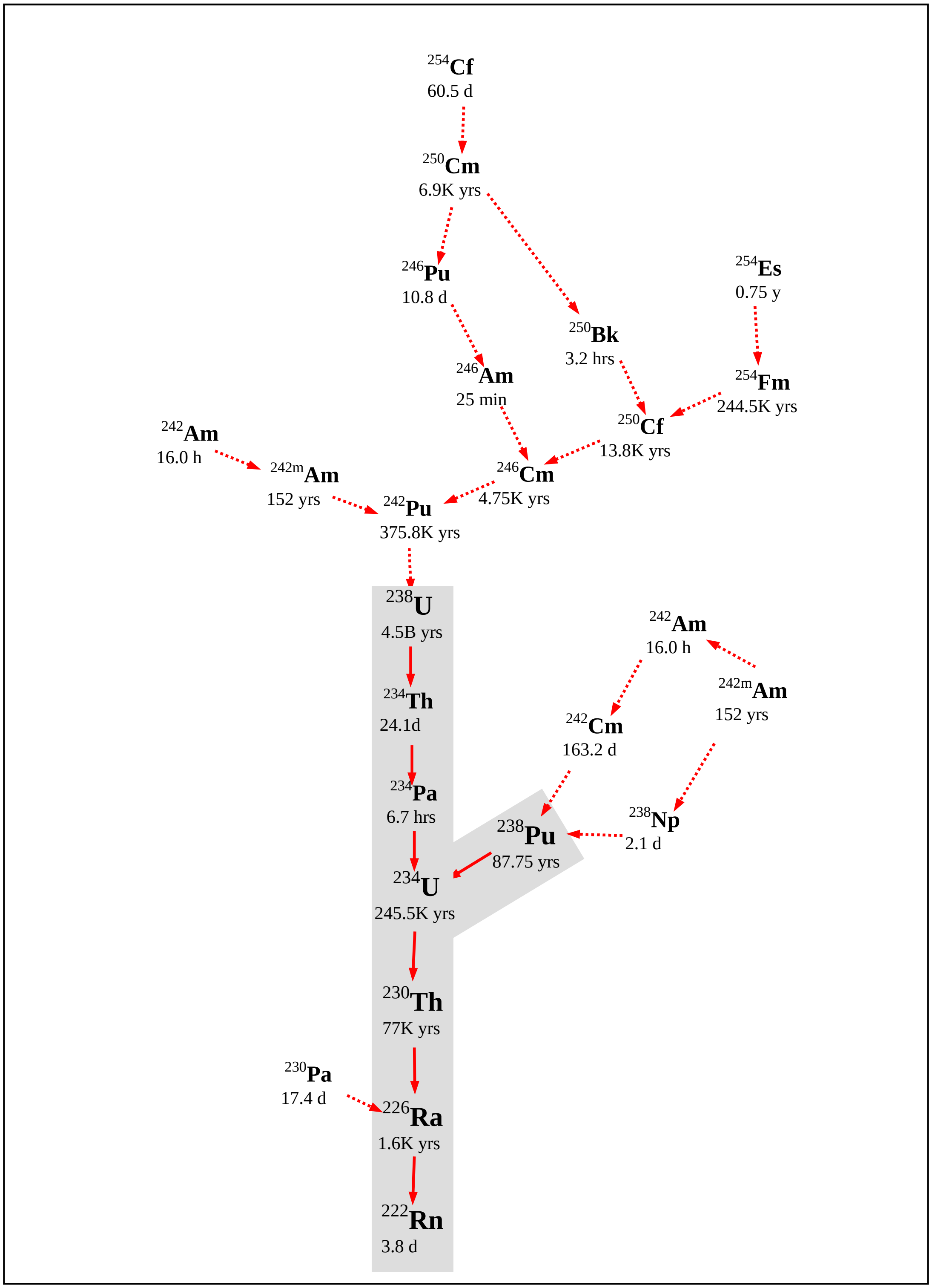

Figure 5-1. Decay chain of parent radionuclides leading to Rn-222 formation.

6.0 DISPOSAL LIMITS

Table 6-1 compares the disposal limits computed for each pathway to the IL vault inventory as of 7/2/04. No limit is shown for nuclides that were previously screened (e.g. Cook (2004) for the intruder and groundwater pathways). Also shown in the table are inventory fractions and the sum-of-fractions for each pathway. GW1 refers to the 0-100 year period, and GW2 to the 100-1,350 year time frame for the groundwater pathway.

Present limits are based on a time of compliance of 1,000 years (1,350 for the groundwater pathway to account for uncertainty in the vault failure time), compared to 10,000 years in the PA. As a consequence, many of the limits are substantially higher than those in Cook (2002b). Limits for U isotopes in the groundwater pathway increased significantly due to a change of K_d in soil from 35 mL/g to 800 mL/g. The revised infiltration scenario in the vadose zone analysis, refinement of the aquifer model, and expanded consideration of solubility limits, among other revisions listed in the Introduction, produced smaller differences.

The largest fraction is 30% for Ra-226 and the radon analysis, followed by 11% for I-129 in the groundwater pathway, and 9% for C-14 and the air pathway. For comparison, the volume-filled fraction is about 36%. Considering that essentially all the radon fraction is due to a single container, continued operation of the IL vault should not challenge performance objectives, assuming future disposal patterns are similar to historic use of the facility.

Table 6-2 summarizes the disposal limits recommended for the IL vault.

Table 6-1 Inventory limits from all pathways compared to the IL vault inventory as of 7/2/04.

nuclide	resident limit (Ci)	air limit (Ci)	radon limit (Ci)	GW1 limit (Ci)	GW2 limit (Ci)	inventory (Ci)	resident fraction	air fraction	radon fraction	GW1 fraction	GW2 fraction
SOF							**0.001**	**0.101**	**0.295**	**0.000**	**0.132**
Ac-227	1.2E+07						0.0E+00				
Ac-228						1.8E-05					
Ag-108m	3.9E+04						0.0E+00				
Ag-110m						3.0E-09					
Al-26	6.6E+02						0.0E+00				
Am-241	4.1E+10			≥1.0E+20	7.6E+09	3.5E-01	8.6E-12			3.5E-21	4.6E-11
Am-242m	5.7E+06					3.2E-04	5.5E-11				
Am-243	4.4E+07			≥1.0E+20	≥1.0E+20	4.3E-04	9.8E-12			4.3E-24	4.3E-24
Ba-133	1.7E+09						0.0E+00				
Ba-137m						1.5E+02					
Bi-207	4.3E+04						0.0E+00				
Bi-210				≥1.0E+20	≥1.0E+20	6.1E-07				6.1E-27	6.1E-27
Bi-211						3.2E-07					
Bi-212						1.3E-04					
Bi-214						7.7E-01					
Bk-249	8.1E+08						0.0E+00				
C-14	≥1.0E+20	4.2E+00		≥1.0E+20	9.1E+07	3.6E-01	3.6E-21	8.7E-02		3.6E-21	4.0E-09
C-14_KB		4.2E+00		≥1.0E+20	2.6E+06	6.1E-02		1.4E-02		6.1E-22	2.4E-08
Ca-41	≥1.0E+20						0.0E+00				
Cd-113m	≥1.0E+20						0.0E+00				
Ce-144						4.2E-01					
Cf-249	2.1E+06			≥1.0E+20	1.9E+11	5.6E-07	2.7E-13			5.6E-27	3.0E-18
Cf-250	2.1E+18						0.0E+00				
Cf-251	3.7E+08					1.7E-06	4.6E-15				
Cf-252	6.3E+14			≥1.0E+20	≥1.0E+20		0.0E+00			0.0E+00	0.0E+00
Cl-36	≥1.0E+20						0.0E+00				
Cm-242	5.5E+11			≥1.0E+20	≥1.0E+20	1.4E-05	2.6E-17			1.4E-25	1.4E-25
Cm-243	9.7E+08					7.1E-03	7.3E-12				
Cm-244	2.5E+17			≥1.0E+20	≥1.0E+20	5.9E-01	2.4E-18			5.9E-21	5.9E-21
Cm-245	8.2E+09			≥1.0E+20	4.8E+09	7.0E-06	8.5E-16			7.0E-26	1.4E-15
Cm-246	5.7E+15			≥1.0E+20	≥1.0E+20	8.5E-06	1.5E-21			8.5E-26	8.5E-26
Cm-247	1.4E+06			≥1.0E+20	6.8E+18	2.0E-10	1.4E-16			2.0E-30	2.9E-29
Cm-248	4.6E+09			≥1.0E+20	≥1.0E+20	3.1E-15	6.7E-25			3.1E-35	3.1E-35
Co-57						5.1E-05					
Co-58						2.3E+00					
Co-60	8.0E+08					7.5E+01	9.4E-08				
Cr-51						8.4E-03					
Cs-134						7.7E-01					

nuclide	resident limit (Ci)	air limit (Ci)	radon limit (Ci)	GW1 limit (Ci)	GW2 limit (Ci)	inventory (Ci)	resident fraction	air fraction	radon fraction	GW1 fraction	GW2 fraction
Cs-135	≥1.0E+20			≥1.0E+20	≥1.0E+20		0.0E+00			0.0E+00	0.0E+00
Cs-137	8.3E+05					2.2E+02	2.6E-04				
Eu-152	8.9E+05					4.1E-05	4.6E-11				
Eu-154	1.6E+07					1.8E-01	1.1E-08				
Eu-155	1.6E+18					1.2E-02	8.0E-21				
Fe-55						8.4E+01					
Fe-59						1.6E-02					
H-3	≥1.0E+20	1.3E+09		5.3E+09	5.5E+09	5.3E+05	5.3E-15	4.0E-04		9.9E-05	9.6E-05
Hf-175						1.9E-05					
Hf-181						6.1E-03					
I-129	≥1.0E+20			4.3E+10	4.6E-04	5.1E-05	5.1E-25			1.2E-15	1.1E-01
I-129_ETF-Carbon				1.2E+13	9.7E-02	2.0E-03				1.6E-16	2.1E-02
I-129_KB				≥1.0E+20	6.2E+03	6.0E-06				6.0E-26	9.7E-10
In-113m						5.0E-06					
K-40	1.5E+04			2.3E+19	2.0E-01	7.8E-07	5.1E-11			3.3E-26	3.9E-06
Kr-85	3.8E+10					2.0E+01	5.3E-10				
Mn-54						4.2E-01					
Mo-93	≥1.0E+20						0.0E+00				
Na-22	1.1E+15						0.0E+00				
Nb-93m	≥1.0E+20					2.7E-03	2.7E-23				
Nb-94	1.3E+04			≥1.0E+20	≥1.0E+20	1.1E-03	8.0E-08			1.1E-23	1.1E-23
Nb-95						2.5E-02					
Nb-95m				≥1.0E+20	≥1.0E+20	9.6E-05				9.6E-25	9.6E-25
Ni-59	≥1.0E+20			≥1.0E+20	≥1.0E+20	5.4E-02	5.4E-22			5.4E-22	5.4E-22
Ni-63	≥1.0E+20					1.2E+01	1.2E-19				
Np-237	6.4E+06			≥1.0E+20	1.5E+06	1.9E-03	3.0E-10			1.9E-23	1.3E-09
Pa-231	5.1E+05						0.0E+00				
Pa-234						1.3E-01					
Pa-234m						1.8E-01					
Pb-210	5.5E+10					7.7E-01	1.4E-11				
Pb-212						1.3E-04					
Pb-214						7.7E-01					
Pd-107	≥1.0E+20						0.0E+00				
Pm-147						2.8E+00					
Po-210						6.1E-07					
Po-212						5.3E-07					
Po-214						7.7E-01					
Po-216						1.3E-04					
Po-218						7.7E-01					

nuclide	resident limit (Ci)	air limit (Ci)	radon limit (Ci)	GW1 limit (Ci)	GW2 limit (Ci)	inventory (Ci)	resident fraction	air fraction	radon fraction	GW1 fraction	GW2 fraction
Pr-144						3.3E-01					
Pr-144m						3.1E-03					
Pu-238	2.8E+09		4.2E+06	≥1.0E+20	≥1.0E+20	1.3E+00	4.8E-10		3.2E-07	1.3E-20	1.3E-20
Pu-239	3.3E+13			≥1.0E+20	≥1.0E+20	3.6E-01	1.1E-14			3.6E-21	3.6E-21
Pu-240	6.4E+14			≥1.0E+20	≥1.0E+20	4.5E-02	7.0E-17			4.5E-22	4.5E-22
Pu-241	1.2E+12			≥1.0E+20	2.3E+11	1.5E+00	1.2E-12			1.5E-20	6.4E-12
Pu-242	5.0E+12			≥1.0E+20	≥1.0E+20	3.0E-03	6.0E-16			3.0E-23	3.0E-23
Pu-244	3.7E+04			≥1.0E+20	≥1.0E+20	1.2E-02	3.2E-07			1.2E-22	1.2E-22
Ra-224						1.3E-04					
Ra-226	1.4E+03		2.6E+00	≥1.0E+20	≥1.0E+20	7.7E-01	5.4E-04		3.0E-01	7.7E-21	7.7E-21
Ra-228	5.2E+07					1.8E-05	3.5E-13				
Rb-87	≥1.0E+20						0.0E+00				
Rh-103m						6.9E-05					
Rh-106						4.1E-02					
Rn-220						1.3E-04					
Rn-222						7.7E-01					
Ru-103						6.9E-05					
Ru-106						1.1E-01					
Sb-125	2.0E+16					1.0E-01	5.1E-18				
Se-79	≥1.0E+20			≥1.0E+20	1.2E+06	1.0E-04	1.0E-24			1.0E-24	8.7E-11
Sm-151	≥1.0E+20						0.0E+00				
Sn-113						5.0E-06					
Sn-121m	≥1.0E+20						0.0E+00				
Sn-126	2.1E+04			≥1.0E+20	≥1.0E+20	4.9E-04	2.3E-08			4.9E-24	4.9E-24
Sr-90	≥1.0E+20			≥1.0E+20	6.1E+11	2.1E+01	2.1E-19			2.1E-19	3.4E-11
Ta-182						3.4E-05					
Tc-99	7.7E+17			4.0E+19	1.3E+02	6.1E-02	8.0E-20			1.5E-21	4.7E-04
Tc-99_KB	7.7E+17			≥1.0E+20	2.4E+04	2.0E-02	2.7E-20			2.0E-22	8.5E-07
Te-125m						3.0E-03					
Th-228	2.6E+18			≥1.0E+20	≥1.0E+20	1.3E-04	4.9E-23			1.3E-24	1.3E-24
Th-229	5.3E+04						0.0E+00				
Th-230	3.9E+03		6.8E+00	≥1.0E+20	≥1.0E+20	1.8E-05	4.7E-09		2.7E-06	1.8E-25	1.8E-25
Th-231						1.9E-03					
Th-232	4.4E+02			≥1.0E+20	≥1.0E+20	4.9E-05	1.1E-07			4.9E-25	4.9E-25
Th-234						3.1E-01					
Tl-208						1.2E-07					
U-232	1.3E+03			≥1.0E+20	≥1.0E+20	1.1E-04	8.5E-08			1.1E-24	1.1E-24
U-233	5.8E+05			≥1.0E+20	≥1.0E+20	1.2E-01	2.1E-07			1.2E-21	1.2E-21
U-234	7.9E+05		1.2E+03	≥1.0E+20	≥1.0E+20	2.4E-01	3.1E-07		2.0E-04	2.4E-21	2.4E-21
U-235	2.4E+07			≥1.0E+20	≥1.0E+20	8.5E-03	3.5E-10			8.5E-23	8.5E-23
U-236	9.1E+09			≥1.0E+20	≥1.0E+20	1.7E-03	1.9E-13			1.7E-23	1.7E-23

nuclide	resident limit (Ci)	air limit (Ci)	radon limit (Ci)	GW1 limit (Ci)	GW2 limit (Ci)	inventory (Ci)	resident fraction	air fraction	radon fraction	GW1 fraction	GW2 fraction
U-238	7.7E+05		1.1E+06	≥1.0E+20	≥1.0E+20	5.8E-01	7.4E-07		5.2E-07	5.8E-21	5.8E-21
W-188	≥1.0E+20						0.0E+00				
Y-90						1.6E+01					
Zn-65						3.6E-01					
Zr-93	≥1.0E+20			≥1.0E+20	≥1.0E+20	6.4E-06	6.4E-26			6.4E-26	6.4E-26
Zr-95				≥1.0E+20	≥1.0E+20	1.1E-02				1.1E-22	1.1E-22

Table 6-2 Disposal limits for IL vaults.

nuclide	resident limit (Ci)	air limit (Ci)	radon limit (Ci)	GW1 limit (Ci)	GW2 limit (Ci)
Ac-227	1.2E+07				
Ag-108m	3.9E+04				
Al-26	6.6E+02				
Am-241	4.1E+10				7.6E+09
Am-242m	5.7E+06				
Am-243	4.4E+07				
Ba-133	1.7E+09				
Bi-207	4.3E+04				
Bk-249	8.1E+08				
C-14		4.2E+00			9.1E+07
C-14_KB		4.2E+00			2.6E+06
Cf-249	2.1E+06				1.9E+11
Cf-250	2.1E+18				
Cf-251	3.7E+08				
Cf-252	6.3E+14				
Cm-242	5.5E+11				
Cm-243	9.7E+08				
Cm-244	2.5E+17				
Cm-245	8.2E+09				4.8E+09
Cm-246	5.7E+15				
Cm-247	1.4E+06				6.8E+18
Cm-248	4.6E+09				
Co-60	8.0E+08				
Cs-137	8.3E+05				
Eu-152	8.9E+05				
Eu-154	1.6E+07				
Eu-155	1.6E+18				
H-3		1.3E+09		5.3E+09	5.5E+09
I-129				4.3E+10	4.6E-04
I-129_ETF-Carbon				1.2E+13	9.7E-02
I-129_KB					6.2E+03
K-40	1.5E+04			2.3E+19	2.0E-01
Kr-85	3.8E+10				
Na-22	1.1E+15				
Nb-94	1.3E+04				
Np-237	6.4E+06				1.5E+06
Pa-231	5.1E+05				
Pb-210	5.5E+10				
Pu-238	2.8E+09		4.2E+06		
Pu-239	3.3E+13				
Pu-240	6.4E+14				
Pu-241	1.2E+12				2.3E+11
Pu-242	5.0E+12				
Pu-244	3.7E+04				
Ra-226	1.4E+03		2.6E+00		
Ra-228	5.2E+07				
Sb-125	2.0E+16				
Se-79					1.2E+06
Sn-126	2.1E+04				
Sr-90					6.1E+11
Tc-99	7.7E+17			4.0E+19	1.3E+02
Tc-99_KB	7.7E+17				2.4E+04
Th-228	2.6E+18				
Th-229	5.3E+04				
Th-230	3.9E+03		6.8E+00		

nuclide	resident limit (Ci)	air limit (Ci)	radon limit (Ci)	GW1 limit (Ci)	GW2 limit (Ci)
Th-232	4.4E+02				
U-232	1.3E+03				
U-233	5.8E+05				
U-234	7.9E+05		1.2E+03		
U-235	2.4E+07				
U-236	9.1E+09				
U-238	7.7E+05		1.1E+06		

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7.0 CONCLUSIONS AND RECOMMENDATIONS

New disposal limits have been computed for the IL vaults based on several revisions to the PA, as noted in the Introduction. The most important changes were implementation of a 1,000 year time of compliance (1,350 for the groundwater pathway to account for uncertainty in the vault failure time), rather than 10,000 years, and consideration of additional radon precursors. Based on the IL vault inventory as of 7/2/04 and inventory limits developed herein, the largest inventory fractions are 30% for Ra-226 and the radon analysis, 11% for I-129 and the groundwater pathway, and 9% for C-14 and the air pathway. Considering that 36% of the volume is currently filled and nearly all the radon fraction is due to a single container, continued operation of the IL vault should not challenge performance objectives, assuming future disposal patterns are similar to historic use of the facility.

A significant decrease in the limits for I-129 (generic) and I-129_ETF-Carbon was speculated in the FY2003 interim measures assessment, in response to refinement of the aquifer mesh and source node definition (Wilhite and Butcher 2003). In fact, the new limits for these nuclides are only slightly lower. Because several changes were made to the groundwater analysis, a rigorous explanation for the present outcome is not possible without performing a detailed sensitivity analysis. Apparently the impact of mesh and source node refinement was less than speculated and/or other model changes compensated. Mitigating factors probably include a decrease in vertical mesh resolution and slower groundwater travel introduced in switching from the GSA/FACT model to the GSA/PORFLOW model.

Phifer (2004b) developed a preliminary estimate of infiltration through the new IL vault cover system described in the recently revised E-Area closure plan (Phifer 2004a). For expediency the HELP code analysis did not consider the potential influence of the very-low permeability IL vault on cover performance. The resulting infiltration estimate produced ponding of water above the cap in PORFLOW simulations. This behavior indicates that a more rigorous analysis of cap infiltration, explicitly incorporating the IL vault into the HELP model, is needed. A follow-up analysis of this nature is recommended as part of the PA revision scheduled for FY05.

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APPENDIX A – ADDITIONAL INFORMATION ON GROUNDWATER ANALYSIS

This appendix provides additional detail about the groundwater pathway on assorted topics, primarily for design checking and diagnostic purposes. The topics addressed are

- Vadose zone flow field results
- Implementation of new Pu chemistry
- Input parameters to transport simulations
- Method for refining the GSA/PORFLOW saturation and velocity fields
- Implementation of solubility limits for Pu and U isotopes
- Recommendations for groundwater analysis improvements
- Peak flux to the water table from PORFLOW vadose zone transport simulations
- Peak concentration and SOF results from PORFLOW aquifer transport simulations
- Plots of peak water table flux and 100 meter well concentration from PORFLOW aquifer transport simulations

Vadose model flow field results

Saturation and Darcy velocity from the vadose zone flow simulation are used as inputs to the transport calculation. Figures A-1 through A-6 below show the steady-state saturation and flow fields computed for each of 6 stages to the infiltration transient depicted in Figure 2-1: 0-25, 25-125, 125-325, 325-575, 575-1075, and 1075+ years. The left image shows flow direction and magnitudes (Darcy velocity vectors), while the right image depicts flow direction only using constant length arrows.

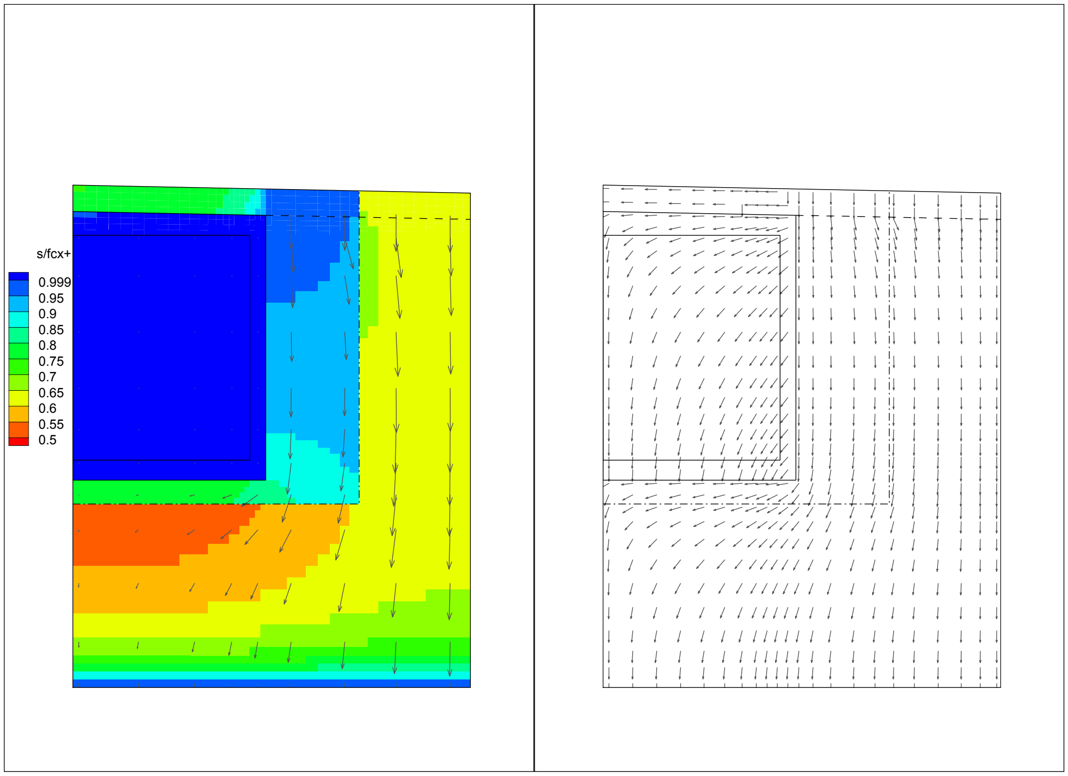


Figure A-1 Saturation and velocity fields for 0-25 years.

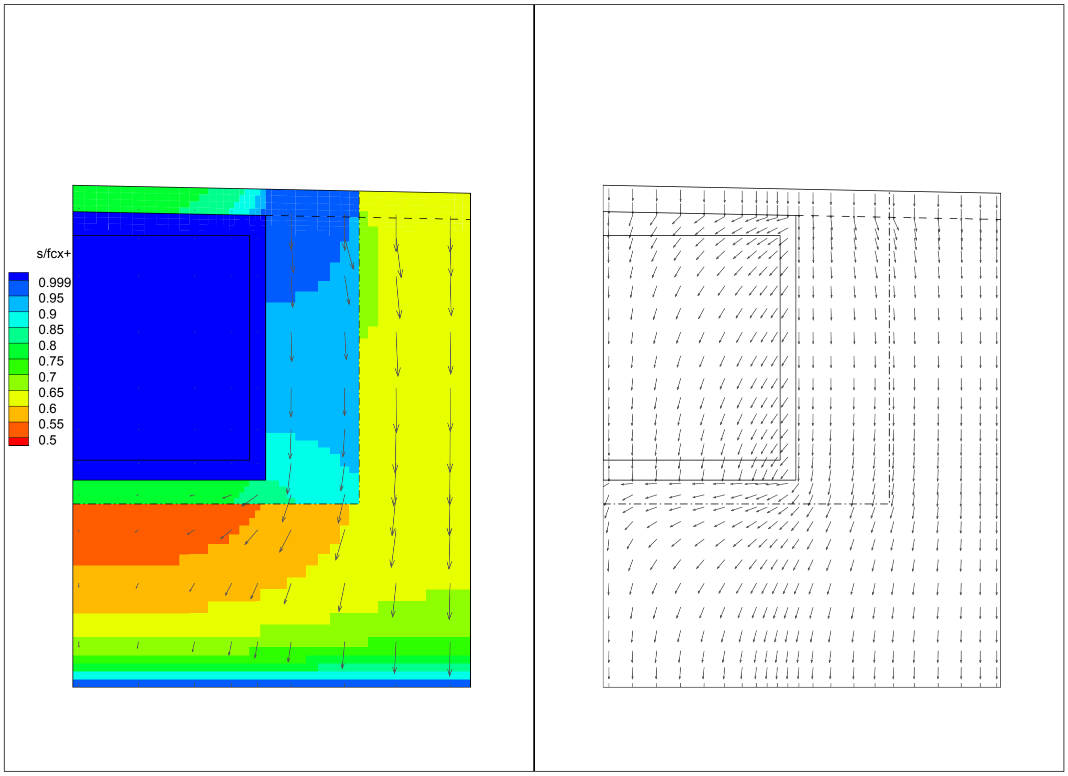


Figure A-2 Saturation and velocity fields for 25-125 years.

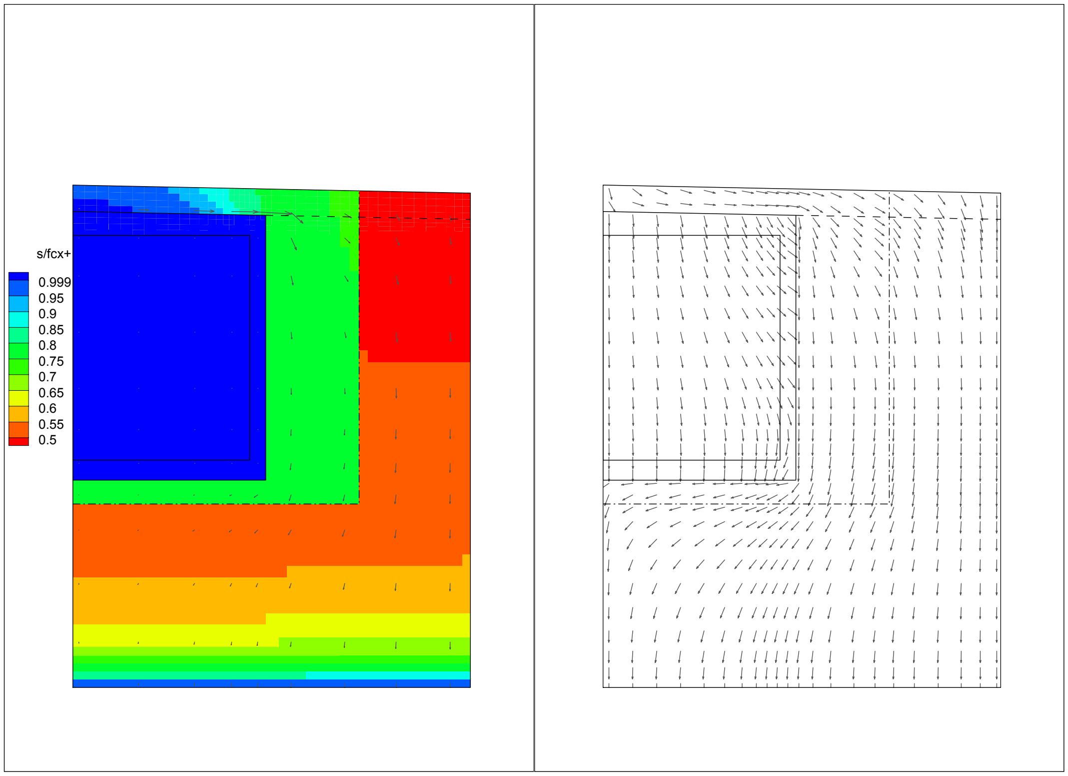


Figure A-3 Saturation and velocity fields for 125-325 years.

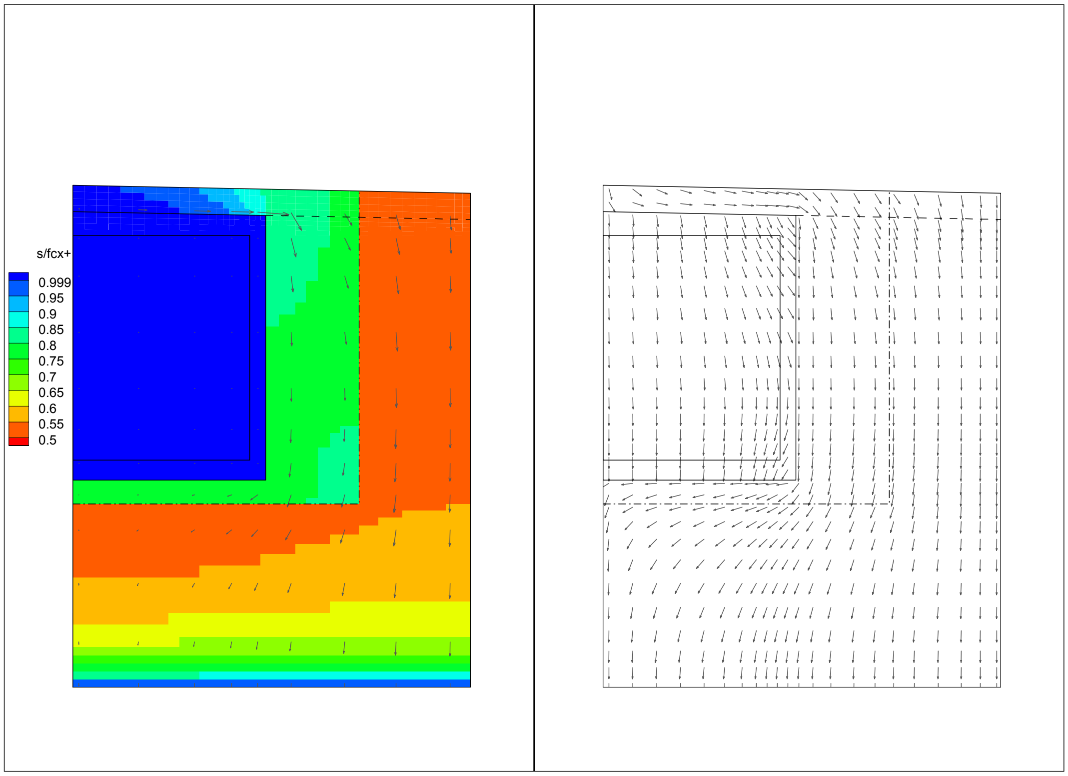


Figure A-4 Saturation and velocity fields for 325-575 years.

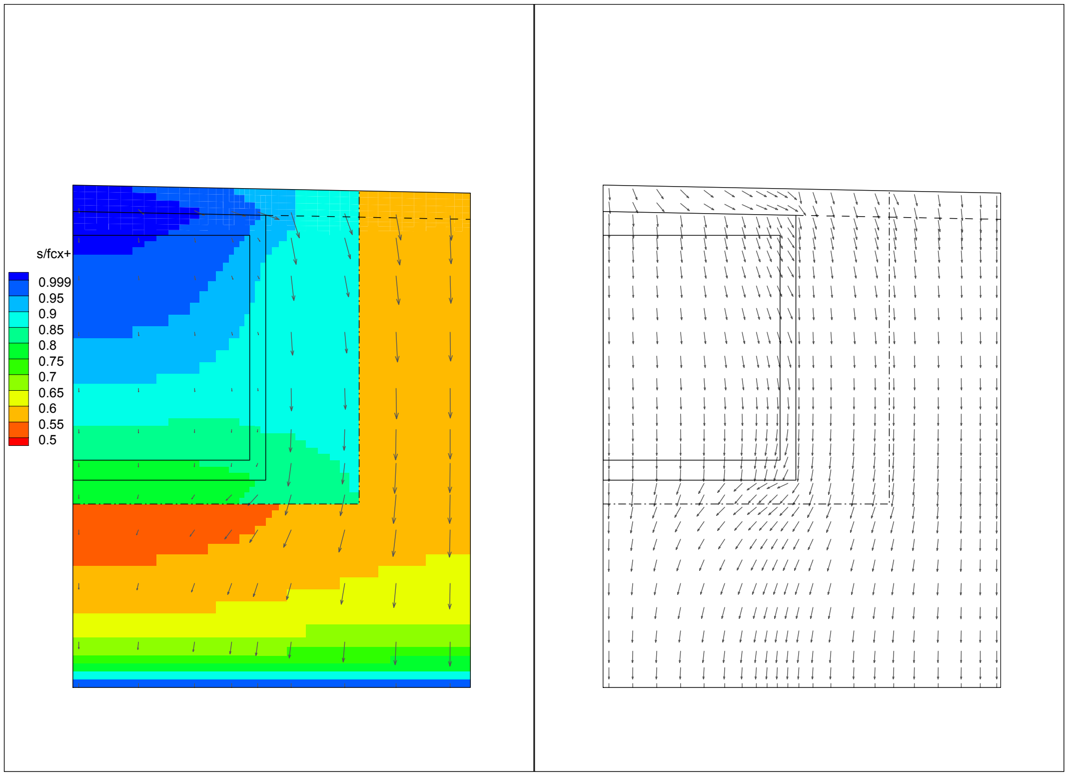


Figure A-5 Saturation and velocity fields for 575-1075 years.

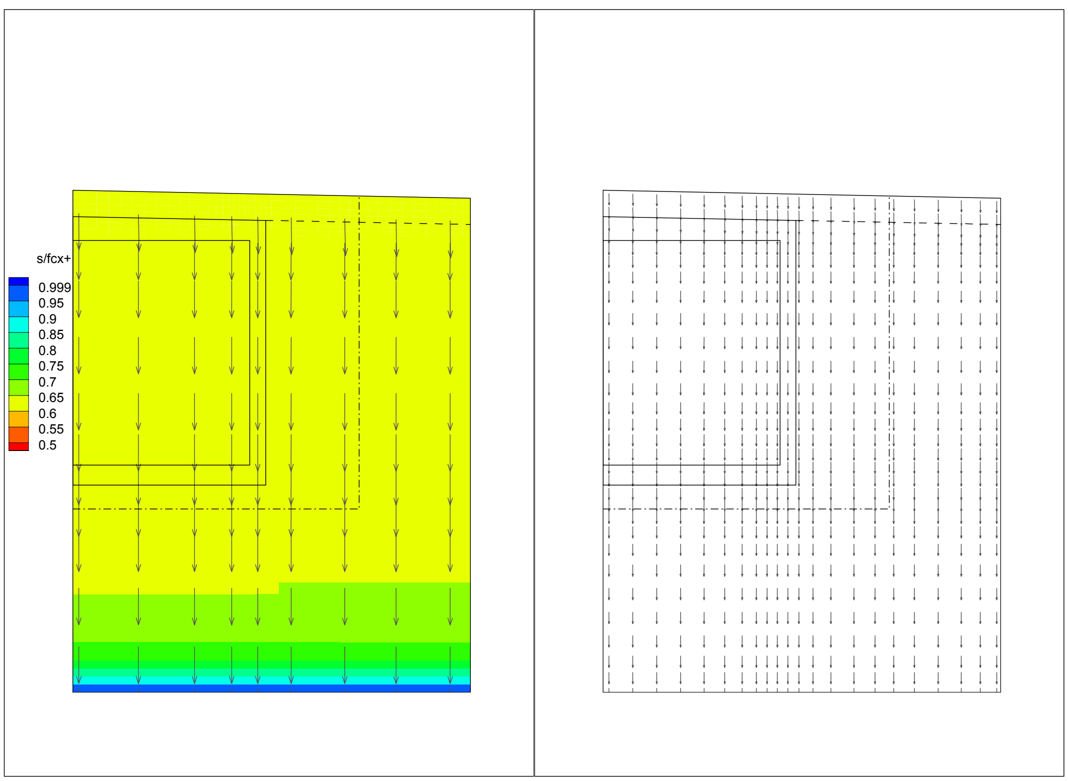


Figure A-6 Saturation and velocity fields for 1075+ years.

Implementation of new Pu chemistry

Cook (2002b) describes a new approach to modeling transport of Pu isotopes in performance assessments that accounts for the differing geochemical behavior of Pu oxidation states (III/IV) and (V/VI). Pu(V/VI) is significantly more mobile than Pu(III/IV). Kaplan (2004) subsequently updated the kinetic rates assigned to Pu(V/VI) → Pu(III/IV) reduction and Pu(III/IV) → Pu(V/VI) oxidation as 1×10^{-3} hr^{-1} (8.77 yr^{-1}) and 1.5×10^{-8} hr^{-1} (1.31×10^{-4} yr^{-1}), respectively. Cook (2002b) viewed the reduction/oxidation processes as mathematically equivalent to first-order radioactive decay/regeneration. In this section, parameters required by the PORFLOW DECAy and REGEneration keywords are derived for an arbitrary n-member system of species.

For the ith species, a mass balance in terms of moles can be written as

$$\begin{aligned}\frac{d}{dt}N_i &= -\sum_{j\neq i}\lambda_{ij}\times N_i + \sum_{j\neq i}\lambda_{ji}N_j \\ &= -\lambda_i N_i + \sum_{j\neq i}\lambda_{ji}N_j\end{aligned} \tag{A-1}$$

where λ_{ij} is the rate of conversion from species i to species j and

$$\lambda_i = \sum_{j\neq i}\lambda_{ij} \tag{A-2}$$

is the total decay rate for species i. Activity is defined by

$$A = \lambda N \tag{A-3}$$

where N is the number of nuclei. Equation (A-1) can be rewritten in terms of activity using Equation (A-3) as follows

$$\frac{d}{dt}\left(\frac{A_i}{\lambda_i}\right) = -A_i + \sum_{j\neq i}\lambda_{ji}\left(\frac{A_j}{\lambda_j}\right) \tag{A-4}$$

$$\frac{d}{dt}A_i = -\lambda_i A_i + \lambda_i\sum_{j\neq i}\left(\frac{\lambda_{ji}}{\lambda_j}\right)A_j \tag{A-5}$$

$$\frac{d}{dt}A_i = -\lambda_i A_i + \sum_{j\neq i}\left(\frac{\lambda_{ji}}{\lambda_j}\right)\left(\frac{\lambda_i}{\lambda_j}\right)\lambda_j A_j \tag{A-6}$$

$$\frac{d}{dt}A_i = -\lambda_i A_i + \sum_{j\neq i}f_{ji}\left(\frac{\lambda_i}{\lambda_j}\right)\times\lambda_j A_j \tag{A-7}$$

In Equation (A-7), f_{ji} is recognized as a "branching fraction", the fraction of decaying species j that converts to species i.

In PORFLOW parlance, the DECAy rate for the i^{th} species is

$$\lambda_i = \sum_{j\neq i}\lambda_{ij}$$

The REGEneration rate is described as the "factor to convert the decay rate of Ψ to the source for the decay product Φ". With respect to Equation (A-7), $\lambda_j A_j$ is the decay rate of species *j*. Thus

$$R_{ji} = f_{ji}\left(\frac{\lambda_i}{\lambda_j}\right) \quad \text{(A-8)}$$

is the REGEneration factor to convert the decay rate of species *j* to the source for decay product *i*. Example PORFLOW input for the chain Pu-239(III/IV), Pu-239(V/VI) and U-235 is shown below:

```
!Decay
DECAy half LIFE for C  4.326E+03 !years Pu-239
DECAy half LIFE for C2 7.907E-02 !years Pu-239_56
DECAy half LIFE for C3 7.038E+08 !years U-235
!Regeneration, activity basis
REGEneration C  from C2  1.828E-05 !Pu-239    from Pu-239_56
REGEneration C2 from C   4.489E+04 !Pu-239_56 from Pu-239
REGEneration C3 from C   1.103E-06 !U-235     from Pu-239
REGEneration C3 from C2  3.685E-16 !U-235     from Pu-239_56
```

The above values generated by a pre-processing program can be confirmed by hand-calculation as follows:

```
Pu-239(III/IV) → U-235 rate:       2.875e-5 1/yr = ln(2)/24110 yr
Pu-239(V/VI) → U-235 rate:         2.875e-5 1/yr
U-235 → decay rate:                9.846e-10 = ln(2)/7.04e+8 yr
Pu-239(III/IV)→ Pu-239(V/VI) rate: 1.315e-4 1/yr
Pu-239(V/VI)→ Pu-239(III/IV) rate: 8.766 1/yr

Pu-239(III/IV) decay rate:         1.603e-4 1/yr = 2.875e-5 + 1.315e-4
Pu-239(V/VI) decay rate:           8.766 1/yr= 2.875e-5 + 8.766

Pu-239(III/IV) halflife:           4.324e+3 yr
Pu-239(V/VI) halflife:             7.907e-2 yr

Pu-239(III/IV) → U-235 fraction:   0.179 = 2.875e-5/1.603e-4
Pu-239(III/IV) → Pu-239(V/VI) fraction: 0.820= 1.315e-4/1.603e-4
Pu-239(V/VI) → U-235 fraction:     0.000 = 2.875e-5/8.766
Pu-239(V/VI) → Pu-239(III/IV) fraction: 1.000 = 8.766/8.766

Regen Pu-239(III/IV) from Pu-239(V/VI): 1.83e-5 = 1.000*1.603e-4/8.766
Regen Pu-239(V/VI) from Pu-239(III/IV): 4.48e+4 = 0.820*8.766/1.603e-4
Regen U-235 from Pu-239(III/IV):   1.10e-6 = 0.179*9.846e-10/1.603e-4
Regen U-235 from Pu-239(V/VI):     0.000 = 0.000 ...
```

For Pu isotopes, activity as defined by equation (A-3) includes both radiological and chemical transformations, unlike the conventional definition which considers only radioactive decay. Letting λ_r denote the first-order rate of radiological decay, and λ_c the first-order rate of oxidation or reduction, equation (A-3) becomes for Pu isotopes

$$A_{r+c} = (\lambda_r + \lambda_c)N \quad \text{(A-9)}$$

compared to the conventional radiological definition of

$$A_r = \lambda_r N \tag{A-10}$$

The two definitions of activity can be related by eliminating N between the two equations

$$\frac{A_{r+c}}{\lambda_r + \lambda_c} = \frac{A_r}{\lambda_r} \tag{A-11}$$

Upon input to PORFLOW, radiological activity A_r must be converted to combined radiological and chemical activity A_{r+c} to be consistent with the new Pu chemistry model. PORFLOW outputs will be in terms of combined radiological and chemical activity, which can be reverted to the conventional radiological activity using equation (A-11).

Input parameters to transport simulations

Table A-1 lists key inputs to transport simulations, including parents analyzed, half-lives, atomic mass, concentration limits, solubility limits, K_d values and assumed decay chains.

Table A-1. Key inputs to transport calculations.

ID	Nuclide	Type	Element	Atomic number	Mass number	BNL half-life	BNL units	Half-life (yr)	Rad+Chem "Decay" rate (yr-1)	BNL atomic mass (u)	Molecular weight (g/mol)	Specific activity (Ci/g)	EPA MCL (µg/L)	EPA MCL (pCi/L)	25 mrem/yr dose	Conc. limit (pCi/L)	Solubility limit (mol/L)	Solubility limit (µg/L)	Solubility limit (pCi/L)	Solubility limit (pCi/mL)	Soil Kd (mL/g)	Corrosion Kd (mL/g)	Grouted Waste Kd (mL/g)	Gravel Kd (mL/g)	Clay Kd (mL/g)	Concrete Kd (mL/g)	ID	Progeny 1	Progeny 2	Progeny 3	Progeny 4	Progeny 5	Inventory1 (Ci)	Inventory2 (Ci)	Inventory3 (Ci)	Inventory4 (Ci)	Inventory5 (Ci)
Tracer	Tracer		Tracer	0	0	1.00E+20	yr	1.000E+20	6.931E-21	0.000	0.000	#DIV/0!				1.000E+20					0	0	0	0	0	0	Tracer						1				
H-3	H-3		H	1	3	12.33	yr	1.233E+01	5.622E-02	3.016	3.016	9.613E+03		20000	540000	20000					0	0	0	0	0	0	H-3						1				
C-14	C-14		C	6	14	5730	yr	5.730E+03	1.210E-04	14.003	14.003	4.455E+00		2000	17000	2000					2	2	5000	2	1	5000	C-14						1				
C-14_KB	C-14	KB	C	6	14	5730	yr	5.730E+03	1.210E-04	14.003	14.003	4.455E+00		2000	17000	2000					2	2	140	2	1	5000	C-14_KB						1				
K-40	K-40		K	19	40	1.28E+09	yr	1.277E+09	5.428E-10	39.964	39.964	7.005E-06		300	1800	300					3		2		5	2	K-40						1				
Co-60	Co-60		Co	27	60	1925.1	d	5.271E+00	1.315E-01	59.934	59.934	1.132E+03		100		100					8		100		96	100	Co-60						1				
Ni-59	Ni-59		Ni	28	59	76000	yr	7.600E+04	9.120E-06	58.934	58.934	7.982E-02		300	170000	300					400	1200	100	400	650	100	Ni-59						1				
Ni-63	Ni-63		Ni	28	63	100.1	yr	1.001E+02	6.925E-03	62.930	62.930	5.675E+01		50		50					400	1200	100	400	650	100	Ni-63						1				
Se-79	Se-79		Se	34	79	1100000	yr	1.100E+06	6.301E-07	78.918	78.918	4.118E-03		700	4100	700					36	170	0.1	5	76	0.1	Se-79						1				
Kr-85	Kr-85		Kr	36	85	3934.4	d	1.077E+01	6.435E-02	84.913	84.913	3.909E+02									0		0		0	0	Kr-85						1				
Sr-90	Sr-90		Sr	38	90	28.79	yr	2.879E+01	2.408E-02	89.908	89.908	1.381E+02		8	250	8					10	3	1	10	110	1	Sr-90						1				
Zr-93	Zr-93		Zr	40	93	1530000	yr	1.530E+06	4.530E-07	92.906	92.906	2.515E-03		2000	16000	2000					600	600	5000	600	3300	5000	Zr-93	Nb-93m					1				
Zr-95	Zr-95		Zr	40	95	64.02	d	1.753E-01	3.955E+00	94.908	94.908	2.149E+04		200		200					600	600	5000	600	3300	5000	Zr-95	Nb-95					1				
Nb-94	Nb-94		Nb	41	94	20300	yr	2.030E+04	3.415E-05	93.907	93.907	1.875E-01		1000	6800	1000					160	160	500	160	900	500	Nb-94						1				
Nb-95	Nb-95		Nb	41	95	34.997	d	9.582E-02	7.234E+00	94.907	94.907	3.931E+04		300		300					160	160	500	160	900	500	Nb-95						1				
Nb-93m	Nb-93m		Nb	41	93m	16.13	yr	1.613E+01	4.297E-02	92.906	92.906	2.386E+02		1000	68000	1000					160	160	500	160	900	500	Nb-93m						1				
Nb-95m	Nb-95m		Nb	41	95m	86.6	h	9.879E-03	7.016E+01	94.907	94.907	3.813E+05			3E+03	3000					160	160	500	160	900	500	Nb-95m	Nb-95					1				
Tc-99	Tc-99		Tc	43	99	211100	yr	2.111E+05	3.284E-06	98.906	98.906	1.712E-02		900	26000	900					0.1	0.1	1	0.1	0.1	1000	Tc-99						1				
Tc-99_KB	Tc-99	KB	Tc	43	99	211100	yr	2.111E+05	3.284E-06	99.906	99.906	1.695E-02		900	26000	900					0.1	0.1	810	0.1	0.1	1000	Tc-99_KB						1				
Sn-126	Sn-126		Sn	50	126	100000	yr	1.000E+05	6.931E-06	125.908	125.908	2.839E-02		300	1900	300					130	55	1000	130	670	1000	Sn-126						1				
I-129	I-129		I	53	129	15700000	yr	1.570E+07	4.415E-08	128.905	128.905	1.766E-04		1	130	1					0.6	0.6	2	0.6	1	2	I-129						1				
I-129_ETF-Carbon	I-129	ETF-Carbon	I	53	129	15700000	yr	1.570E+07	4.415E-08	128.905	128.905	1.766E-04		1	130	1					0.6	0.6	600	0.6	1	2	I-129_ETF-Carbon						1				
I-129_KB	I-129	KB	I	53	129	15700000	yr	1.570E+07	4.415E-08	128.905	128.905	1.766E-04		1	130	1					0.6	0.6	3700	0.6	1	3700	I-129_KB						1				
Cs-135	Cs-135		Cs	55	135	2300000	yr	2.300E+06	3.014E-07	134.906	134.906	1.152E-03		900	4800	900					330	330	20	330	1900	20	Cs-135						1				
Cs-137	Cs-137		Cs	55	137	30.07	yr	3.007E+01	2.305E-02	136.907	136.907	8.684E+01		200		200					330	330	20	330	1900	20	Cs-137						1				
Eu-152	Eu-152		Eu	63	152	13.516	yr	1.352E+01	5.128E-02	151.9217	151.922	1.741E+02		200		200					1900		5000		8400	5000	Eu-152						1				
Eu-154	Eu-154		Eu	63	154	8.592	yr	8.592E+00	8.067E-02	153.923	153.923	2.703E+02		60		60					1900		5000		8400	5000	Eu-154						1				
Pb-210	Pb-210		Pb	82	210	22.3	yr	2.230E+01	3.108E-02	209.984	209.984	7.634E+01		1	6.8	1					270	270	500	270	550	500	Pb-210						1				
Bi-210	Bi-210		Bi	83	210	5.013	d	1.372E-02	5.050E+01	209.984	209.984	1.240E+05			900	900					450	450	5000	450	12000	5000	Bi-210	Po-210					1				
Po-210	Po-210		Po	84	210	138.376	d	3.789E-01	1.830E+00	209.983	209.983	4.494E+03		15	21	15					150	150	500	150	3000	500	Po-210						1				
Rn-222	Rn-222		Rn	86	222	3.8235	d	1.047E-02	6.621E+01	222.018	222.018	1.538E+05				0					0		0		0	0	Rn-222						1				
Ra-223	Ra-223		Ra	88	223	11.435	d	3.131E-02	2.214E+01	223.019	223.019	5.120E+04		15	63	15					500	60	50	500	9100	50	Ra-223						1				
Ra-224	Ra-224		Ra	88	224	3.66	d	1.002E-02	6.917E+01	224.020	224.020	1.593E+05		15	93	15					500	60	50	500	9100	50	Ra-224						1				
Ra-225	Ra-225		Ra	88	225	14.9	d	4.079E-02	1.699E+01	225.024	225.024	3.894E+04		20	83	20					500	60	50	500	9100	50	Ra-225						1				
Ra-226	Ra-226		Ra	88	226	1600	yr	1.600E+03	4.332E-04	226.025	226.025	9.885E-01		5	31	5					500	60	50	500	9100	50	Ra-226	Pb-210	Po-210				1				
Ra-228	Ra-228		Ra	88	228	5.75	yr	5.750E+00	1.205E-01	228.031	228.031	2.727E+02		5	28	5					500	60	50	500	9100	50	Ra-228						1				
Ac-227	Ac-227		Ac	89	227	21.773	yr	2.177E+01	3.184E-02	227.028	227.028	7.232E+01		1	2.5	1					450	450	5000	450	2400	5000	Ac-227						1				
Th-227	Th-227		Th	90	227	18.72	d	5.125E-02	1.352E+01	227.028	227.028	3.072E+04		15	960	15					3200	2200	5000	3200	5800	5000	Th-227						1				
Th-228	Th-228		Th	90	228	1.9116	yr	1.912E+00	3.626E-01	228.029	228.029	8.201E+02		15	89	15					3200	2200	5000	3200	5800	5000	Th-228						1				
Th-229	Th-229		Th	90	229	7340	yr	7.340E+03	9.443E-05	229.032	229.032	2.127E-01		15	9.6	9.6					3200	2200	5000	3200	5800	5000	Th-229						1				
Th-230	Th-230		Th	90	230	75380	yr	7.538E+04	9.195E-06	230.033	230.033	2.062E-02		15	64	15					3200	2200	5000	3200	5800	5000	Th-230	Ra-226	Pb-210	Po-210			1				
Th-232	Th-232		Th	90	232	1.41E+10	yr	1.405E+10	4.933E-11	232.038	232.038	1.097E-07		15	13	13					3200	2200	5000	3200	5800	5000	Th-232	Ra-228	Th-228	Ra-224			1				
Th-234	Th-234		Th	90	234	24.1	d	6.598E-02	1.051E+01	234.044	234.044	2.315E+04		400	2600	400					3200	2200	5000	3200	5800	5000	Th-234						1				
Pa-231	Pa-231		Pa	91	231	32760	yr	3.276E+04	2.116E-05	231.036	231.036	4.723E-02		15	3.1	3.1					550	550	5000	550	2700	5000	Pa-231						1				
U-232	U-232		U	92	232	68.9	yr	6.890E+01	1.006E-02	232.037	232.037	2.236E+01	30	6.71E+08	26	26	3.00E-10	6.96E-02	1.56E+06	1.56E+03	800	6000	2000	800	1600	2000	U-232	Th-228	Ra-224				0.001	0.01	0.1	1	
U-233	U-233		U	92	233	159200	yr	1.592E+05	4.354E-06	233.040	233.040	9.636E-03	30	2.89E+05	130	130	3.00E-10	6.99E-02	6.74E+02	6.74E-01	800	6000	2000	800	1600	2000	U-233	Th-229	Ra-225				0.001	0.01	0.1	1	
U-234	U-234		U	92	234	245500	yr	2.455E+05	2.823E-06	234.041	234.041	6.222E-03	30	1.87E+05	130	130	3.00E-10	7.02E-02	4.37E+02	4.37E-01	800	6000	2000	800	1600	2000	U-234	Th-230	Ra-226	Pb-210	Po-210		0.001	0.01	0.1	1	
U-235	U-235		U	92	235	7.04E+08	yr	7.038E+08	9.849E-10	235.044	235.044	2.161E-06	30	64.8	140	65	3.00E-10	7.05E-02	1.52E-01	1.52E-04	800	6000	2000	800	1600	2000	U-235	Pa-231	Ac-227	Th-227	Ra-223		0.001	0.01	0.1	1	
U-236	U-236		U	92	236	23420000	yr	2.342E+07	2.960E-08	236.046	236.046	6.467E-05	30	1940	140	140	3.00E-10	7.08E-02	4.58E+00	4.58E-03	800	6000	2000	800	1600	2000	U-236						0.001	0.01	0.1	1	
U-238	U-238		U	92	238	4.47E+09	yr	4.468E+09	1.551E-10	238.051	238.051	3.361E-07	30	10.1	150	10.1	3.00E-10	7.14E-02	2.40E-02	2.40E-05	800	6000	2000	800	1600	2000	U-238	Th-234	U-234				0.001	0.01	0.1	1	
Np-237	Np-237		Np	93	237	2144000	yr	2.144E+06	3.233E-07	237.048	237.048	7.034E-04		15	8.9	8.9					5	750	5000	5	55	5000	Np-237						1				
Np-239	Np-239		Np	93	239	2.3565	yr	2.357E+00	2.941E-01	239.053	239.053	6.346E+02		300	12000	300					5	750	5000	5	55	5000	Np-239						1				
Pu-238_3456	Pu-238	3456	Pu	94	238	87.7	yr	8.770E+01	7.904E-03	238.050	238.050	1.712E+01		15	8.9	8.9	4.40E-13	1.05E-04	1.79E+03	1.79E+00							Pu-238_3456						1				
Pu-238	Pu-238		Pu	94	238	87.7	yr	8.770E+01	8.035E-03	238.050	238.050	1.741E+01				9.048E+00	4.40E-13	1.05E-04	1.82E+03	1.82E+00	370		100		6500	5000	Pu-238	Pu-238_56	U-234				0.001	0.01	0.1	1	10
Pu-238_56	Pu-238	56	Pu	94	238	87.7	yr	8.770E+01	8.774E+00	238.050	238.050	1.901E+04				9.880E+03	4.40E-13	1.05E-04	1.99E+06	1.99E+03	15		100		50	5000	Pu-238_56						1				
Pu-239_3456	Pu-239	3456	Pu	94	239	24110	yr	2.411E+04	2.875E-05	239.052	239.052	6.203E-02		15	8.1	8.1	4.40E-13	1.05E-04	6.52E+00	6.52E-03							Pu-239_3456						1				
Pu-239	Pu-239		Pu	94	239	24110	yr	2.411E+04	1.602E-04	239.052	239.052	3.457E-01				4.515E+01	4.40E-13	1.05E-04	3.64E+01	3.64E-02	370		100		6500	5000	Pu-239	Pu-239_56	U-235				0.001	0.01	0.1	1	
Pu-239_56	Pu-239	56	Pu	94	239	24110	yr	2.411E+04	8.766E+00	239.052	239.052	1.891E+04				2.470E+06	4.40E-13	1.05E-04	1.99E+06	1.99E+03	15		100		50	5000	Pu-239_56						1				
Pu-240_3456	Pu-240	3456	Pu	94	240	6564	yr	6.564E+03	1.056E-04	240.054	240.054	2.269E-01		15	8.1	8.1	4.40E-13	1.06E-04	2.40E+01	2.40E-02							Pu-240_3456						1				
Pu-240	Pu-240		Pu	94	240	6564	yr	6.564E+03	2.371E-04	240.054	240.054	5.094E-01				1.819E+01	4.40E-13	1.06E-04	5.38E+01	5.38E-02	370		100		6500	5000	Pu-240	Pu-240_56	U-236				0.001	0.01	0.1	1	
Pu-240_56	Pu-240	56	Pu	94	240	6564	yr	6.564E+03	8.766E+00	240.054	240.054	1.883E+04				6.724E+05	4.40E-13	1.06E-04	1.99E+06	1.99E+03	15		100		50	5000	Pu-240_56						1				
Pu-241_3456	Pu-241	3456	Pu	94	241	14.29	yr	1.429E+01	4.851E-02	241.057	241.057	1.038E+02		300	400	300	4.40E-13	1.06E-04	1.10E+04	1.10E+01							Pu-241_3456						1				
Pu-241	Pu-241		Pu	94	241	14.29	yr	1.429E+01	4.864E-02	241.057	241.057	1.041E+02				3.008E+02	4.40E-13	1.06E-04	1.10E+04	1.10E+01	370		100		6500	5000	Pu-241	Pu-241_56	Am-241	Np-237			1				
Pu-241_56	Pu-241	56	Pu	94	241	14.29	yr	1.429E+01	8.815E+00	241.057	241.057	1.886E+04				5.452E+04	4.40E-13	1.06E-04	2.00E+06	2.00E+03	15		100		50	5000	Pu-241_56						1				
Pu-242_3456	Pu-242	3456	Pu	94	242	373300	yr	3.733E+05	1.857E-06	242.059	242.059	3.956E-03		15	8.3	8.3	4.40E-13	1.07E-04	4.21E-01	4.21E-04							Pu-242_3456						1				
Pu-242	Pu-242		Pu	94	242	373300	yr	3.733E+05	1.333E-04	242.059	242.059	2.841E-01				5.961E+02	4.40E-13	1.07E-04	3.03E+01	3.03E-02	370		100		6500	5000	Pu-242	Pu-242_56	U-238				0.001	0.01	0.1	1	
Pu-242_56	Pu-242	56	Pu	94	242	373300	yr	3.733E+05	8.766E+00	242.059	242.059	1.868E+04				3.918E+07	4.40E-13	1.07E-04	1.99E+06	1.99E+03	15		100		50	5000	Pu-242_56						1				
Pu-244_3456	Pu-244	3456	Pu	94	244	80000000	yr	8.000E+07	8.664E-09	244.064	244.064	1.831E-05		15	8.6	8.6	4.40E-13	1.07E-04	1.97E-03	1.97E-06							Pu-244_3456						1				
Pu-244	Pu-244		Pu	94	244	80000000	yr	8.000E+07	1.315E-04	244.064	244.064	2.779E-01				1.305E+05	4.40E-13	1.07E-04	2.98E+01	2.98E-02	370		100		6500	5000	Pu-244	Pu-244_56					0.001	0.01	0.1	1	
Pu-244_56	Pu-244	56	Pu	94	244	80000000	yr	8.000E+07	8.766E+00	244.064	244.064	1.852E+04				8.701E+09	4.40E-13	1.07E-04	1.99E+06	1.99E+03	15		100		50	5000	Pu-244_56						1				
Pu-All_Colloid	Pu-All	Colloid	Pu	94	All																0	0	0	0	0	0	Pu-All_Colloid						1				
Am-241	Am-241		Am	95	241	432.2	yr	4.322E+02	1.604E-03	241.057	241.057	3.431E+00		15	7.6	7.6					1900	3700	5000	1900	8400	5000	Am-241	Np-237					1				
Am-243	Am-243		Am	95	243	7370	yr	7.370E+03	9.405E-05	243.061	243.061	1.996E-01		15	7.6	7.6					1900	3700	5000	1900	8400	5000	Am-243	Pu-239	Pu-239_56	U-234			0.001	0.01	0.1	1	
Am-242m	Am-242m		Am	95	242m	141	yr	1.410E+02	4.916E-03	242.060	242.060	1.047E+01		1		1					1900	3700	5000	1900	8400	5000	Am-242m						1				
Cm-242	Cm-242		Cm	96	242	162.8	d	4.457E-01	1.555E+00	242.059	242.059	3.313E+03		15		15					4000	3700	5000	4000	6000	5000	Cm-242	Pu-238	Pu-238_56	U-234			1				
Cm-243	Cm-243		Cm	96	243	29.1	yr	2.910E+01	2.382E-02	243.061	243.061	5.054E+01		15		15					4000	3700	5000	4000	6000	5000	Cm-243						1				
Cm-244	Cm-244		Cm	96	244	18.1	yr	1.810E+01	3.830E-02	244.063	244.063	8.093E+01		15	17	15					4000	3700	5000	4000	6000	5000	Cm-244	Pu-240	Pu-240_56	U-236			1				
Cm-245	Cm-245		Cm	96	245	8500	yr	8.500E+03	8.155E-05	245.065	245.065	1.716E-01		15	7.6	7.6					4000	3700	5000	4000	6000	5000	Cm-245	Pu-241	Pu-241_56	Am-241	Np-237		0.001	0.01	0.1	1	
Cm-246	Cm-246		Cm	96	246	4760	yr	4.760E+03	1.456E-04	246.067	246.067	3.052E-01		15	7.6	7.6					4000	3700	5000	4000	6000	5000	Cm-246						1				
Cm-247	Cm-247		Cm	96	247	15600000	yr	1.560E+07	4.443E-08	247.070	247.070	9.275E-05		15	8.3	8.3					4000	3700	5000	4000	6000	5000	Cm-247	Am-243	Np-239	Pu-239	Pu-239_56		0.001	0.01	0.1	1	
Cm-248	Cm-248		Cm	96	248	348000	yr	3.480E+05	1.992E-06	248.072	248.072	4.141E-03		15	2.1	2.1					4000	3700	5000	4000	6000	5000	Cm-248	Pu-244	Pu-244_56				0.001	0.01	0.1	1	
Cf-249	Cf-249		Cf	98	249	351	yr	3.510E+02	1.975E-03	249.075	249.075	4.089E+00		15	7.4	7.4					510	3700	5000	510	8400	5000	Cf-249	Cm-245	Pu-241	Pu-241_56	Am-241	Np-237	0.001	0.01	0.1	1	
Cf-251	Cf-251		Cf	98	251	898	yr	8.980E+02	7.719E-04	251.080	251.080	1.586E+00		15		15					510	3700	5000	510	8400	5000	Cf-251						1				
Cf-252	Cf-252		Cf	98	252	2.645	yr	2.645E+00	2.621E-01	252.082	252.082	5.362E+02		15	36	15					510	3700	5000	510	8400	5000	Cf-252	Cm-248	Pu-244	Pu-244_56			1				

Method for refining the GSA/PORFLOW saturation and velocity fields

Inputs to the PORFLOW saturated zone solute transport model include water saturation and Darcy velocity fields. Rather than develop a fine-scale flow model of the IL vault area, we chose to refine the steady-state saturation and velocity fields previously computed for the entire General Separations Area using PORFLOW (Flach 2004). Mesh refinement was performed by defining a sub-zone of grid blocks surrounding the IL vaults, and uniformly dividing these into an integer number of smaller blocks. The refined mesh has a footprint as indicated in Figure A-7. The resolution is 50 ft in the horizontal plane. No refinement was made to the vertical mesh. Under current plans a second IL vault will be constructed at footprint #5, 150 ft away from the existing vault (cf. drawing W2017860 and Appendix B). However, adjoining IL footprints are modeled as a conservatism.

Cells in the refined mesh are assigned the saturation value of the parent coarse-mesh cell in which they reside. The resulting saturation field retains the coarseness of that computed from the GSA/PORFLOW model, but this attribute is of little consequence because plume migration occurs below the water table where cells are 100% saturated.

The Darcy velocity field computed from the GSA/PORFLOW model is in the form of volumetric flowrates defined at faces between adjoining cells (“FC” variable). For steady-state and constant properties, flowrates across the six faces of a cell satisfy the mass balance

$$FC_{X-} - FC_{X+} + FC_{Y-} - FC_{Y+} + FC_{Z-} - FC_{Z+} = 0 \qquad \text{(A-12)}$$

where flow in the positive coordinate direction is positive. In developing an interpolation scheme to transfer flowrates from the coarse-mesh to the refined-mesh, each face flow is assumed to be uniformly distributed across its face. The flowrate across an arbitrary plane perpendicular to the X-axis and within the cell of interest can be written

$$FC_X = FC_{X-} + \xi(FC_{Y-} - FC_{Y+} + FC_{Z-} - FC_{Z+}) \qquad \text{(A-13)}$$

where

$$\xi = \frac{x - x^-}{x^+ - x^-} \qquad \text{(A-14)}$$

ranges between 0 and 1. Letting ny and nz denote the number of subdivisions in the Y and Z directions, a coarse-mesh X face is comprised of $ny \cdot nz$ faces in the refined mesh. The flowrate across each of these smaller faces at position ξ becomes

$$fc_X = \frac{FC_X}{ny \cdot nz} \qquad \text{(A-15)}$$

Similar expressions can be written for the other two coordinate directions.

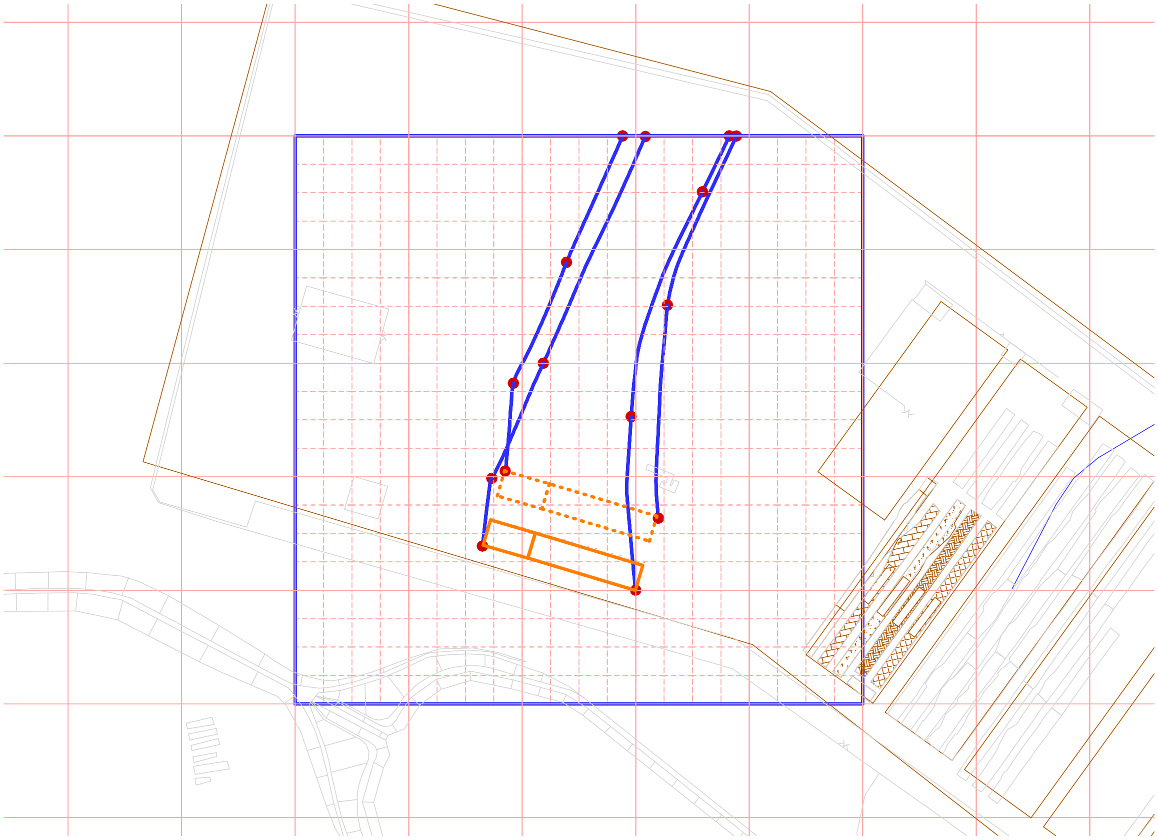


Figure A-7 Mesh refinement for IL vault Special Analysis.

Implementation of solubility limits for Pu and U isotopes in PORFLOW

Solubility controls are implemented in the IL vault waste zone using the DISTribution keyword in PORFLOW. Mode 3 of the command allows the user to specify a table of solid and liquid concentration pairs, which defines the radionuclide distribution between the two phases. Typically PORFLOW uses linear interpolation of TABLe values, in which case 3 pairs would be sufficient to describe a linear soil-solute distribution with a solubility cutoff:

$$(0,0)$$

$$(K_d C_{sol}, C_{sol})$$

$$(\infty, C_{sol})$$

where K_d is the soil-solute distribution coefficient and C_{sol} is the liquid solubility limit. However, PORFLOW apparently uses step-wise interpolation in connection with this mode. To mimic the desired variation below the solubility limit across several orders of magnitude, a large number (2000-3000) of additional points are added between the first two points listed above. Adjacent points in the series differ by 1%.

Inspection of the results for Pu-244 revealed that significant numerical inaccuracies occur when the initial inventory exceeds that required to produce the solubility limit by four or more orders of magnitude. For Pu-244, the four inventories considered in PORFLOW simulations range from 2 to 5 times that required to achieve the solubility limit. All four runs should produce the same groundwater concentration, yet the latter two runs produced noticeably higher values. A diagnostic run was performed using the SOLUbility limited SOURce keyword and omitting the DISTribution command. The results from the diagnostic case were close to those from the baseline runs at the lower initial inventories.

The inaccuracy described above is much less significant for the other Pu nuclides and U isotopes. In all cases, the limits derived from peak groundwater concentration results are not impacted. The inaccuracy produces a higher $1/SOF$ value and the minimum value is used to define the limit.

Recommendations for groundwater analysis improvements

A number of modifications to the groundwater analysis should be considered for implementation in the upcoming PA revision

- if numerically feasible, combine the vadose zone and aquifer zone simulations to avoid having to perform and design check two PORFLOW analyses and the handshaking between the vadose zone flux and aquifer source node placement
- simplify implementation of the Pu chemistry model by performing PORFLOW simulations in terms of moles and instead of activity; this avoids the overhead and potential confusion in converting between radiological activity and combined radiological and chemical activity
- use the solubility-limited source keyword command in PORFLOW to implement solubility limits for parents; this avoids apparent numerical inaccuracies discussed above

Peak flux to the water table from PORFLOW vadose zone transport simulations

For each parent and inventory modeled with PORFLOW, Table A-2 provides the peak flux (Ci/yr) to the water table for each member of the modeled chain. Also included in the table are the time the peak occurred, and the fractional flux (flux divided by the disposal unit inventory).

Table A-2. Peak water table flux results.

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
Tracer	1	0.5	627	2.51E-02	2.51E-02
H-3	1	0.5	96	2.98E-11	2.98E-11
C-14	1	0.5	10000	7.11E-07	7.11E-07
C-14_KB	1	0.5	8897	1.79E-05	1.79E-05
K-40	1	0.5	1152	1.22E-02	1.22E-02
Ni-59	1	0.5	10000	1.71E-04	1.71E-04
Se-79	1	0.5	1745	2.41E-03	2.41E-03
Sr-90	1	0.5	1203	1.13E-15	1.13E-15
Zr-93	1	0.5	10000	2.58E-09	2.58E-09
Nb-93m			10000	1.06E-08	1.06E-08
Zr-95	1	0.5	7	6.96E-123	6.96E-123
Nb-95			4	3.17E-112	3.17E-112
Nb-94	1	0.5	8067	5.15E-05	5.15E-05
Nb-95	1	0.5	4	1.36E-112	1.36E-112
Tc-99	1	0.5	2773	2.88E-04	2.88E-04
Tc-99_KB	1	0.5	9645	4.14E-05	4.14E-05
Sn-126	1	0.5	10000	3.14E-05	3.14E-05
I-129	1	0.5	1105	1.46E-02	1.46E-02
I-129_ET	1	0.5	1127	6.22E-05	6.22E-05
I-129_KB	1	0.5	10000	4.99E-06	4.99E-06
Cs-135	1	0.5	7865	2.73E-04	2.73E-04
Po-210	1	0.5	14	2.59E-96	2.59E-96
Ra-226	1	0.5	9965	1.66E-06	1.66E-06
Pb-210			9937	3.15E-06	3.15E-06
Po-210			9936	5.68E-06	5.68E-06
Th-228	1	0.5	72	1.54E-112	1.54E-112
Th-230	1	0.5	10000	4.86E-21	4.86E-21
Ra-226			10000	3.30E-06	3.30E-06
Pb-210			10000	6.32E-06	6.32E-06
Po-210			10000	1.14E-05	1.14E-05
Th-232	1	0.5	10000	5.33E-21	5.33E-21
Ra-228			10000	3.85E-20	3.85E-20
Th-228			10000	6.01E-21	6.01E-21
Ra-224			10000	3.85E-20	3.85E-20
U-232	0.001	0.0005	3273	1.25E-38	1.25E-35
Th-228			3275	3.15E-39	3.15E-36

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
Ra-224			3275	2.02E-38	2.02E-35
U-232	0.01	0.005	3310	1.59E-37	1.59E-35
Th-228			3312	4.00E-38	4.00E-36
Ra-224			3312	2.56E-37	2.56E-35
U-232	0.1	0.05	3316	1.61E-36	1.61E-35
Th-228			3318	4.06E-37	4.06E-36
Ra-224			3318	2.60E-36	2.60E-35
U-232	1	0.5	3317	1.61E-35	1.61E-35
Th-228			3319	4.06E-36	4.06E-36
Ra-224			3319	2.60E-35	2.60E-35
U-233	0.001	0.0005	10000	2.28E-12	2.28E-09
Th-229			10000	3.73E-14	3.73E-11
Ra-225			10000	2.39E-13	2.39E-10
U-233	0.01	0.005	10000	2.28E-11	2.28E-09
Th-229			10000	3.73E-13	3.73E-11
Ra-225			10000	2.38E-12	2.38E-10
U-233	0.1	0.05	10000	2.28E-10	2.28E-09
Th-229			10000	3.73E-12	3.73E-11
Ra-225			10000	2.38E-11	2.38E-10
U-233	1	0.5	10000	2.28E-09	2.28E-09
Th-229			10000	3.73E-11	3.73E-11
Ra-225			10000	2.39E-10	2.39E-10
U-234	0.001	0.0005	10000	2.32E-12	2.32E-09
Th-230			10000	3.90E-15	3.90E-12
Ra-226			10000	5.66E-11	5.66E-08
Pb-210			10000	1.09E-10	1.09E-07
Po-210			10000	1.97E-10	1.97E-07
U-234	0.01	0.005	10000	2.32E-11	2.32E-09
Th-230			10000	3.91E-14	3.91E-12
Ra-226			10000	5.66E-10	5.66E-08
Pb-210			10000	1.09E-09	1.09E-07
Po-210			10000	1.97E-09	1.97E-07
U-234	0.1	0.05	10000	2.32E-10	2.32E-09
Th-230			10000	3.91E-13	3.91E-12
Ra-226			10000	5.66E-09	5.66E-08
Pb-210			10000	1.09E-08	1.09E-07
Po-210			10000	1.97E-08	1.97E-07

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
U-234	1	0.5	10000	2.32E-09	2.32E-09
Th-230			10000	3.91E-12	3.91E-12
Ra-226			10000	5.66E-08	5.66E-08
Pb-210			10000	1.09E-07	1.09E-07
Po-210			10000	1.97E-07	1.97E-07
U-235	0.001	0.0005	10000	2.39E-12	2.39E-09
Pa-231			10000	6.66E-12	6.66E-09
Ac-227			10000	8.23E-12	8.23E-09
Th-227			10000	1.16E-12	1.16E-09
Ra-223			10000	7.41E-12	7.41E-09
U-235	0.01	0.005	10000	1.97E-11	1.97E-09
Pa-231			10000	5.52E-11	5.52E-09
Ac-227			10000	6.82E-11	6.82E-09
Th-227			10000	9.59E-12	9.59E-10
Ra-223			10000	6.14E-11	6.14E-09
U-235	0.1	0.05	10000	1.98E-11	1.98E-10
Pa-231			10000	7.13E-11	7.13E-10
Ac-227			10000	8.80E-11	8.80E-10
Th-227			10000	1.24E-11	1.24E-10
Ra-223			10000	7.92E-11	7.92E-10
U-235	1	0.5	10000	1.98E-11	1.98E-11
Pa-231			10000	2.30E-10	2.30E-10
Ac-227			10000	2.84E-10	2.84E-10
Th-227			10000	4.00E-11	4.00E-11
Ra-223			10000	2.56E-10	2.56E-10
U-236	0.001	0.0005	10000	2.39E-12	2.39E-09
U-236	0.01	0.005	10000	2.39E-11	2.39E-09
U-236	0.1	0.05	10000	2.39E-10	2.39E-09
U-236	1	0.5	10000	5.96E-10	5.96E-10
U-238	0.001	0.0005	10000	2.39E-12	2.39E-09
Th-234			10000	5.97E-13	5.97E-10
U-234			10000	6.66E-14	6.66E-11
U-238	0.01	0.005	10000	3.12E-12	3.12E-10
Th-234			10000	7.81E-13	7.81E-11
U-234			10000	1.77E-13	1.77E-11
U-238	0.1	0.05	10000	3.12E-12	3.12E-11
Th-234			10000	7.81E-13	7.81E-12

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
U-234			10000	1.11E-12	1.11E-11
U-238	1	0.5	10000	3.12E-12	3.12E-12
Th-234			10000	7.81E-13	7.81E-13
U-234			10000	1.04E-11	1.04E-11
Np-237	1	0.5	10000	2.35E-06	2.35E-06
Pu-238	0.001	0.0005	3499	5.61E-29	5.61E-26
Pu-238_5			3497	2.09E-32	2.09E-29
U-234			10000	8.34E-16	8.34E-13
Pu-238	0.01	0.005	3499	5.61E-28	5.61E-26
Pu-238_5			3497	2.09E-31	2.09E-29
U-234			10000	8.33E-15	8.33E-13
Pu-238	0.1	0.05	3499	5.61E-27	5.61E-26
Pu-238_5			3497	2.09E-30	2.09E-29
U-234			10000	8.32E-14	8.32E-13
Pu-238	1	0.5	3499	5.61E-26	5.61E-26
Pu-238_5			3497	2.09E-29	2.09E-29
U-234			10000	8.32E-13	8.32E-13
Pu-238	10	5	3499	5.61E-25	5.61E-26
Pu-238_5			3497	2.09E-28	2.09E-29
U-234			10000	8.31E-12	8.31E-13
Pu-239	0.001	0.0005	10000	3.75E-09	3.75E-06
Pu-239_5			10000	1.37E-12	1.37E-09
U-235			10000	3.13E-15	3.13E-12
Pu-239	0.01	0.005	10000	3.75E-08	3.75E-06
Pu-239_5			10000	1.37E-11	1.37E-09
U-235			10000	3.13E-14	3.13E-12
Pu-239	0.1	0.05	10000	7.26E-08	7.26E-07
Pu-239_5			10000	2.65E-11	2.65E-10
U-235			10000	5.98E-14	5.98E-13
Pu-239	1	0.5	10000	7.26E-08	7.26E-08
Pu-239_5			10000	2.65E-11	2.65E-11
U-235			10000	6.31E-14	6.31E-14
Pu-240	0.001	0.0005	10000	1.74E-09	1.74E-06
Pu-240_5			10000	6.34E-13	6.34E-10
U-236			10000	4.95E-14	4.95E-11
Pu-240	0.01	0.005	10000	1.74E-08	1.74E-06
Pu-240_5			10000	6.34E-12	6.34E-10

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
U-236			10000	4.95E-13	4.95E-11
Pu-240	0.1	0.05	10000	1.42E-07	1.42E-06
Pu-240_5			10000	5.17E-11	5.17E-10
U-236			10000	3.95E-12	3.95E-11
Pu-240	1	0.5	10000	1.44E-07	1.44E-07
Pu-240_5			10000	5.24E-11	5.24E-11
U-236			10000	4.06E-12	4.06E-12
Pu-242	0.001	0.0005	10000	4.91E-09	4.91E-06
Pu-242_5			10000	1.79E-12	1.79E-09
U-238			10000	6.19E-16	6.19E-13
Pu-242	0.01	0.005	10000	5.82E-09	5.82E-07
Pu-242_5			10000	2.12E-12	2.12E-10
U-238			10000	7.30E-16	7.30E-14
Pu-242	0.1	0.05	10000	5.83E-09	5.83E-08
Pu-242_5			10000	2.12E-12	2.12E-11
U-238			10000	7.83E-16	7.83E-15
Pu-242	1	0.5	10000	5.90E-09	5.90E-09
Pu-242_5			10000	2.15E-12	2.15E-12
U-238			10000	1.32E-15	1.32E-15
Pu-244	0.001	0.0005	10000	2.76E-11	2.76E-08
Pu-244_5			10000	1.01E-14	1.01E-11
Pu-244	0.01	0.005	10000	2.83E-11	2.83E-09
Pu-244_5			10000	1.03E-14	1.03E-12
Pu-244	0.1	0.05	10000	3.53E-11	3.53E-10
Pu-244_5			10000	1.29E-14	1.29E-13
Pu-244	1	0.5	10000	5.50E-11	5.50E-11
Pu-244_5			10000	2.01E-14	2.01E-14
Am-243	0.001	0.0005	10000	4.69E-20	4.69E-17
Pu-239			10000	2.04E-10	2.04E-07
Pu-239_5			10000	7.42E-14	7.42E-11
U-234			10000	4.47E-13	4.47E-10
Am-243	0.01	0.005	10000	4.69E-19	4.69E-17
Pu-239			10000	2.04E-09	2.04E-07
Pu-239_5			10000	7.42E-13	7.42E-11
U-234			10000	4.47E-12	4.47E-10
Am-243	0.1	0.05	10000	4.69E-18	4.69E-17
Pu-239			10000	2.04E-08	2.04E-07

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
Pu-239_5			10000	7.43E-12	7.43E-11
U-234			10000	4.47E-11	4.47E-10
Am-243	1	0.5	10000	4.69E-17	4.69E-17
Pu-239			10000	7.85E-08	7.85E-08
Pu-239_5			10000	2.86E-11	2.86E-11
U-234			10000	1.82E-10	1.82E-10
Cm-245	0.001	0.0005	10000	2.49E-26	2.49E-23
Pu-241			10000	5.46E-25	5.46E-22
Pu-241_5			10000	3.86E-26	3.86E-23
Am-241			10000	1.40E-23	1.40E-20
Np-237			10000	6.57E-12	6.57E-09
Cm-245	0.01	0.005	10000	2.49E-25	2.49E-23
Pu-241			10000	5.46E-24	5.46E-22
Pu-241_5			10000	3.86E-25	3.86E-23
Am-241			10000	1.40E-22	1.40E-20
Np-237			10000	6.57E-11	6.57E-09
Cm-245	0.1	0.05	10000	2.49E-24	2.49E-23
Pu-241			10000	5.46E-23	5.46E-22
Pu-241_5			10000	3.86E-24	3.86E-23
Am-241			10000	1.40E-21	1.40E-20
Np-237			10000	6.57E-10	6.57E-09
Cm-245	1	0.5	10000	2.49E-23	2.49E-23
Pu-241			10000	5.46E-22	5.46E-22
Pu-241_5			10000	3.86E-23	3.86E-23
Am-241			10000	1.40E-20	1.40E-20
Np-237			10000	6.57E-09	6.57E-09
Cm-246	1	0.5	10000	1.31E-23	1.31E-23
Cm-247	0.001	0.0005	10000	5.64E-26	5.64E-23
Am-243			10000	1.75E-20	1.75E-17
Np-239			10000	4.20E-14	4.20E-11
Pu-239			10000	2.49E-11	2.49E-08
Pu-239_5			10000	9.07E-15	9.07E-12
Cm-247	0.01	0.005	10000	5.64E-25	5.64E-23
Am-243			10000	1.75E-19	1.75E-17
Np-239			10000	4.20E-13	4.20E-11
Pu-239			10000	2.49E-10	2.49E-08
Pu-239_5			10000	9.07E-14	9.07E-12

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
Cm-247	0.1	0.05	10000	5.64E-24	5.64E-23
Am-243			10000	1.75E-18	1.75E-17
Np-239			10000	4.20E-12	4.20E-11
Pu-239			10000	2.49E-09	2.49E-08
Pu-239_5			10000	9.07E-13	9.07E-12
Cm-247	1	0.5	10000	5.64E-23	5.64E-23
Am-243			10000	1.75E-17	1.75E-17
Np-239			10000	4.20E-11	4.20E-11
Pu-239			10000	2.47E-08	2.47E-08
Pu-239_5			10000	9.01E-12	9.01E-12
Cm-248	0.001	0.0005	10000	5.53E-26	5.53E-23
Pu-244			10000	8.81E-14	8.81E-11
Pu-244_5			10000	3.21E-17	3.21E-14
Cm-248	0.01	0.005	10000	5.53E-25	5.53E-23
Pu-244			10000	8.81E-13	8.81E-11
Pu-244_5			10000	3.21E-16	3.21E-14
Cm-248	0.1	0.05	10000	5.53E-24	5.53E-23
Pu-244			10000	8.81E-12	8.81E-11
Pu-244_5			10000	3.21E-15	3.21E-14
Cm-248	1	0.5	10000	5.53E-23	5.53E-23
Pu-244			10000	3.04E-11	3.04E-11
Pu-244_5			10000	1.11E-14	1.11E-14
Cf-249	0.001	0.0005	7972	7.01E-20	7.01E-17
Cm-245			10000	4.05E-21	4.05E-18
Pu-241			10000	4.66E-20	4.66E-17
Pu-241_5			10000	3.08E-21	3.08E-18
Am-241			10000	1.09E-20	1.09E-17
Np-237			10000	2.66E-13	2.66E-10
Cf-249	0.01	0.005	7972	7.01E-19	7.01E-17
Cm-245			10000	4.05E-20	4.05E-18
Pu-241			10000	4.66E-19	4.66E-17
Pu-241_5			10000	3.08E-20	3.08E-18
Am-241			10000	1.09E-19	1.09E-17
Np-237			10000	2.66E-12	2.66E-10
Cf-249	0.1	0.05	7972	7.01E-18	7.01E-17
Cm-245			10000	4.05E-19	4.05E-18
Pu-241			10000	4.66E-18	4.66E-17

Nuclide chains	Inventory for 2 disposal units (Ci)	Inventory per disposal unit (Ci)	Time peak flux occurred (yr)	Peak flux from 2 disposal units (Ci/yr)	Fractional flux (1/yr)
Pu-241_5			10000	3.08E-19	3.08E-18
Am-241			10000	1.09E-18	1.09E-17
Np-237			10000	2.66E-11	2.66E-10
Cf-249	1	0.5	7972	7.01E-17	7.01E-17
Cm-245			10000	4.05E-18	4.05E-18
Pu-241			10000	4.66E-17	4.66E-17
Pu-241_5			10000	3.08E-18	3.08E-18
Am-241			10000	1.09E-17	1.09E-17
Np-237			10000	2.66E-10	2.66E-10

Peak concentration and SOF results from PORFLOW aquifer transport simulations

For each parent and inventory modeled with PORFLOW, Table A-3 provides the peak sum-of-fractions for the periods 0-100, 100-1350, and 1350-10,000 years. Also shown are the location and time of the peak, groundwater concentrations at the peak SOF, the 1/SOF “limit”, and the percentage contribution of each member of the chain to the limit.

Each decay chain was simulated over a 10,000 year period, with the exception of H-3, Zr-95 and Nb-95. H-3 is unretarded ($K_d = 0$) and rapidly migrates out of the model domain after vault failure at 1075 years. Zr-95 and Nb-95 have short half-lives and rapidly decay to negligible amounts. For these three nuclides, PORFLOW simulations were performed to 1500 years.

Table A-3. Peak groundwater concentration and SOF results.

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Tracer	1	0.5	3871	12	15	11	0	100	100	5.20E-04	1E+20	5.20E-24	1.04E-23	100
SOF-chain													1.04E-23	9.61E+22
Tracer	1	0.5	3871	12	15	11	100	1350	630	2.04E+03	1E+20	2.04E-17	4.08E-17	100
SOF-chain													4.08E-17	2.45E+16
Tracer	1	0.5	1475	16	15	5	1350	10000	1360	5.68E-04	1E+20	5.68E-24	1.14E-23	100
SOF-chain													1.14E-23	8.80E+22
H-3	1	0.5	3871	12	15	11	0	100	100	1.88E-06	20000	9.40E-11	1.88E-10	100
SOF-chain													1.88E-10	5.32E+09
H-3	1	0.5	3871	12	15	11	100	1350	110	1.83E-06	20000	9.12E-11	1.83E-10	100
SOF-chain													1.83E-10	5.48E+09
H-3	1	0.5	1475	16	15	5	1350	1500	1360	1.54E-36	20000	7.70E-41	1.54E-40	100
SOF-chain													1.54E-40	6.50E+39
C-14	1	0.5	4671	12	15	13	0	100	100	4.86E-29	2000	2.43E-32	4.86E-32	100
SOF-chain													4.86E-32	2.06E+31
C-14	1	0.5	3871	12	15	11	100	1350	1350	1.10E-05	2000	5.51E-09	1.10E-08	100
SOF-chain													1.10E-08	9.07E+07
C-14	1	0.5	3871	12	15	11	1350	10000	10000	5.91E-02	2000	2.96E-05	5.91E-05	100
SOF-chain													5.91E-05	1.69E+04
C-14_KB	1	0.5	4671	12	15	13	0	100	100	1.73E-27	2000	8.67E-31	1.73E-30	100
SOF-chain													1.73E-30	5.77E+29
C-14_KB	1	0.5	3871	12	15	11	100	1350	1350	3.92E-04	2000	1.96E-07	3.92E-07	100
SOF-chain													3.92E-07	2.55E+06
C-14_KB	1	0.5	3871	12	15	11	1350	10000	8950	1.49E+00	2000	7.45E-04	1.49E-03	100
SOF-chain													1.49E-03	6.72E+02
K-40	1	0.5	4671	12	15	13	0	100	100	6.40E-18	300	2.13E-20	4.27E-20	100
SOF-chain													4.27E-20	2.34E+19
K-40	1	0.5	3871	12	15	11	100	1350	1200	7.59E+02	300	2.53E+00	5.06E+00	100
SOF-chain													5.06E+00	1.98E-01
K-40	1	0.5	3871	12	15	11	1350	10000	1360	6.43E+00	300	2.14E-02	4.29E-02	100
SOF-chain													4.29E-02	2.33E+01

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Ni-59	1	0.5	4673	14	15	13	0	100	100	2.09E-81	300	6.98E-84	1.40E-83	100
SOF-chain													1.40E-83	7.17E+82
Ni-59	1	0.5	4673	14	15	13	100	1350	1350	3.87E-38	300	1.29E-40	2.58E-40	100
SOF-chain													2.58E-40	3.87E+39
Ni-59	1	0.5	4671	12	15	13	1350	10000	10000	9.16E-01	300	3.05E-03	6.11E-03	100
SOF-chain													6.11E-03	1.64E+02
Se-79	1	0.5	4673	14	15	13	0	100	100	5.66E-39	700	8.09E-42	1.62E-41	100
SOF-chain													1.62E-41	6.18E+40
Se-79	1	0.5	4673	14	15	13	100	1350	1350	3.00E-04	700	4.29E-07	8.57E-07	100
SOF-chain													8.57E-07	1.17E+06
Se-79	1	0.5	3871	12	15	11	1350	10000	2310	1.07E+02	700	1.52E-01	3.04E-01	100
SOF-chain													3.04E-01	3.29E+00
Sr-90	1	0.5	4673	14	15	13	0	100	100	2.50E-28	8	3.13E-29	6.26E-29	100
SOF-chain													6.26E-29	1.60E+28
Sr-90	1	0.5	4671	12	15	13	100	1350	1280	6.54E-12	8	8.17E-13	1.63E-12	100
SOF-chain													1.63E-12	6.12E+11
Sr-90	1	0.5	4671	12	15	13	1350	10000	1360	2.19E-12	8	2.74E-13	5.47E-13	100
SOF-chain													5.47E-13	1.83E+12
Zr-93	1	0.5	4673	14	15	13	0	100	100	1.26E-93	2000	6.28E-97	1.26E-96	0
Nb-93m										8.21E-75	1000	8.21E-78	1.64E-77	100
SOF-chain													1.64E-77	6.09E+76
Zr-93	1	0.5	4673	14	15	13	100	1350	1350	3.78E-50	2000	1.89E-53	3.78E-53	0
Nb-93m										6.85E-36	1000	6.85E-39	1.37E-38	100
SOF-chain													1.37E-38	7.30E+37
Zr-93	1	0.5	4673	14	15	13	1350	10000	10000	1.82E-07	2000	9.07E-11	1.82E-10	10.325
Nb-93m										7.88E-07	1000	7.88E-10	1.58E-09	89.675
SOF-chain													1.76E-09	5.69E+08
Zr-95	1	0.5	4673	14	15	13	0	100	5.08	2.01E-146	200	1.00E-148	2.01E-148	0
Nb-95										3.20E-132	300	1.07E-134	2.13E-134	0
SOF-chain													2.13E-134	1.00E+99
Zr-95	1	0.5	4673	14	15	13	100	1350	100.1	1.53E-243	200	7.64E-246	1.53E-245	0
Nb-95										2.03E-242	300	6.77E-245	1.35E-244	0
SOF-chain													1.51E-244	1.00E+99

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Zr-95	1	0.5	1488	9	16	5	1350	1500	1350	0.00E+00	200	0.00E+00	0.00E+00	0
Nb-95										0.00E+00	300	0.00E+00	0.00E+00	0
SOF-chain													0.00E+00	1.00E+99
Nb-94	1	0.5	4673	14	15	13	0	100	100	5.26E-72	1000	5.26E-75	1.05E-74	100
SOF-chain													1.05E-74	9.51E+73
Nb-94	1	0.5	4673	14	15	13	100	1350	1350	3.58E-29	1000	3.58E-32	7.16E-32	100
SOF-chain													7.16E-32	1.40E+31
Nb-94	1	0.5	3871	12	15	11	1350	10000	10000	3.31E+00	1000	3.31E-03	6.62E-03	100
SOF-chain													6.62E-03	1.51E+02
Nb-95	1	0.5	4673	14	15	13	0	100	5.08	1.42E-132	300	4.72E-135	9.45E-135	0
SOF-chain													9.45E-135	1.00E+99
Nb-95	1	0.5	4673	14	15	13	100	1350	100.1	2.899E-316	300	9.663E-319	1.933E-318	0
SOF-chain													1.933E-318	1.00E+99
Nb-95	1	0.5	1488	9	16	5	1350	1500	1350	0.00E+00	300	0.00E+00	0.00E+00	0
SOF-chain													0.00E+00	1.00E+99
Tc-99	1	0.5	3871	12	15	11	0	100	100	1.12E-17	900	1.24E-20	2.48E-20	100
SOF-chain													2.48E-20	4.04E+19
Tc-99	1	0.5	3871	12	15	11	100	1350	1350	3.42E+00	900	3.80E-03	7.60E-03	100
SOF-chain													7.60E-03	1.32E+02
Tc-99	1	0.5	3871	12	15	11	1350	10000	2780	2.41E+01	900	2.68E-02	5.36E-02	100
SOF-chain													5.36E-02	1.87E+01
Tc-99_KB	1	0.5	3871	12	15	11	0	100	100	1.49E-20	900	1.66E-23	3.31E-23	100
SOF-chain													3.31E-23	3.02E+22
Tc-99_KB	1	0.5	3871	12	15	11	100	1350	1350	1.87E-02	900	2.08E-05	4.16E-05	100
SOF-chain													4.16E-05	2.41E+04
Tc-99_KB	1	0.5	3871	12	15	11	1350	10000	9410	3.47E+00	900	3.85E-03	7.71E-03	100
SOF-chain													7.71E-03	1.30E+02
Sn-126	1	0.5	4673	14	15	13	0	100	100	1.82E-70	300	6.06E-73	1.21E-72	100
SOF-chain													1.21E-72	8.25E+71
Sn-126	1	0.5	4673	14	15	13	100	1350	1350	8.60E-28	300	2.87E-30	5.73E-30	100
SOF-chain													5.73E-30	1.74E+29
Sn-126	1	0.5	3871	12	15	11	1350	10000	10000	2.07E+00	300	6.89E-03	1.38E-02	100
SOF-chain													1.38E-02	7.26E+01

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
I-129	1	0.5	4671	12	15	13	0	100	100	1.15E-11	1	1.15E-11	2.31E-11	100
SOF-chain													2.31E-11	4.33E+10
I-129	1	0.5	3871	12	15	11	100	1350	1120	1.10E+03	1	1.10E+03	2.20E+03	100
SOF-chain													2.20E+03	4.55E-04
I-129	1	0.5	1475	16	15	5	1350	10000	1360	1.42E-02	1	1.42E-02	2.83E-02	100
SOF-chain													2.83E-02	3.54E+01
I-129_ETF-Carbon	1	0.5	4671	12	15	13	0	100	100	4.01E-14	1	4.01E-14	8.01E-14	100
SOF-chain													8.01E-14	1.25E+13
I-129_ETF-Carbon	1	0.5	3871	12	15	11	100	1350	1150	5.17E+00	1	5.17E+00	1.03E+01	100
SOF-chain													1.03E+01	9.67E-02
I-129_ETF-Carbon	1	0.5	3871	12	15	11	1350	10000	8030	4.85E+00	1	4.85E+00	9.71E+00	100
SOF-chain													9.71E+00	1.03E-01
I-129_KB	1	0.5	4671	12	15	13	0	100	100	1.17E-24	1	1.17E-24	2.34E-24	100
SOF-chain													2.34E-24	4.28E+23
I-129_KB	1	0.5	3871	12	15	11	100	1350	1350	8.02E-05	1	8.02E-05	1.60E-04	100
SOF-chain													1.60E-04	6.24E+03
I-129_KB	1	0.5	3871	12	15	11	1350	10000	10000	4.18E-01	1	4.18E-01	8.35E-01	100
SOF-chain													8.35E-01	1.20E+00
Cs-135	1	0.5	4673	14	15	13	0	100	100	4.80E-76	900	5.33E-79	1.07E-78	100
SOF-chain													1.07E-78	9.38E+77
Cs-135	1	0.5	4673	14	15	13	100	1350	1350	3.75E-33	900	4.17E-36	8.34E-36	100
SOF-chain													8.34E-36	1.20E+35
Cs-135	1	0.5	4671	12	15	13	1350	10000	10000	9.77E+00	900	1.09E-02	2.17E-02	100
SOF-chain													2.17E-02	4.60E+01
Po-210	1	0.5	4673	14	15	13	0	100	20	2.20E-111	15	1.47E-112	2.93E-112	0
SOF-chain													2.93E-112	1.00E+99
Po-210	1	0.5	4673	14	15	13	100	1350	110	2.95E-141	15	1.96E-142	3.93E-142	0
SOF-chain													3.93E-142	1.00E+99
Po-210	1	0.5	1488	9	16	5	1350	10000	1360	0.00E+00	15	0.00E+00	0.00E+00	0
SOF-chain													0.00E+00	1.00E+99
Ra-226	1	0.5	4673	14	15	13	0	100	100	3.29E-83	5	6.59E-84	1.32E-83	0
Pb-210										7.62E-77	1	7.62E-77	1.52E-76	87.69
Po-210										1.60E-76	15	1.07E-77	2.14E-77	12.31

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
SOF-chain													1.74E-76	5.76E+75
Ra-226	1	0.5	4673	14	15	13	100	1350	1350	3.46E-40	5	6.92E-41	1.38E-40	0.001
Pb-210										5.62E-36	1	5.62E-36	1.13E-35	88.65
Po-210										1.08E-35	15	7.20E-37	1.44E-36	11.348
SOF-chain													1.27E-35	7.88E+34
Ra-226	1	0.5	4671	12	15	13	1350	10000	10000	2.18E-03	5	4.36E-04	8.72E-04	8.37
Pb-210										4.26E-03	1	4.26E-03	8.52E-03	81.803
Po-210										7.68E-03	15	5.12E-04	1.02E-03	9.828
SOF-chain													1.04E-02	9.60E+01
Th-228	1	0.5	4673	14	15	13	0	100	90	1.50E-132	15	1.00E-133	2.00E-133	0
SOF-chain													2.00E-133	1.00E+99
Th-228	1	0.5	4673	14	15	13	100	1350	110	1.04E-132	15	6.91E-134	1.38E-133	0
SOF-chain													1.38E-133	1.00E+99
Th-228	1	0.5	4673	14	15	13	1350	10000	1360	1.77E-281	15	1.18E-282	2.36E-282	0
SOF-chain													2.36E-282	1.00E+99
Th-230	1	0.5	4673	14	15	13	0	100	100	4.10E-116	15	2.73E-117	5.47E-117	0
Ra-226										4.41E-86	5	8.82E-87	1.76E-86	0
Pb-210										1.07E-79	1	1.07E-79	2.14E-79	87.648
Po-210										2.26E-79	15	1.51E-80	3.01E-80	12.352
SOF-chain													2.44E-79	4.10E+78
Th-230	1	0.5	4673	14	15	13	100	1350	1350	1.88E-72	15	1.25E-73	2.50E-73	0
Ra-226										1.13E-40	5	2.26E-41	4.53E-41	0.001
Pb-210										2.03E-36	1	2.03E-36	4.07E-36	88.646
Po-210										3.91E-36	15	2.61E-37	5.21E-37	11.353
SOF-chain													4.59E-36	2.18E+35
Th-230	1	0.5	4671	12	15	13	1350	10000	10000	5.26E-25	15	3.51E-26	7.02E-26	0
Ra-226										2.37E-03	5	4.73E-04	9.46E-04	8.338
Pb-210										4.64E-03	1	4.64E-03	9.28E-03	81.829
Po-210										8.37E-03	15	5.58E-04	1.12E-03	9.833
SOF-chain													1.14E-02	8.81E+01
Th-232	1	0.5	4673	14	15	13	0	100	100	4.11E-116	13	3.16E-117	6.32E-117	0
Ra-228										4.25E-89	5	8.51E-90	1.70E-89	78.6
Th-228										4.69E-90	15	3.13E-91	6.25E-91	2.889

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Ra-224										3.01E-89	15	2.00E-90	4.01E-90	18.511
SOF-chain													2.16E-89	4.62E+88
Th-232	1	0.5	4673	14	15	13	100	1350	1350	1.90E-72	13	1.46E-73	2.92E-73	0
Ra-228										9.75E-56	5	1.95E-56	3.90E-56	71.874
Th-228										1.55E-56	15	1.03E-57	2.06E-57	3.797
Ra-224										9.90E-56	15	6.60E-57	1.32E-56	24.329
SOF-chain													5.43E-56	1.84E+55
Th-232	1	0.5	4673	14	15	13	1350	10000	10000	1.09E-24	13	8.39E-26	1.68E-25	3.548
Ra-228										8.23E-24	5	1.65E-24	3.29E-24	69.618
Th-228										1.29E-24	15	8.58E-26	1.72E-25	3.627
Ra-224										8.24E-24	15	5.49E-25	1.10E-24	23.207
SOF-chain													4.73E-24	2.11E+23
U-232	0.001	0.0005	4673	14	15	13	0	100	100	2.24E-99	26	8.62E-101	1.72E-97	32.641
Th-228										3.60E-100	15	2.40E-101	4.80E-98	9.086
Ra-224										2.31E-99	15	1.54E-100	3.08E-97	58.272
SOF-chain													5.28E-97	1.89E+96
U-232	0.001	0.0005	4673	14	15	13	100	1350	1350	2.67E-61	26	1.03E-62	2.06E-59	26.514
Th-228										5.77E-62	15	3.85E-63	7.69E-60	9.927
Ra-224										3.69E-61	15	2.46E-62	4.93E-59	63.559
SOF-chain													7.75E-59	1.29E+58
U-232	0.001	0.0005	4673	14	15	13	1350	10000	3970	8.42E-42	26	3.24E-43	6.48E-40	23.645
Th-228										2.12E-42	15	1.41E-43	2.83E-40	10.321
Ra-224										1.36E-41	15	9.04E-43	1.81E-39	66.034
SOF-chain													2.74E-39	3.65E+38
U-232	0.01	0.005	4673	14	15	13	0	100	100	2.24E-98	26	8.62E-100	1.72E-97	32.641
Th-228										3.60E-99	15	2.40E-100	4.80E-98	9.086
Ra-224										2.31E-98	15	1.54E-99	3.08E-97	58.272
SOF-chain													5.28E-97	1.89E+96
U-232	0.01	0.005	4673	14	15	13	100	1350	1350	2.67E-60	26	1.03E-61	2.06E-59	26.514
Th-228										5.77E-61	15	3.85E-62	7.69E-60	9.927
Ra-224										3.69E-60	15	2.46E-61	4.93E-59	63.559
SOF-chain													7.75E-59	1.29E+58
U-232	0.01	0.005	4673	14	15	13	1350	10000	4010	1.07E-40	26	4.12E-42	8.24E-40	23.644

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Th-228										2.70E-41	15	1.80E-42	3.60E-40	10.321
Ra-224										1.73E-40	15	1.15E-41	2.30E-39	66.035
SOF-chain													3.48E-39	2.87E+38
U-232	0.1	0.05	4673	14	15	13	0	100	100	2.24E-97	26	8.62E-99	1.72E-97	32.641
Th-228										3.60E-98	15	2.40E-99	4.80E-98	9.086
Ra-224										2.31E-97	15	1.54E-98	3.08E-97	58.272
SOF-chain													5.28E-97	1.89E+96
U-232	0.1	0.05	4673	14	15	13	100	1350	1350	2.67E-59	26	1.03E-60	2.06E-59	26.514
Th-228										5.77E-60	15	3.85E-61	7.69E-60	9.927
Ra-224										3.69E-59	15	2.46E-60	4.93E-59	63.559
SOF-chain													7.75E-59	1.29E+58
U-232	0.1	0.05	4673	14	15	13	1350	10000	4020	1.09E-39	26	4.19E-41	8.38E-40	23.644
Th-228										2.74E-40	15	1.83E-41	3.66E-40	10.321
Ra-224										1.76E-39	15	1.17E-40	2.34E-39	66.035
SOF-chain													3.54E-39	2.82E+38
U-232	1	0.5	4673	14	15	13	0	100	100	2.24E-96	26	8.62E-98	1.72E-97	32.641
Th-228										3.60E-97	15	2.40E-98	4.80E-98	9.086
Ra-224										2.31E-96	15	1.54E-97	3.08E-97	58.272
SOF-chain													5.28E-97	1.89E+96
U-232	1	0.5	4673	14	15	13	100	1350	1350	2.67E-58	26	1.03E-59	2.06E-59	26.514
Th-228										5.77E-59	15	3.85E-60	7.69E-60	9.927
Ra-224										3.69E-58	15	2.46E-59	4.93E-59	63.559
SOF-chain													7.75E-59	1.29E+58
U-232	1	0.5	4673	14	15	13	1350	10000	4020	1.09E-38	26	4.19E-40	8.39E-40	23.644
Th-228										2.75E-39	15	1.83E-40	3.66E-40	10.321
Ra-224										1.76E-38	15	1.17E-39	2.34E-39	66.035
SOF-chain													3.55E-39	2.82E+38
U-233	0.001	0.0005	4673	14	15	13	0	100	100	6.77E-99	130	5.21E-101	1.04E-97	99.387
Th-229										7.52E-103	9.6	7.83E-104	1.57E-100	0.149
Ra-225										4.86E-102	20	2.43E-103	4.86E-100	0.463
SOF-chain													1.05E-97	9.54E+96
U-233	0.001	0.0005	4673	14	15	13	100	1350	1350	2.30E-55	130	1.77E-57	3.54E-54	98.085
Th-229										8.12E-59	9.6	8.46E-60	1.69E-56	0.469

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Ra-225										5.21E-58	20	2.61E-59	5.21E-56	1.446
SOF-chain													3.60E-54	2.77E+53
U-233	0.001	0.0005	4673	14	15	13	1350	10000	10000	2.37E-11	130	1.83E-13	3.65E-10	61.359
Th-229										2.71E-13	9.6	2.82E-14	5.65E-11	9.494
Ra-225										1.73E-12	20	8.67E-14	1.73E-10	29.147
SOF-chain													5.95E-10	1.68E+09
U-233	0.01	0.005	4673	14	15	13	0	100	100	6.77E-98	130	5.20E-100	1.04E-97	99.387
Th-229										7.51E-102	9.6	7.82E-103	1.56E-100	0.149
Ra-225										4.85E-101	20	2.43E-102	4.85E-100	0.463
SOF-chain													1.05E-97	9.55E+96
U-233	0.01	0.005	4673	14	15	13	100	1350	1350	2.30E-54	130	1.77E-56	3.54E-54	98.085
Th-229										8.13E-58	9.6	8.47E-59	1.69E-56	0.469
Ra-225										5.22E-57	20	2.61E-58	5.22E-56	1.445
SOF-chain													3.61E-54	2.77E+53
U-233	0.01	0.005	4673	14	15	13	1350	10000	10000	2.37E-10	130	1.82E-12	3.65E-10	61.359
Th-229										2.71E-12	9.6	2.82E-13	5.64E-11	9.494
Ra-225										1.73E-11	20	8.66E-13	1.73E-10	29.147
SOF-chain													5.94E-10	1.68E+09
U-233	0.1	0.05	4673	14	15	13	0	100	100	6.76E-97	130	5.20E-99	1.04E-97	99.387
Th-229										7.50E-101	9.6	7.82E-102	1.56E-100	0.149
Ra-225										4.85E-100	20	2.42E-101	4.85E-100	0.463
SOF-chain													1.05E-97	9.56E+96
U-233	0.1	0.05	4673	14	15	13	100	1350	1350	2.30E-53	130	1.77E-55	3.54E-54	98.086
Th-229										8.13E-57	9.6	8.46E-58	1.69E-56	0.469
Ra-225										5.21E-56	20	2.61E-57	5.21E-56	1.445
SOF-chain													3.61E-54	2.77E+53
U-233	0.1	0.05	4673	14	15	13	1350	10000	10000	2.37E-09	130	1.82E-11	3.64E-10	61.359
Th-229										2.71E-11	9.6	2.82E-12	5.64E-11	9.494
Ra-225										1.73E-10	20	8.66E-12	1.73E-10	29.147
SOF-chain													5.94E-10	1.68E+09
U-233	1	0.5	4673	14	15	13	0	100	100	6.75E-96	130	5.20E-98	1.04E-97	99.387
Th-229										7.50E-100	9.6	7.81E-101	1.56E-100	0.149
Ra-225										4.84E-99	20	2.42E-100	4.84E-100	0.463

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
SOF-chain													1.05E-97	9.57E+96
U-233	1	0.5	4673	14	15	13	100	1350	1350	2.30E-52	130	1.77E-54	3.54E-54	98.086
Th-229										8.12E-56	9.6	8.46E-57	1.69E-56	0.469
Ra-225										5.21E-55	20	2.61E-56	5.21E-56	1.445
SOF-chain													3.61E-54	2.77E+53
U-233	1	0.5	4673	14	15	13	1350	10000	10000	2.38E-08	130	1.83E-10	3.66E-10	61.355
Th-229										2.72E-10	9.6	2.83E-11	5.66E-11	9.495
Ra-225										1.74E-09	20	8.68E-11	1.74E-10	29.15
SOF-chain													5.96E-10	1.68E+09
U-234	0.001	0.0005	4673	14	15	13	0	100	100	6.77E-99	130	5.21E-101	1.04E-97	0
Th-230										7.32E-104	15	4.88E-105	9.75E-102	0
Ra-226										1.24E-93	5	2.47E-94	4.95E-91	0
Pb-210										3.13E-87	1	3.13E-87	6.27E-84	87.607
Po-210										6.65E-87	15	4.43E-88	8.87E-85	12.393
SOF-chain													7.15E-84	1.40E+83
U-234	0.001	0.0005	4673	14	15	13	100	1350	1350	2.31E-55	130	1.77E-57	3.55E-54	0
Th-230										7.94E-60	15	5.29E-61	1.06E-57	0
Ra-226										3.67E-46	5	7.35E-47	1.47E-43	0.001
Pb-210										7.31E-42	1	7.31E-42	1.46E-38	88.641
Po-210										1.41E-41	15	9.37E-43	1.87E-39	11.358
SOF-chain													1.65E-38	6.06E+37
U-234	0.001	0.0005	4671	12	15	13	1350	10000	10000	1.90E-11	130	1.46E-13	2.92E-10	0
Th-230										2.15E-14	15	1.43E-15	2.87E-12	0
Ra-226										2.43E-08	5	4.87E-09	9.73E-06	8.305
Pb-210										4.80E-08	1	4.80E-08	9.59E-05	81.857
Po-210										8.65E-08	15	5.77E-09	1.15E-05	9.838
SOF-chain													1.17E-04	8.53E+03
U-234	0.01	0.005	4673	14	15	13	0	100	100	6.76E-98	130	5.20E-100	1.04E-97	0
Th-230										7.31E-103	15	4.87E-104	9.75E-102	0
Ra-226										1.24E-92	5	2.47E-93	4.95E-91	0
Pb-210										3.13E-86	1	3.13E-86	6.27E-84	87.607
Po-210										6.65E-86	15	4.43E-87	8.87E-85	12.393
SOF-chain													7.15E-84	1.40E+83

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
U-234	0.01	0.005	4673	14	15	13	100	1350	1350	2.31E-54	130	1.77E-56	3.55E-54	0
Th-230										7.94E-59	15	5.29E-60	1.06E-57	0
Ra-226										3.67E-45	5	7.35E-46	1.47E-43	0.001
Pb-210										7.31E-41	1	7.31E-41	1.46E-38	88.641
Po-210										1.41E-40	15	9.37E-42	1.87E-39	11.358
SOF-chain													1.65E-38	6.06E+37
U-234	0.01	0.005	4671	12	15	13	1350	10000	10000	1.90E-10	130	1.46E-12	2.92E-10	0
Th-230										2.15E-13	15	1.44E-14	2.87E-12	0
Ra-226										2.43E-07	5	4.87E-08	9.73E-06	8.305
Pb-210										4.80E-07	1	4.80E-07	9.59E-05	81.857
Po-210										8.65E-07	15	5.77E-08	1.15E-05	9.838
SOF-chain													1.17E-04	8.53E+03
U-234	0.1	0.05	4673	14	15	13	0	100	100	6.75E-97	130	5.19E-99	1.04E-97	0
Th-230										7.30E-102	15	4.87E-103	9.73E-102	0
Ra-226										1.24E-91	5	2.47E-92	4.95E-91	0
Pb-210										3.13E-85	1	3.13E-85	6.27E-84	87.607
Po-210										6.65E-85	15	4.43E-86	8.86E-85	12.393
SOF-chain													7.15E-84	1.40E+83
U-234	0.1	0.05	4673	14	15	13	100	1350	1350	2.31E-53	130	1.77E-55	3.55E-54	0
Th-230										7.94E-58	15	5.30E-59	1.06E-57	0
Ra-226										3.67E-44	5	7.35E-45	1.47E-43	0.001
Pb-210										7.31E-40	1	7.31E-40	1.46E-38	88.641
Po-210										1.41E-39	15	9.37E-41	1.87E-39	11.358
SOF-chain													1.65E-38	6.06E+37
U-234	0.1	0.05	4671	12	15	13	1350	10000	10000	1.90E-09	130	1.46E-11	2.92E-10	0
Th-230										2.15E-12	15	1.44E-13	2.87E-12	0
Ra-226										2.43E-06	5	4.87E-07	9.73E-06	8.305
Pb-210										4.80E-06	1	4.80E-06	9.59E-05	81.857
Po-210										8.65E-06	15	5.77E-07	1.15E-05	9.838
SOF-chain													1.17E-04	8.53E+03
U-234	1	0.5	4673	14	15	13	0	100	100	6.81E-96	130	5.24E-98	1.05E-97	0
Th-230										7.37E-101	15	4.91E-102	9.82E-102	0
Ra-226										1.24E-90	5	2.47E-91	4.95E-91	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pb-210										3.13E-84	1	3.13E-84	6.27E-84	87.607
Po-210										6.65E-84	15	4.43E-85	8.87E-85	12.393
SOF-chain													7.15E-84	1.40E+83
U-234	1	0.5	4673	14	15	13	100	1350	1350	2.31E-52	130	1.77E-54	3.55E-54	0
Th-230										7.94E-57	15	5.30E-58	1.06E-57	0
Ra-226										3.67E-43	5	7.35E-44	1.47E-43	0.001
Pb-210										7.31E-39	1	7.31E-39	1.46E-38	88.641
Po-210										1.41E-38	15	9.37E-40	1.87E-39	11.358
SOF-chain													1.65E-38	6.06E+37
U-234	1	0.5	4671	12	15	13	1350	10000	10000	1.90E-08	130	1.46E-10	2.92E-10	0
Th-230										2.15E-11	15	1.43E-12	2.87E-12	0
Ra-226										2.43E-05	5	4.87E-06	9.73E-06	8.305
Pb-210										4.80E-05	1	4.80E-05	9.59E-05	81.857
Po-210										8.65E-05	15	5.77E-06	1.15E-05	9.838
SOF-chain													1.17E-04	8.53E+03
U-235	0.001	0.0005	4673	14	15	13	0	100	100	6.81E-99	65	1.05E-100	2.10E-97	0.003
Pa-231										1.78E-97	3.1	5.75E-98	1.15E-94	1.453
Ac-227										3.65E-96	1	3.65E-96	7.31E-93	92.252
Th-227										5.05E-97	15	3.37E-98	6.74E-95	0.851
Ra-223										3.23E-96	15	2.15E-97	4.31E-94	5.442
SOF-chain													7.92E-93	1.26E+92
U-235	0.001	0.0005	4673	14	15	13	100	1350	1350	2.31E-55	65	3.56E-57	7.11E-54	0.001
Pa-231										7.38E-53	3.1	2.38E-53	4.76E-50	8.856
Ac-227										2.29E-52	1	2.29E-52	4.58E-49	85.256
Th-227										3.21E-53	15	2.14E-54	4.27E-51	0.795
Ra-223										2.05E-52	15	1.37E-53	2.74E-50	5.091
SOF-chain													5.37E-49	1.86E+48
U-235	0.001	0.0005	4673	14	15	13	1350	10000	10000	2.48E-11	65	3.81E-13	7.63E-10	0.036
Pa-231										6.48E-10	3.1	2.09E-10	4.18E-07	19.535
Ac-227										8.05E-10	1	8.05E-10	1.61E-06	75.211
Th-227										1.13E-10	15	7.55E-12	1.51E-08	0.705
Ra-223										7.24E-10	15	4.83E-11	9.65E-08	4.513
SOF-chain													2.14E-06	4.68E+05

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
U-235	0.01	0.005	4673	14	15	13	0	100	100	6.80E-98	65	1.05E-99	2.09E-97	0.003
Pa-231										1.78E-96	3.1	5.75E-97	1.15E-94	1.453
Ac-227										3.65E-95	1	3.65E-95	7.30E-93	92.252
Th-227										5.05E-96	15	3.37E-97	6.73E-95	0.851
Ra-223										3.23E-95	15	2.15E-96	4.31E-94	5.442
SOF-chain													7.91E-93	1.26E+92
U-235	0.01	0.005	4673	14	15	13	100	1350	1350	2.31E-54	65	3.55E-56	7.10E-54	0.001
Pa-231										7.37E-52	3.1	2.38E-52	4.75E-50	8.857
Ac-227										2.29E-51	1	2.29E-51	4.58E-49	85.255
Th-227										3.20E-52	15	2.14E-53	4.27E-51	0.795
Ra-223										2.05E-51	15	1.37E-52	2.73E-50	5.091
SOF-chain													5.37E-49	1.86E+48
U-235	0.01	0.005	4673	14	15	13	1350	10000	10000	2.06E-10	65	3.17E-12	6.34E-10	0.036
Pa-231										5.41E-09	3.1	1.74E-09	3.49E-07	19.535
Ac-227										6.72E-09	1	6.72E-09	1.34E-06	75.211
Th-227										9.45E-10	15	6.30E-11	1.26E-08	0.705
Ra-223										6.04E-09	15	4.03E-10	8.06E-08	4.513
SOF-chain													1.79E-06	5.60E+05
U-235	0.1	0.05	4673	14	15	13	0	100	100	8.92E-98	65	1.37E-99	2.75E-98	0.002
Pa-231										2.44E-96	3.1	7.87E-97	1.57E-95	1.421
Ac-227										5.11E-95	1	5.11E-95	1.02E-93	92.282
Th-227										7.07E-96	15	4.71E-97	9.42E-96	0.851
Ra-223										4.52E-95	15	3.01E-96	6.03E-95	5.443
SOF-chain													1.11E-93	9.03E+92
U-235	0.1	0.05	4673	14	15	13	100	1350	1350	2.47E-54	65	3.80E-56	7.61E-55	0.001
Pa-231										1.43E-51	3.1	4.62E-52	9.24E-51	8.761
Ac-227										4.50E-51	1	4.50E-51	9.00E-50	85.346
Th-227										6.30E-52	15	4.20E-53	8.40E-52	0.796
Ra-223										4.03E-51	15	2.69E-52	5.38E-51	5.096
SOF-chain													1.06E-49	9.48E+48
U-235	0.1	0.05	4673	14	15	13	1350	10000	10000	2.07E-10	65	3.19E-12	6.38E-11	0.027
Pa-231										7.18E-09	3.1	2.32E-09	4.63E-08	19.539
Ac-227										8.91E-09	1	8.91E-09	1.78E-07	75.216

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Th-227										1.25E-09	15	8.36E-11	1.67E-09	0.705
Ra-223										8.02E-09	15	5.35E-10	1.07E-08	4.513
SOF-chain													2.37E-07	4.22E+06
U-235	1	0.5	4673	14	15	13	0	100	100	8.92E-98	65	1.37E-99	2.75E-99	0.001
Pa-231										3.51E-96	3.1	1.13E-96	2.26E-96	1.235
Ac-227										8.47E-95	1	8.47E-95	1.69E-94	92.457
Th-227										1.17E-95	15	7.81E-97	1.56E-96	0.853
Ra-223										7.50E-95	15	5.00E-96	9.99E-96	5.454
SOF-chain													1.83E-94	5.46E+93
U-235	1	0.5	4673	14	15	13	100	1350	1350	2.47E-54	65	3.80E-56	7.61E-56	0
Pa-231										7.91E-51	3.1	2.55E-51	5.10E-51	8.656
Ac-227										2.52E-50	1	2.52E-50	5.04E-50	85.444
Th-227										3.52E-51	15	2.35E-52	4.70E-52	0.797
Ra-223										2.26E-50	15	1.50E-51	3.01E-51	5.102
SOF-chain													5.89E-50	1.70E+49
U-235	1	0.5	4673	14	15	13	1350	10000	10000	2.07E-10	65	3.19E-12	6.38E-12	0.008
Pa-231										2.46E-08	3.1	7.92E-09	1.58E-08	19.546
Ac-227										3.05E-08	1	3.05E-08	6.10E-08	75.227
Th-227										4.29E-09	15	2.86E-10	5.72E-10	0.706
Ra-223										2.74E-08	15	1.83E-09	3.66E-09	4.514
SOF-chain													8.11E-08	1.23E+07
U-236	0.001	0.0005	4673	14	15	13	0	100	100	6.80E-99	140	4.86E-101	9.71E-98	100
SOF-chain													9.71E-98	1.03E+97
U-236	0.001	0.0005	4673	14	15	13	100	1350	1350	2.31E-55	140	1.65E-57	3.30E-54	100
SOF-chain													3.30E-54	3.03E+53
U-236	0.001	0.0005	4673	14	15	13	1350	10000	10000	2.48E-11	140	1.77E-13	3.55E-10	100
SOF-chain													3.55E-10	2.82E+09
U-236	0.01	0.005	4673	14	15	13	0	100	100	6.79E-98	140	4.85E-100	9.70E-98	100
SOF-chain													9.70E-98	1.03E+97
U-236	0.01	0.005	4673	14	15	13	100	1350	1350	2.31E-54	140	1.65E-56	3.31E-54	100
SOF-chain													3.31E-54	3.03E+53
U-236	0.01	0.005	4673	14	15	13	1350	10000	10000	2.49E-10	140	1.78E-12	3.56E-10	100
SOF-chain													3.56E-10	2.81E+09

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
U-236	0.1	0.05	4673	14	15	13	0	100	100	6.79E-97	140	4.85E-99	9.70E-98	100
SOF-chain													9.70E-98	1.03E+97
U-236	0.1	0.05	4673	14	15	13	100	1350	1350	2.32E-53	140	1.65E-55	3.31E-54	100
SOF-chain													3.31E-54	3.02E+53
U-236	0.1	0.05	4673	14	15	13	1350	10000	10000	2.49E-09	140	1.78E-11	3.56E-10	100
SOF-chain													3.56E-10	2.81E+09
U-236	1	0.5	4673	14	15	13	0	100	100	2.69E-96	140	1.92E-98	3.84E-98	100
SOF-chain													3.84E-98	2.60E+97
U-236	1	0.5	4673	14	15	13	100	1350	1350	7.45E-53	140	5.32E-55	1.06E-54	100
SOF-chain													1.06E-54	9.40E+53
U-236	1	0.5	4673	14	15	13	1350	10000	10000	6.25E-09	140	4.46E-11	8.93E-11	100
SOF-chain													8.93E-11	1.12E+10
U-238	0.001	0.0005	4673	14	15	13	0	100	100	6.76E-99	10.1	6.70E-100	1.34E-96	99.381
Th-234										1.66E-99	400	4.15E-102	8.29E-99	0.615
U-234										2.82E-102	130	2.17E-104	4.34E-101	0.003
SOF-chain													1.35E-96	7.42E+95
U-238	0.001	0.0005	4673	14	15	13	100	1350	1350	2.31E-55	10.1	2.29E-56	4.58E-53	99.347
Th-234										5.75E-56	400	1.44E-58	2.87E-55	0.623
U-234										8.85E-58	130	6.81E-60	1.36E-56	0.03
SOF-chain													4.61E-53	2.17E+52
U-238	0.001	0.0005	4673	14	15	13	1350	10000	10000	2.48E-11	10.1	2.46E-12	4.92E-09	99.159
Th-234										6.21E-12	400	1.55E-14	3.11E-11	0.626
U-234										6.93E-13	130	5.33E-15	1.07E-11	0.215
SOF-chain													4.96E-09	2.02E+08
U-238	0.01	0.005	4673	14	15	13	0	100	100	1.41E-98	10.1	1.40E-99	2.79E-97	99.378
Th-234										3.46E-99	400	8.64E-102	1.73E-99	0.615
U-234										1.23E-101	130	9.49E-104	1.90E-101	0.007
SOF-chain													2.81E-97	3.56E+96
U-238	0.01	0.005	4673	14	15	13	100	1350	1350	3.90E-55	10.1	3.86E-56	7.73E-54	99.277
Th-234										9.70E-56	400	2.43E-58	4.85E-56	0.623
U-234										5.05E-57	130	3.88E-59	7.76E-57	0.1
SOF-chain													7.78E-54	1.29E+53
U-238	0.01	0.005	4673	14	15	13	1350	10000	10000	3.28E-11	10.1	3.24E-12	6.49E-10	98.966

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Th-234										8.19E-12	400	2.05E-14	4.09E-12	0.625
U-234										1.74E-12	130	1.34E-14	2.68E-12	0.409
SOF-chain													6.55E-10	1.53E+09
U-238	0.1	0.05	4673	14	15	13	0	100	100	1.41E-98	10.1	1.40E-99	2.79E-98	99.338
Th-234										3.46E-99	400	8.64E-102	1.73E-100	0.615
U-234										8.58E-101	130	6.60E-103	1.32E-101	0.047
SOF-chain													2.81E-98	3.56E+97
U-238	0.1	0.05	4673	14	15	13	100	1350	1350	3.90E-55	10.1	3.86E-56	7.73E-55	98.529
Th-234										9.70E-56	400	2.43E-58	4.85E-57	0.618
U-234										4.35E-56	130	3.35E-58	6.69E-57	0.853
SOF-chain													7.84E-55	1.28E+54
U-238	0.1	0.05	4673	14	15	13	1350	10000	10000	3.28E-11	10.1	3.24E-12	6.49E-11	97.008
Th-234										8.19E-12	400	2.05E-14	4.09E-13	0.612
U-234										1.03E-11	130	7.95E-14	1.59E-12	2.379
SOF-chain													6.69E-11	1.50E+10
U-238	1	0.5	4673	14	15	13	0	100	100	1.41E-98	10.1	1.40E-99	2.79E-99	98.94
Th-234										3.46E-99	400	8.64E-102	1.73E-101	0.613
U-234										8.20E-100	130	6.31E-102	1.26E-101	0.447
SOF-chain													2.82E-99	3.55E+98
U-238	1	0.5	4673	14	15	13	100	1350	1350	3.90E-55	10.1	3.86E-56	7.73E-56	91.621
Th-234										9.70E-56	400	2.43E-58	4.85E-58	0.575
U-234										4.28E-55	130	3.29E-57	6.58E-57	7.804
SOF-chain													8.44E-56	1.19E+55
U-238	1	0.5	4673	14	15	13	1350	10000	10000	3.28E-11	10.1	3.24E-12	6.49E-12	80.988
Th-234										8.19E-12	400	2.05E-14	4.09E-14	0.511
U-234										9.63E-11	130	7.41E-13	1.48E-12	18.501
SOF-chain													8.01E-12	1.25E+11
Np-237	1	0.5	4673	14	15	13	0	100	100	2.44E-35	8.9	2.74E-36	5.48E-36	100
SOF-chain													5.48E-36	1.83E+35
Np-237	1	0.5	4671	12	15	13	100	1350	1350	2.92E-06	8.9	3.28E-07	6.56E-07	100
SOF-chain													6.56E-07	1.53E+06
Np-237	1	0.5	3871	12	15	11	1350	10000	10000	1.93E-01	8.9	2.17E-02	4.34E-02	100
SOF-chain													4.34E-02	2.30E+01

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-238	0.001	0.0005	4673	14	15	13	0	100	100	8.00E-89	8.897	8.99E-90	1.80E-86	99.876
Pu-238_56										9.89E-92	8.901	1.11E-92	2.22E-89	0.123
U-234										7.19E-94	130	5.53E-96	1.11E-92	0
SOF-chain													1.80E-86	5.56E+85
Pu-238	0.001	0.0005	4673	14	15	13	100	1350	1350	8.76E-50	8.897	9.84E-51	1.97E-47	99.952
Pu-238_56										4.17E-53	8.901	4.68E-54	9.36E-51	0.048
U-234										2.85E-54	130	2.19E-56	4.38E-53	0
SOF-chain													1.97E-47	5.08E+46
Pu-238	0.001	0.0005	4673	14	15	13	1350	10000	10000	3.84E-40	8.897	4.32E-41	8.64E-38	0
Pu-238_56										1.40E-43	8.901	1.58E-44	3.16E-41	0
U-234										8.69E-15	130	6.68E-17	1.34E-13	100
SOF-chain													1.34E-13	7.48E+12
Pu-238	0.01	0.005	4673	14	15	13	0	100	100	7.99E-88	8.897	8.99E-89	1.80E-86	99.876
Pu-238_56										9.89E-91	8.901	1.11E-91	2.22E-89	0.123
U-234										7.19E-93	130	5.53E-95	1.11E-92	0
SOF-chain													1.80E-86	5.56E+85
Pu-238	0.01	0.005	4673	14	15	13	100	1350	1350	8.76E-49	8.897	9.84E-50	1.97E-47	99.952
Pu-238_56										4.17E-52	8.901	4.68E-53	9.36E-51	0.048
U-234										2.85E-53	130	2.19E-55	4.38E-53	0
SOF-chain													1.97E-47	5.08E+46
Pu-238	0.01	0.005	4673	14	15	13	1350	10000	10000	3.93E-39	8.897	4.41E-40	8.83E-38	0
Pu-238_56										1.44E-42	8.901	1.61E-43	3.22E-41	0
U-234										8.68E-14	130	6.68E-16	1.34E-13	100
SOF-chain													1.34E-13	7.49E+12
Pu-238	0.1	0.05	4673	14	15	13	0	100	100	7.99E-87	8.897	8.99E-88	1.80E-86	99.876
Pu-238_56										9.89E-90	8.901	1.11E-90	2.22E-89	0.123
U-234										7.19E-92	130	5.53E-94	1.11E-92	0
SOF-chain													1.80E-86	5.56E+85
Pu-238	0.1	0.05	4673	14	15	13	100	1350	1350	8.76E-48	8.897	9.84E-49	1.97E-47	99.952
Pu-238_56										4.17E-51	8.901	4.68E-52	9.36E-51	0.048
U-234										2.85E-52	130	2.19E-54	4.38E-53	0
SOF-chain													1.97E-47	5.08E+46
Pu-238	0.1	0.05	4673	14	15	13	1350	10000	10000	3.97E-38	8.897	4.46E-39	8.92E-38	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-238_56										1.45E-41	8.901	1.63E-42	3.26E-41	0
U-234										8.67E-13	130	6.67E-15	1.33E-13	100
SOF-chain													1.33E-13	7.50E+12
Pu-238	1	0.5	4673	14	15	13	0	100	100	7.99E-86	8.897	8.98E-87	1.80E-86	99.876
Pu-238_56										9.89E-89	8.901	1.11E-89	2.22E-89	0.123
U-234										7.19E-91	130	5.53E-93	1.11E-92	0
SOF-chain													1.80E-86	5.56E+85
Pu-238	1	0.5	4673	14	15	13	100	1350	1350	8.76E-47	8.897	9.84E-48	1.97E-47	99.952
Pu-238_56										4.17E-50	8.901	4.68E-51	9.36E-51	0.048
U-234										2.85E-51	130	2.19E-53	4.38E-53	0
SOF-chain													1.97E-47	5.08E+46
Pu-238	1	0.5	4673	14	15	13	1350	10000	10000	3.99E-37	8.897	4.48E-38	8.97E-38	0
Pu-238_56										1.46E-40	8.901	1.64E-41	3.27E-41	0
U-234										8.66E-12	130	6.66E-14	1.33E-13	100
SOF-chain													1.33E-13	7.51E+12
Pu-238	10	5	4673	14	15	13	0	100	100	6.34E-85	8.897	7.13E-86	1.43E-86	99.876
Pu-238_56										7.86E-88	8.901	8.83E-89	1.77E-89	0.124
U-234										5.70E-90	130	4.39E-92	8.77E-93	0
SOF-chain													1.43E-86	7.00E+85
Pu-238	10	5	4673	14	15	13	100	1350	1350	8.75E-46	8.897	9.84E-47	1.97E-47	99.952
Pu-238_56										4.17E-49	8.901	4.68E-50	9.36E-51	0.048
U-234										2.85E-50	130	2.19E-52	4.38E-53	0
SOF-chain													1.97E-47	5.08E+46
Pu-238	10	5	4673	14	15	13	1350	10000	10000	4.00E-36	8.897	4.49E-37	8.98E-38	0
Pu-238_56										1.46E-39	8.901	1.64E-40	3.28E-41	0
U-234										8.65E-11	130	6.66E-13	1.33E-13	100
SOF-chain													1.33E-13	7.51E+12
Pu-239	0.001	0.0005	4673	14	15	13	0	100	100	1.89E-88	8.1	2.34E-89	4.67E-86	99.878
Pu-239_56										2.30E-91	8.101	2.84E-92	5.68E-89	0.122
U-235										5.68E-97	65	8.74E-99	1.75E-95	0
SOF-chain													4.68E-86	2.14E+85
Pu-239	0.001	0.0005	4673	14	15	13	100	1350	1350	3.89E-45	8.1	4.80E-46	9.60E-43	99.953
Pu-239_56										1.85E-48	8.101	2.28E-49	4.56E-46	0.047

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
U-235										3.72E-53	65	5.72E-55	1.14E-51	0
SOF-chain													9.61E-43	1.04E+42
Pu-239	0.001	0.0005	4671	12	15	13	1350	10000	10000	6.47E-06	8.1	7.99E-07	1.60E-03	99.963
Pu-239_56										2.36E-09	8.101	2.92E-10	5.83E-07	0.036
U-235										3.23E-12	65	4.97E-14	9.94E-11	0
SOF-chain													1.60E-03	6.26E+02
Pu-239	0.01	0.005	4673	14	15	13	0	100	100	1.91E-87	8.1	2.35E-88	4.71E-86	99.879
Pu-239_56										2.32E-90	8.101	2.86E-91	5.72E-89	0.121
U-235										5.72E-96	65	8.80E-98	1.76E-95	0
SOF-chain													4.71E-86	2.12E+85
Pu-239	0.01	0.005	4673	14	15	13	100	1350	1350	3.89E-44	8.1	4.80E-45	9.61E-43	99.953
Pu-239_56										1.85E-47	8.101	2.28E-48	4.56E-46	0.047
U-235										3.72E-52	65	5.72E-54	1.14E-51	0
SOF-chain													9.61E-43	1.04E+42
Pu-239	0.01	0.005	4671	12	15	13	1350	10000	10000	6.47E-05	8.1	7.99E-06	1.60E-03	99.963
Pu-239_56										2.36E-08	8.101	2.92E-09	5.83E-07	0.036
U-235										3.23E-11	65	4.97E-13	9.94E-11	0
SOF-chain													1.60E-03	6.26E+02
Pu-239	0.1	0.05	4673	14	15	13	0	100	100	5.38E-87	8.1	6.64E-88	1.33E-86	99.878
Pu-239_56										6.54E-90	8.101	8.08E-91	1.62E-89	0.122
U-235										1.61E-95	65	2.48E-97	4.97E-96	0
SOF-chain													1.33E-86	7.52E+85
Pu-239	0.1	0.05	4673	14	15	13	100	1350	1350	9.13E-44	8.1	1.13E-44	2.26E-43	99.953
Pu-239_56										4.33E-47	8.101	5.35E-48	1.07E-46	0.047
U-235										8.74E-52	65	1.35E-53	2.69E-52	0
SOF-chain													2.26E-43	4.43E+42
Pu-239	0.1	0.05	4671	12	15	13	1350	10000	10000	1.21E-04	8.1	1.50E-05	3.00E-04	99.963
Pu-239_56										4.43E-08	8.101	5.47E-09	1.09E-07	0.036
U-235										6.05E-11	65	9.31E-13	1.86E-11	0
SOF-chain													3.00E-04	3.34E+03
Pu-239	1	0.5	4673	14	15	13	0	100	100	5.38E-87	8.1	6.64E-88	1.33E-87	99.878
Pu-239_56										6.54E-90	8.101	8.08E-91	1.62E-90	0.122
U-235										1.62E-95	65	2.49E-97	4.97E-97	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
SOF-chain													1.33E-87	7.52E+86
Pu-239	1	0.5	4673	14	15	13	100	1350	1350	9.14E-44	8.1	1.13E-44	2.26E-44	99.953
Pu-239_56										4.33E-47	8.101	5.35E-48	1.07E-47	0.047
U-235										8.75E-52	65	1.35E-53	2.69E-53	0
SOF-chain													2.26E-44	4.43E+43
Pu-239	1	0.5	4671	12	15	13	1350	10000	10000	1.21E-04	8.1	1.50E-05	3.00E-05	99.963
Pu-239_56										4.43E-08	8.101	5.47E-09	1.09E-08	0.036
U-235										6.06E-11	65	9.32E-13	1.86E-12	0
SOF-chain													3.00E-05	3.34E+04
Pu-240	0.001	0.0005	4673	14	15	13	0	100	100	1.88E-88	8.102	2.33E-89	4.65E-86	99.878
Pu-240_56										2.29E-91	8.1	2.83E-92	5.66E-89	0.122
U-236										1.70E-95	140	1.21E-97	2.43E-94	0
SOF-chain													4.66E-86	2.15E+85
Pu-240	0.001	0.0005	4673	14	15	13	100	1350	1350	3.51E-45	8.102	4.33E-46	8.66E-43	99.953
Pu-240_56										1.66E-48	8.1	2.06E-49	4.11E-46	0.047
U-236										1.01E-51	140	7.20E-54	1.44E-50	0
SOF-chain													8.66E-43	1.16E+42
Pu-240	0.001	0.0005	4671	12	15	13	1350	10000	10000	3.00E-06	8.102	3.70E-07	7.41E-04	99.963
Pu-240_56										1.10E-09	8.1	1.35E-10	2.71E-07	0.037
U-236										4.86E-11	140	3.47E-13	6.95E-10	0
SOF-chain													7.41E-04	1.35E+03
Pu-240	0.01	0.005	4673	14	15	13	0	100	100	1.88E-87	8.102	2.32E-88	4.64E-86	99.878
Pu-240_56										2.29E-90	8.1	2.83E-91	5.65E-89	0.122
U-236										1.70E-94	140	1.21E-96	2.43E-94	0
SOF-chain													4.65E-86	2.15E+85
Pu-240	0.01	0.005	4673	14	15	13	100	1350	1350	3.51E-44	8.102	4.33E-45	8.66E-43	99.953
Pu-240_56										1.66E-47	8.1	2.06E-48	4.11E-46	0.047
U-236										1.01E-50	140	7.20E-53	1.44E-50	0
SOF-chain													8.66E-43	1.15E+42
Pu-240	0.01	0.005	4671	12	15	13	1350	10000	10000	3.00E-05	8.102	3.70E-06	7.41E-04	99.963
Pu-240_56										1.10E-08	8.1	1.35E-09	2.71E-07	0.037
U-236										4.86E-10	140	3.47E-12	6.95E-10	0
SOF-chain													7.41E-04	1.35E+03

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-240	0.1	0.05	4673	14	15	13	0	100	100	1.88E-86	8.102	2.32E-87	4.64E-86	99.878
Pu-240_56										2.29E-89	8.1	2.82E-90	5.65E-89	0.122
U-236										1.70E-93	140	1.21E-95	2.42E-94	0
SOF-chain													4.65E-86	2.15E+85
Pu-240	0.1	0.05	4673	14	15	13	100	1350	1350	3.17E-43	8.102	3.92E-44	7.83E-43	99.953
Pu-240_56										1.51E-46	8.1	1.86E-47	3.72E-46	0.047
U-236										9.13E-50	140	6.52E-52	1.31E-50	0
SOF-chain													7.84E-43	1.28E+42
Pu-240	0.1	0.05	4671	12	15	13	1350	10000	10000	2.33E-04	8.102	2.88E-05	5.76E-04	99.963
Pu-240_56										8.52E-08	8.1	1.05E-08	2.10E-07	0.037
U-236										3.76E-09	140	2.68E-11	5.37E-10	0
SOF-chain													5.76E-04	1.74E+03
Pu-240	1	0.5	4673	14	15	13	0	100	100	1.96E-86	8.102	2.42E-87	4.83E-87	99.878
Pu-240_56										2.38E-89	8.1	2.94E-90	5.88E-90	0.122
U-236										1.77E-93	140	1.26E-95	2.52E-95	0
SOF-chain													4.84E-87	2.07E+86
Pu-240	1	0.5	4673	14	15	13	100	1350	1350	3.18E-43	8.102	3.92E-44	7.84E-44	99.953
Pu-240_56										1.51E-46	8.1	1.86E-47	3.72E-47	0.047
U-236										9.14E-50	140	6.53E-52	1.31E-51	0
SOF-chain													7.84E-44	1.28E+43
Pu-240	1	0.5	4671	12	15	13	1350	10000	10000	2.34E-04	8.102	2.88E-05	5.76E-05	99.963
Pu-240_56										8.53E-08	8.1	1.05E-08	2.11E-08	0.037
U-236										3.76E-09	140	2.69E-11	5.37E-11	0
SOF-chain													5.77E-05	1.73E+04
Pu-242	0.001	0.0005	4673	14	15	13	0	100	100	1.91E-88	8.301	2.30E-89	4.59E-86	99.878
Pu-242_56										2.32E-91	8.299	2.79E-92	5.59E-89	0.122
U-238										9.01E-98	10.1	8.92E-99	1.79E-95	0
SOF-chain													4.60E-86	2.18E+85
Pu-242	0.001	0.0005	4673	14	15	13	100	1350	1350	4.04E-45	8.301	4.86E-46	9.73E-43	99.953
Pu-242_56										1.92E-48	8.299	2.31E-49	4.62E-46	0.047
U-238										6.07E-54	10.1	6.01E-55	1.20E-51	0
SOF-chain													9.73E-43	1.03E+42
Pu-242	0.001	0.0005	4671	12	15	13	1350	10000	10000	8.48E-06	8.301	1.02E-06	2.04E-03	99.963

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-242_56										3.10E-09	8.299	3.73E-10	7.46E-07	0.037
U-238										6.50E-13	10.1	6.43E-14	1.29E-10	0
SOF-chain													2.04E-03	4.89E+02
Pu-242	0.01	0.005	4673	14	15	13	0	100	100	3.48E-88	8.301	4.20E-89	8.39E-87	99.878
Pu-242_56										4.24E-91	8.299	5.11E-92	1.02E-89	0.122
U-238										1.65E-97	10.1	1.63E-98	3.26E-96	0
SOF-chain													8.41E-87	1.19E+86
Pu-242	0.01	0.005	4673	14	15	13	100	1350	1350	6.01E-45	8.301	7.24E-46	1.45E-43	99.953
Pu-242_56										2.85E-48	8.299	3.44E-49	6.87E-47	0.047
U-238										9.06E-54	10.1	8.97E-55	1.80E-52	0
SOF-chain													1.45E-43	6.90E+42
Pu-242	0.01	0.005	4671	12	15	13	1350	10000	10000	9.83E-06	8.301	1.18E-06	2.37E-04	99.963
Pu-242_56										3.59E-09	8.299	4.32E-10	8.65E-08	0.037
U-238										7.53E-13	10.1	7.46E-14	1.49E-11	0
SOF-chain													2.37E-04	4.22E+03
Pu-242	0.1	0.05	4673	14	15	13	0	100	100	3.49E-88	8.301	4.20E-89	8.40E-88	99.878
Pu-242_56										4.24E-91	8.299	5.11E-92	1.02E-90	0.122
U-238										1.65E-97	10.1	1.63E-98	3.26E-97	0
SOF-chain													8.41E-88	1.19E+87
Pu-242	0.1	0.05	4673	14	15	13	100	1350	1350	6.02E-45	8.301	7.25E-46	1.45E-44	99.953
Pu-242_56										2.85E-48	8.299	3.44E-49	6.88E-48	0.047
U-238										9.07E-54	10.1	8.98E-55	1.80E-53	0
SOF-chain													1.45E-44	6.89E+43
Pu-242	0.1	0.05	4671	12	15	13	1350	10000	10000	9.84E-06	8.301	1.19E-06	2.37E-05	99.963
Pu-242_56										3.59E-09	8.299	4.33E-10	8.66E-09	0.037
U-238										7.55E-13	10.1	7.47E-14	1.49E-12	0
SOF-chain													2.37E-05	4.22E+04
Pu-242	1	0.5	4673	14	15	13	0	100	100	3.51E-88	8.301	4.23E-89	8.46E-89	99.878
Pu-242_56										4.27E-91	8.299	5.15E-92	1.03E-91	0.122
U-238										1.66E-97	10.1	1.64E-98	3.29E-98	0
SOF-chain													8.47E-89	1.18E+88
Pu-242	1	0.5	4673	14	15	13	100	1350	1350	6.07E-45	8.301	7.32E-46	1.46E-45	99.953
Pu-242_56										2.88E-48	8.299	3.47E-49	6.94E-49	0.047

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
U-238										9.15E-54	10.1	9.06E-55	1.81E-54	0
SOF-chain													1.46E-45	6.83E+44
Pu-242	1	0.5	4671	12	15	13	1350	10000	10000	9.96E-06	8.301	1.20E-06	2.40E-06	99.963
Pu-242_56										3.64E-09	8.299	4.38E-10	8.76E-10	0.037
U-238										7.67E-13	10.1	7.60E-14	1.52E-13	0
SOF-chain													2.40E-06	4.17E+05
Pu-244	0.001	0.0005	4673	14	15	13	0	100	100	1.62E-90	8.597	1.89E-91	3.78E-88	99.878
Pu-244_56										1.98E-93	8.598	2.30E-94	4.60E-91	0.122
SOF-chain													3.78E-88	2.64E+87
Pu-244	0.001	0.0005	4673	14	15	13	100	1350	1350	2.81E-47	8.597	3.27E-48	6.53E-45	99.953
Pu-244_56										1.33E-50	8.598	1.55E-51	3.10E-48	0.047
SOF-chain													6.53E-45	1.53E+44
Pu-244	0.001	0.0005	4671	12	15	13	1350	10000	10000	4.66E-08	8.597	5.42E-09	1.08E-05	99.964
Pu-244_56										1.70E-11	8.598	1.98E-12	3.96E-09	0.036
SOF-chain													1.08E-05	9.23E+04
Pu-244	0.01	0.005	4673	14	15	13	0	100	100	1.65E-90	8.597	1.92E-91	3.83E-89	99.878
Pu-244_56										2.01E-93	8.598	2.33E-94	4.66E-92	0.122
SOF-chain													3.84E-89	2.61E+88
Pu-244	0.01	0.005	4673	14	15	13	100	1350	1350	2.86E-47	8.597	3.33E-48	6.66E-46	99.953
Pu-244_56										1.36E-50	8.598	1.58E-51	3.16E-49	0.047
SOF-chain													6.66E-46	1.50E+45
Pu-244	0.01	0.005	4671	12	15	13	1350	10000	10000	4.78E-08	8.597	5.56E-09	1.11E-06	99.964
Pu-244_56										1.74E-11	8.598	2.03E-12	4.06E-10	0.036
SOF-chain													1.11E-06	9.00E+05
Pu-244	0.1	0.05	4673	14	15	13	0	100	100	1.89E-90	8.597	2.20E-91	4.39E-90	99.878
Pu-244_56										2.30E-93	8.598	2.67E-94	5.35E-93	0.122
SOF-chain													4.40E-90	2.27E+89
Pu-244	0.1	0.05	4673	14	15	13	100	1350	1350	3.41E-47	8.597	3.97E-48	7.93E-47	99.953
Pu-244_56										1.62E-50	8.598	1.88E-51	3.76E-50	0.047
SOF-chain													7.94E-47	1.26E+46
Pu-244	0.1	0.05	4671	12	15	13	1350	10000	10000	5.95E-08	8.597	6.92E-09	1.38E-07	99.964
Pu-244_56										2.17E-11	8.598	2.53E-12	5.05E-11	0.036
SOF-chain													1.38E-07	7.22E+06

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-244	1	0.5	4673	14	15	13	0	100	100	3.19E-90	8.597	3.71E-91	7.41E-91	99.878
Pu-244_56										3.88E-93	8.598	4.51E-94	9.02E-94	0.122
SOF-chain													7.42E-91	1.35E+90
Pu-244	1	0.5	4673	14	15	13	100	1350	1350	5.60E-47	8.597	6.52E-48	1.30E-47	99.953
Pu-244_56										2.66E-50	8.598	3.09E-51	6.18E-51	0.047
SOF-chain													1.30E-47	7.67E+46
Pu-244	1	0.5	4671	12	15	13	1350	10000	10000	9.30E-08	8.597	1.08E-08	2.16E-08	99.964
Pu-244_56										3.40E-11	8.598	3.95E-12	7.90E-12	0.036
SOF-chain													2.16E-08	4.62E+07
Am-243	0.001	0.0005	4673	14	15	13	0	100	100	4.16E-112	7.6	5.47E-113	1.10E-109	0
Pu-239										3.92E-92	8.1	4.84E-93	9.68E-90	99.879
Pu-239_56										4.76E-95	8.101	5.88E-96	1.18E-92	0.121
U-234										3.38E-97	130	2.60E-99	5.20E-96	0
SOF-chain													9.69E-90	1.03E+89
Am-243	0.001	0.0005	4673	14	15	13	100	1350	1350	1.60E-68	7.6	2.10E-69	4.20E-66	0
Pu-239										7.29E-47	8.1	9.00E-48	1.80E-44	99.952
Pu-239_56										3.47E-50	8.101	4.29E-51	8.57E-48	0.048
U-234										1.97E-51	130	1.52E-53	3.03E-50	0
SOF-chain													1.80E-44	5.55E+43
Am-243	0.001	0.0005	4671	12	15	13	1350	10000	10000	3.39E-22	7.6	4.46E-23	8.91E-20	0
Pu-239										2.89E-07	8.1	3.57E-08	7.14E-05	99.955
Pu-239_56										1.06E-10	8.101	1.30E-11	2.61E-08	0.036
U-234										3.97E-10	130	3.06E-12	6.11E-09	0.009
SOF-chain													7.14E-05	1.40E+04
Am-243	0.01	0.005	4673	14	15	13	0	100	100	4.16E-111	7.6	5.47E-112	1.10E-109	0
Pu-239										3.92E-91	8.1	4.84E-92	9.68E-90	99.879
Pu-239_56										4.76E-94	8.101	5.88E-95	1.18E-92	0.121
U-234										3.38E-96	130	2.60E-98	5.20E-96	0
SOF-chain													9.69E-90	1.03E+89
Am-243	0.01	0.005	4673	14	15	13	100	1350	1350	1.60E-67	7.6	2.10E-68	4.20E-66	0
Pu-239										7.29E-46	8.1	9.00E-47	1.80E-44	99.952
Pu-239_56										3.47E-49	8.101	4.29E-50	8.57E-48	0.048
U-234										1.97E-50	130	1.52E-52	3.03E-50	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
SOF-chain													1.80E-44	5.55E+43
Am-243	0.01	0.005	4671	12	15	13	1350	10000	10000	3.39E-21	7.6	4.46E-22	8.91E-20	0
Pu-239										2.89E-06	8.1	3.57E-07	7.14E-05	99.955
Pu-239_56										1.06E-09	8.101	1.30E-10	2.61E-08	0.036
U-234										3.97E-09	130	3.06E-11	6.11E-09	0.009
SOF-chain													7.14E-05	1.40E+04
Am-243	0.1	0.05	4673	14	15	13	0	100	100	4.16E-110	7.6	5.47E-111	1.10E-109	0
Pu-239										3.92E-90	8.1	4.84E-91	9.68E-90	99.879
Pu-239_56										4.76E-93	8.101	5.88E-94	1.18E-92	0.121
U-234										3.38E-95	130	2.60E-97	5.20E-96	0
SOF-chain													9.69E-90	1.03E+89
Am-243	0.1	0.05	4673	14	15	13	100	1350	1350	1.60E-66	7.6	2.10E-67	4.20E-66	0
Pu-239										7.29E-45	8.1	9.00E-46	1.80E-44	99.952
Pu-239_56										3.47E-48	8.101	4.29E-49	8.57E-48	0.048
U-234										1.97E-49	130	1.52E-51	3.03E-50	0
SOF-chain													1.80E-44	5.55E+43
Am-243	0.1	0.05	4671	12	15	13	1350	10000	10000	3.39E-20	7.6	4.46E-21	8.91E-20	0
Pu-239										2.89E-05	8.1	3.57E-06	7.14E-05	99.955
Pu-239_56										1.06E-08	8.101	1.30E-09	2.61E-08	0.036
U-234										3.97E-08	130	3.06E-10	6.11E-09	0.009
SOF-chain													7.14E-05	1.40E+04
Am-243	1	0.5	4673	14	15	13	0	100	100	4.16E-109	7.6	5.47E-110	1.10E-109	0
Pu-239										3.92E-89	8.1	4.84E-90	9.68E-90	99.879
Pu-239_56										4.76E-92	8.101	5.88E-93	1.18E-92	0.121
U-234										3.38E-94	130	2.60E-96	5.20E-96	0
SOF-chain													9.69E-90	1.03E+89
Am-243	1	0.5	4673	14	15	13	100	1350	1350	1.60E-65	7.6	2.10E-66	4.20E-66	0
Pu-239										7.20E-44	8.1	8.89E-45	1.78E-44	99.952
Pu-239_56										3.43E-47	8.101	4.23E-48	8.46E-48	0.048
U-234										1.95E-48	130	1.50E-50	3.00E-50	0
SOF-chain													1.78E-44	5.63E+43
Am-243	1	0.5	4671	12	15	13	1350	10000	10000	3.39E-19	7.6	4.46E-20	8.91E-20	0
Pu-239										1.28E-04	8.1	1.58E-05	3.15E-05	99.955

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-239_56										4.66E-08	8.101	5.76E-09	1.15E-08	0.036
U-234										1.81E-07	130	1.39E-09	2.79E-09	0.009
SOF-chain													3.16E-05	3.17E+04
Cm-245	0.001	0.0005	4673	14	15	13	0	100	100	4.05E-122	7.6	5.33E-123	1.07E-119	0
Pu-241										3.63E-91	300.8	1.21E-93	2.41E-90	0
Pu-241_56										8.93E-92	54520	1.64E-96	3.28E-93	0
Am-241										5.87E-94	7.6	7.72E-95	1.55E-91	0
Np-237										2.37E-44	8.9	2.66E-45	5.33E-42	100
SOF-chain													5.33E-42	1.88E+41
Cm-245	0.001	0.0005	4671	12	15	13	100	1350	1350	7.99E-79	7.6	1.05E-79	2.10E-76	0
Pu-241										9.11E-53	300.8	3.03E-55	6.06E-52	0
Pu-241_56										8.65E-54	54520	1.59E-58	3.17E-55	0
Am-241										5.57E-55	7.6	7.33E-56	1.47E-52	0
Np-237										9.20E-13	8.9	1.03E-13	2.07E-10	100
SOF-chain													2.07E-10	4.84E+09
Cm-245	0.001	0.0005	3871	12	15	11	1350	10000	10000	3.18E-34	7.6	4.19E-35	8.38E-32	0
Pu-241										1.18E-32	300.8	3.93E-35	7.86E-32	0
Pu-241_56										8.64E-34	54520	1.59E-38	3.17E-35	0
Am-241										5.92E-29	7.6	7.79E-30	1.56E-26	0
Np-237										5.37E-07	8.9	6.04E-08	1.21E-04	100
SOF-chain													1.21E-04	8.28E+03
Cm-245	0.01	0.005	4673	14	15	13	0	100	100	4.05E-121	7.6	5.33E-122	1.07E-119	0
Pu-241										3.63E-90	300.8	1.21E-92	2.41E-90	0
Pu-241_56										8.93E-91	54520	1.64E-95	3.28E-93	0
Am-241										5.87E-93	7.6	7.72E-94	1.55E-91	0
Np-237										2.37E-43	8.9	2.66E-44	5.33E-42	100
SOF-chain													5.33E-42	1.88E+41
Cm-245	0.01	0.005	4671	12	15	13	100	1350	1350	7.99E-78	7.6	1.05E-78	2.10E-76	0
Pu-241										9.12E-52	300.8	3.03E-54	6.06E-52	0
Pu-241_56										8.65E-53	54520	1.59E-57	3.17E-55	0
Am-241										5.58E-54	7.6	7.34E-55	1.47E-52	0
Np-237										9.20E-12	8.9	1.03E-12	2.07E-10	100
SOF-chain													2.07E-10	4.84E+09

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Cm-245	0.01	0.005	3871	12	15	11	1350	10000	10000	3.18E-33	7.6	4.19E-34	8.38E-32	0
Pu-241										1.18E-31	300.8	3.93E-34	7.86E-32	0
Pu-241_56										8.64E-33	54520	1.59E-37	3.17E-35	0
Am-241										5.92E-28	7.6	7.79E-29	1.56E-26	0
Np-237										5.37E-06	8.9	6.04E-07	1.21E-04	100
SOF-chain													1.21E-04	8.28E+03
Cm-245	0.1	0.05	4673	14	15	13	0	100	100	4.05E-120	7.6	5.33E-121	1.07E-119	0
Pu-241										3.63E-89	300.8	1.21E-91	2.41E-90	0
Pu-241_56										8.93E-90	54520	1.64E-94	3.28E-93	0
Am-241										5.87E-92	7.6	7.73E-93	1.55E-91	0
Np-237										2.37E-42	8.9	2.66E-43	5.33E-42	100
SOF-chain													5.33E-42	1.88E+41
Cm-245	0.1	0.05	4671	12	15	13	100	1350	1350	7.99E-77	7.6	1.05E-77	2.10E-76	0
Pu-241										9.12E-51	300.8	3.03E-53	6.06E-52	0
Pu-241_56										8.65E-52	54520	1.59E-56	3.17E-55	0
Am-241										5.57E-53	7.6	7.33E-54	1.47E-52	0
Np-237										9.20E-11	8.9	1.03E-11	2.07E-10	100
SOF-chain													2.07E-10	4.84E+09
Cm-245	0.1	0.05	3871	12	15	11	1350	10000	10000	3.18E-32	7.6	4.19E-33	8.38E-32	0
Pu-241										1.18E-30	300.8	3.93E-33	7.86E-32	0
Pu-241_56										8.64E-32	54520	1.59E-36	3.17E-35	0
Am-241										5.92E-27	7.6	7.79E-28	1.56E-26	0
Np-237										5.37E-05	8.9	6.04E-06	1.21E-04	100
SOF-chain													1.21E-04	8.28E+03
Cm-245	1	0.5	4673	14	15	13	0	100	100	4.05E-119	7.6	5.33E-120	1.07E-119	0
Pu-241										1.85E-88	300.8	6.15E-91	1.23E-90	0
Pu-241_56										4.86E-89	54520	8.92E-94	1.78E-93	0
Am-241										2.90E-91	7.6	3.81E-92	7.63E-92	0
Np-237										1.29E-41	8.9	1.44E-42	2.89E-42	100
SOF-chain													2.89E-42	3.46E+41
Cm-245	1	0.5	4671	12	15	13	100	1350	1350	7.99E-76	7.6	1.05E-76	2.10E-76	0
Pu-241										9.12E-50	300.8	3.03E-52	6.06E-52	0
Pu-241_56										8.65E-51	54520	1.59E-55	3.17E-55	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Am-241										5.57E-52	7.6	7.33E-53	1.47E-52	0
Np-237										9.20E-10	8.9	1.03E-10	2.07E-10	100
SOF-chain													2.07E-10	4.84E+09
Cm-245	1	0.5	3871	12	15	11	1350	10000	10000	3.18E-31	7.6	4.19E-32	8.38E-32	0
Pu-241										1.18E-29	300.8	3.93E-32	7.86E-32	0
Pu-241_56										8.64E-31	54520	1.59E-35	3.17E-35	0
Am-241										5.92E-26	7.6	7.79E-27	1.56E-26	0
Np-237										5.37E-04	8.9	6.04E-05	1.21E-04	100
SOF-chain													1.21E-04	8.28E+03
Cm-246	1	0.5	4673	14	15	13	0	100	100	4.02E-119	7.6	5.29E-120	1.06E-119	0
SOF-chain													1.06E-119	1.00E+99
Cm-246	1	0.5	4673	14	15	13	100	1350	1350	1.58E-75	7.6	2.08E-76	4.16E-76	100
SOF-chain													4.16E-76	2.40E+75
Cm-246	1	0.5	4673	14	15	13	1350	10000	10000	4.57E-28	7.6	6.01E-29	1.20E-28	100
SOF-chain													1.20E-28	8.32E+27
Cm-247	0.001	0.0005	4673	14	15	13	0	100	100	4.09E-122	8.3	4.93E-123	9.85E-120	0
Am-243										7.04E-115	7.6	9.27E-116	1.85E-112	0
Np-239										8.12E-50	300	2.71E-52	5.42E-49	99.987
Pu-239										2.84E-55	8.1	3.51E-56	7.01E-53	0.013
Pu-239_56										1.04E-58	8.101	1.28E-59	2.56E-56	0
SOF-chain													5.42E-49	1.85E+48
Cm-247	0.001	0.0005	4673	14	15	13	100	1350	1350	1.93E-78	8.3	2.32E-79	4.65E-76	0
Am-243										1.49E-69	7.6	1.96E-70	3.92E-67	0
Np-239										2.20E-20	300	7.34E-23	1.47E-19	99.907
Pu-239										5.51E-25	8.1	6.81E-26	1.36E-22	0.093
Pu-239_56										2.03E-28	8.101	2.50E-29	5.00E-26	0
SOF-chain													1.47E-19	6.81E+18
Cm-247	0.001	0.0005	4671	12	15	13	1350	10000	10000	1.01E-30	8.3	1.22E-31	2.44E-28	0
Am-243										1.01E-22	7.6	1.32E-23	2.65E-20	0
Np-239										5.59E-13	300	1.86E-15	3.73E-12	0
Pu-239										2.70E-08	8.1	3.33E-09	6.66E-06	99.963
Pu-239_56										9.85E-12	8.101	1.22E-12	2.43E-09	0.037
SOF-chain													6.66E-06	1.50E+05

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Cm-247	0.01	0.005	4673	14	15	13	0	100	100	4.09E-121	8.3	4.93E-122	9.85E-120	0
Am-243										7.04E-114	7.6	9.27E-115	1.85E-112	0
Np-239										8.12E-49	300	2.71E-51	5.42E-49	99.987
Pu-239										2.84E-54	8.1	3.51E-55	7.01E-53	0.013
Pu-239_56										1.04E-57	8.101	1.28E-58	2.56E-56	0
SOF-chain													5.42E-49	1.85E+48
Cm-247	0.01	0.005	4673	14	15	13	100	1350	1350	1.93E-77	8.3	2.32E-78	4.65E-76	0
Am-243										1.49E-68	7.6	1.96E-69	3.92E-67	0
Np-239										2.20E-19	300	7.34E-22	1.47E-19	99.907
Pu-239										5.51E-24	8.1	6.81E-25	1.36E-22	0.093
Pu-239_56										2.03E-27	8.101	2.50E-28	5.00E-26	0
SOF-chain													1.47E-19	6.81E+18
Cm-247	0.01	0.005	4671	12	15	13	1350	10000	10000	1.01E-29	8.3	1.22E-30	2.44E-28	0
Am-243										1.01E-21	7.6	1.32E-22	2.65E-20	0
Np-239										5.59E-12	300	1.86E-14	3.73E-12	0
Pu-239										2.70E-07	8.1	3.33E-08	6.66E-06	99.963
Pu-239_56										9.85E-11	8.101	1.22E-11	2.43E-09	0.037
SOF-chain													6.66E-06	1.50E+05
Cm-247	0.1	0.05	4673	14	15	13	0	100	100	4.09E-120	8.3	4.93E-121	9.85E-120	0
Am-243										7.04E-113	7.6	9.27E-114	1.85E-112	0
Np-239										8.12E-48	300	2.71E-50	5.42E-49	99.987
Pu-239										2.84E-53	8.1	3.51E-54	7.01E-53	0.013
Pu-239_56										1.04E-56	8.101	1.28E-57	2.56E-56	0
SOF-chain													5.42E-49	1.85E+48
Cm-247	0.1	0.05	4673	14	15	13	100	1350	1350	1.93E-76	8.3	2.32E-77	4.65E-76	0
Am-243										1.49E-67	7.6	1.96E-68	3.92E-67	0
Np-239										2.20E-18	300	7.34E-21	1.47E-19	99.907
Pu-239										5.51E-23	8.1	6.81E-24	1.36E-22	0.093
Pu-239_56										2.03E-26	8.101	2.50E-27	5.00E-26	0
SOF-chain													1.47E-19	6.81E+18
Cm-247	0.1	0.05	4671	12	15	13	1350	10000	10000	1.01E-28	8.3	1.22E-29	2.44E-28	0
Am-243										1.01E-20	7.6	1.32E-21	2.65E-20	0
Np-239										5.59E-11	300	1.86E-13	3.73E-12	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-239										2.70E-06	8.1	3.33E-07	6.66E-06	99.963
Pu-239_56										9.85E-10	8.101	1.22E-10	2.43E-09	0.037
SOF-chain													6.66E-06	1.50E+05
Cm-247	1	0.5	4673	14	15	13	0	100	100	4.09E-119	8.3	4.93E-120	9.85E-120	0
Am-243										7.04E-112	7.6	9.27E-113	1.85E-112	0
Np-239										8.12E-47	300	2.71E-49	5.42E-49	99.987
Pu-239										2.84E-52	8.1	3.51E-53	7.01E-53	0.013
Pu-239_56										1.04E-55	8.101	1.28E-56	2.56E-56	0
SOF-chain													5.42E-49	1.85E+48
Cm-247	1	0.5	4673	14	15	13	100	1350	1350	1.93E-75	8.3	2.32E-76	4.65E-76	0
Am-243										1.49E-66	7.6	1.96E-67	3.92E-67	0
Np-239										2.20E-17	300	7.34E-20	1.47E-19	99.907
Pu-239										5.51E-22	8.1	6.81E-23	1.36E-22	0.093
Pu-239_56										2.03E-25	8.101	2.50E-26	5.00E-26	0
SOF-chain													1.47E-19	6.81E+18
Cm-247	1	0.5	4671	12	15	13	1350	10000	10000	1.01E-27	8.3	1.22E-28	2.44E-28	0
Am-243										1.01E-19	7.6	1.32E-20	2.65E-20	0
Np-239										5.59E-10	300	1.86E-12	3.73E-12	0
Pu-239										2.70E-05	8.1	3.33E-06	6.66E-06	99.963
Pu-239_56										9.85E-09	8.101	1.22E-09	2.43E-09	0.037
SOF-chain													6.66E-06	1.50E+05
Cm-248	0.001	0.0005	4673	14	15	13	0	100	100	4.09E-122	2.1	1.95E-122	3.89E-119	0
Pu-244										1.18E-95	8.597	1.38E-96	2.75E-93	99.879
Pu-244_56										1.44E-98	8.598	1.67E-99	3.34E-96	0.121
SOF-chain													2.76E-93	3.63E+92
Cm-248	0.001	0.0005	4673	14	15	13	100	1350	1350	1.92E-78	2.1	9.16E-79	1.83E-75	0
Pu-244										2.33E-50	8.597	2.71E-51	5.43E-48	99.952
Pu-244_56										1.11E-53	8.598	1.29E-54	2.59E-51	0.048
SOF-chain													5.43E-48	1.84E+47
Cm-248	0.001	0.0005	4671	12	15	13	1350	10000	10000	9.92E-31	2.1	4.72E-31	9.45E-28	0
Pu-244										1.23E-10	8.597	1.43E-11	2.86E-08	99.963
Pu-244_56										4.49E-14	8.598	5.22E-15	1.05E-11	0.037
SOF-chain													2.86E-08	3.49E+07

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Cm-248	0.01	0.005	4673	14	15	13	0	100	100	4.09E-121	2.1	1.95E-121	3.89E-119	0
Pu-244										1.18E-94	8.597	1.38E-95	2.75E-93	99.879
Pu-244_56										1.44E-97	8.598	1.67E-98	3.34E-96	0.121
SOF-chain													2.76E-93	3.63E+92
Cm-248	0.01	0.005	4673	14	15	13	100	1350	1350	1.92E-77	2.1	9.16E-78	1.83E-75	0
Pu-244										2.33E-49	8.597	2.71E-50	5.43E-48	99.952
Pu-244_56										1.11E-52	8.598	1.29E-53	2.59E-51	0.048
SOF-chain													5.43E-48	1.84E+47
Cm-248	0.01	0.005	4671	12	15	13	1350	10000	10000	9.92E-30	2.1	4.72E-30	9.45E-28	0
Pu-244										1.23E-09	8.597	1.43E-10	2.86E-08	99.963
Pu-244_56										4.49E-13	8.598	5.22E-14	1.05E-11	0.037
SOF-chain													2.86E-08	3.49E+07
Cm-248	0.1	0.05	4673	14	15	13	0	100	100	4.09E-120	2.1	1.95E-120	3.89E-119	0
Pu-244										1.18E-93	8.597	1.38E-94	2.75E-93	99.879
Pu-244_56										1.44E-96	8.598	1.67E-97	3.35E-96	0.121
SOF-chain													2.76E-93	3.63E+92
Cm-248	0.1	0.05	4673	14	15	13	100	1350	1350	1.92E-76	2.1	9.16E-77	1.83E-75	0
Pu-244										2.33E-48	8.597	2.71E-49	5.43E-48	99.952
Pu-244_56										1.11E-51	8.598	1.29E-52	2.59E-51	0.048
SOF-chain													5.43E-48	1.84E+47
Cm-248	0.1	0.05	4671	12	15	13	1350	10000	10000	9.92E-29	2.1	4.72E-29	9.45E-28	0
Pu-244										1.23E-08	8.597	1.43E-09	2.86E-08	99.963
Pu-244_56										4.49E-12	8.598	5.22E-13	1.05E-11	0.037
SOF-chain													2.86E-08	3.49E+07
Cm-248	1	0.5	4673	14	15	13	0	100	100	4.09E-119	2.1	1.95E-119	3.89E-119	0
Pu-244										1.18E-92	8.597	1.38E-93	2.75E-93	99.879
Pu-244_56										1.44E-95	8.598	1.67E-96	3.35E-96	0.121
SOF-chain													2.76E-93	3.63E+92
Cm-248	1	0.5	4673	14	15	13	100	1350	1350	1.92E-75	2.1	9.16E-76	1.83E-75	0
Pu-244										2.29E-47	8.597	2.66E-48	5.33E-48	99.952
Pu-244_56										1.09E-50	8.598	1.27E-51	2.54E-51	0.048
SOF-chain													5.33E-48	1.88E+47
Cm-248	1	0.5	4671	12	15	13	1350	10000	10000	9.92E-28	2.1	4.72E-28	9.45E-28	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-244										4.95E-08	8.597	5.76E-09	1.15E-08	99.964
Pu-244_56										1.81E-11	8.598	2.10E-12	4.21E-12	0.036
SOF-chain													1.15E-08	8.68E+07
Cf-249	0.001	0.0005	4673	14	15	13	0	100	100	1.52E-94	7.4	2.05E-95	4.11E-92	0
Cm-245										6.43E-99	7.6	8.46E-100	1.69E-96	0
Pu-241										7.69E-95	300.8	2.56E-97	5.11E-94	0
Pu-241_56										2.22E-95	54520	4.08E-100	8.16E-97	0
Am-241										1.16E-97	7.6	1.53E-98	3.06E-95	0
Np-237										4.31E-48	8.9	4.84E-49	9.69E-46	100
SOF-chain													9.69E-46	1.03E+45
Cf-249	0.001	0.0005	4671	12	15	13	100	1350	1350	1.69E-52	7.4	2.28E-53	4.57E-50	0
Cm-245										2.32E-56	7.6	3.05E-57	6.10E-54	0
Pu-241										4.32E-54	300.8	1.44E-56	2.87E-53	0
Pu-241_56										4.11E-55	54520	7.54E-60	1.51E-56	0
Am-241										2.53E-56	7.6	3.33E-57	6.65E-54	0
Np-237										2.37E-14	8.9	2.66E-15	5.32E-12	100
SOF-chain													5.32E-12	1.88E+11
Cf-249	0.001	0.0005	3871	12	15	11	1350	10000	10000	4.31E-19	7.4	5.83E-20	1.17E-16	0
Cm-245										7.85E-21	7.6	1.03E-21	2.07E-18	0
Pu-241										9.07E-20	300.8	3.02E-22	6.03E-19	0
Pu-241_56										6.01E-21	54520	1.10E-25	2.21E-22	0
Am-241										1.57E-20	7.6	2.06E-21	4.13E-18	0
Np-237										2.17E-08	8.9	2.44E-09	4.89E-06	100
SOF-chain													4.89E-06	2.05E+05
Cf-249	0.01	0.005	4673	14	15	13	0	100	100	1.52E-93	7.4	2.05E-94	4.11E-92	0
Cm-245										6.43E-98	7.6	8.46E-99	1.69E-96	0
Pu-241										7.69E-94	300.8	2.56E-96	5.11E-94	0
Pu-241_56										2.22E-94	54520	4.08E-99	8.16E-97	0
Am-241										1.16E-96	7.6	1.53E-97	3.06E-95	0
Np-237										4.31E-47	8.9	4.85E-48	9.69E-46	100
SOF-chain													9.69E-46	1.03E+45
Cf-249	0.01	0.005	4671	12	15	13	100	1350	1350	1.69E-51	7.4	2.28E-52	4.57E-50	0
Cm-245										2.32E-55	7.6	3.05E-56	6.10E-54	0

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Pu-241										4.32E-53	300.8	1.44E-55	2.87E-53	0
Pu-241_56										4.11E-54	54520	7.54E-59	1.51E-56	0
Am-241										2.53E-55	7.6	3.33E-56	6.66E-54	0
Np-237										2.37E-13	8.9	2.66E-14	5.32E-12	100
SOF-chain													5.32E-12	1.88E+11
Cf-249	0.01	0.005	3871	12	15	11	1350	10000	10000	4.31E-18	7.4	5.83E-19	1.17E-16	0
Cm-245										7.85E-20	7.6	1.03E-20	2.07E-18	0
Pu-241										9.07E-19	300.8	3.02E-21	6.03E-19	0
Pu-241_56										6.01E-20	54520	1.10E-24	2.21E-22	0
Am-241										1.57E-19	7.6	2.06E-20	4.13E-18	0
Np-237										2.17E-07	8.9	2.44E-08	4.89E-06	100
SOF-chain													4.89E-06	2.05E+05
Cf-249	0.1	0.05	4673	14	15	13	0	100	100	1.52E-92	7.4	2.05E-93	4.11E-92	0
Cm-245										6.43E-97	7.6	8.46E-98	1.69E-96	0
Pu-241										7.69E-93	300.8	2.56E-95	5.11E-94	0
Pu-241_56										2.22E-93	54520	4.08E-98	8.16E-97	0
Am-241										1.16E-95	7.6	1.53E-96	3.06E-95	0
Np-237										4.31E-46	8.9	4.85E-47	9.69E-46	100
SOF-chain													9.69E-46	1.03E+45
Cf-249	0.1	0.05	4671	12	15	13	100	1350	1350	1.69E-50	7.4	2.28E-51	4.57E-50	0
Cm-245										2.32E-54	7.6	3.05E-55	6.10E-54	0
Pu-241										4.32E-52	300.8	1.44E-54	2.87E-53	0
Pu-241_56										4.11E-53	54520	7.54E-58	1.51E-56	0
Am-241										2.53E-54	7.6	3.33E-55	6.66E-54	0
Np-237										2.37E-12	8.9	2.66E-13	5.32E-12	100
SOF-chain													5.32E-12	1.88E+11
Cf-249	0.1	0.05	3871	12	15	11	1350	10000	10000	4.31E-17	7.4	5.83E-18	1.17E-16	0
Cm-245										7.85E-19	7.6	1.03E-19	2.07E-18	0
Pu-241										9.07E-18	300.8	3.02E-20	6.03E-19	0
Pu-241_56										6.01E-19	54520	1.10E-23	2.21E-22	0
Am-241										1.57E-18	7.6	2.06E-19	4.13E-18	0
Np-237										2.17E-06	8.9	2.44E-07	4.89E-06	100
SOF-chain													4.89E-06	2.05E+05

nuclide chain	model inventory (Ci)	disposal unit inventory (Ci)	element	node I	node J	node K	start time (yr)	end time (yr)	time of peak (yr)	groundwater concentration at peak SOF (pCi/L)	concentration limit (pCi/L)	concentration ratio	fraction or SOF: ratio per disposal unit inventory (1/Ci)	limit (Ci) or % of limit
Cf-249	1	0.5	4673	14	15	13	0	100	100	1.52E-91	7.4	2.05E-92	4.11E-92	0
Cm-245										6.43E-96	7.6	8.46E-97	1.69E-96	0
Pu-241										7.69E-92	300.8	2.56E-94	5.11E-94	0
Pu-241_56										2.22E-92	54520	4.08E-97	8.16E-97	0
Am-241										1.16E-94	7.6	1.53E-95	3.06E-95	0
Np-237										4.31E-45	8.9	4.85E-46	9.69E-46	100
SOF-chain													9.69E-46	1.03E+45
Cf-249	1	0.5	4671	12	15	13	100	1350	1350	1.69E-49	7.4	2.28E-50	4.57E-50	0
Cm-245										2.32E-53	7.6	3.05E-54	6.10E-54	0
Pu-241										4.32E-51	300.8	1.44E-53	2.87E-53	0
Pu-241_56										4.11E-52	54520	7.54E-57	1.51E-56	0
Am-241										2.53E-53	7.6	3.33E-54	6.66E-54	0
Np-237										2.37E-11	8.9	2.66E-12	5.32E-12	100
SOF-chain													5.32E-12	1.88E+11
Cf-249	1	0.5	3871	12	15	11	1350	10000	10000	4.31E-16	7.4	5.83E-17	1.17E-16	0
Cm-245										7.85E-18	7.6	1.03E-18	2.07E-18	0
Pu-241										9.07E-17	300.8	3.02E-19	6.03E-19	0
Pu-241_56										6.01E-18	54520	1.10E-22	2.21E-22	0
Am-241										1.57E-17	7.6	2.06E-18	4.13E-18	0
Np-237										2.17E-05	8.9	2.44E-06	4.89E-06	100
SOF-chain													4.89E-06	2.05E+05

Plots of peak water table flux and 100 meter well concentration from PORFLOW aquifer transport simulations

Figures A-8 through A-94 show PORFLOW flux and concentration data in graphical form, with the exception of Zr-95, Nb-95, Po-210, Th-228, which were too short-lived to produce meaningful groundwater concentrations. These figures were automatically generated using computer batch files from a generic template, which introduces minor formatting problems. The labels “C”, “C2”, etc. refer to sequential members of the chain being modeled. The chain is defined in the figure caption. A key is provided for up to 6 species in the groundwater concentration plots, but typically a smaller number of species is present. Each case plotted is a combination of a nuclide parent and an initial inventory (Ci) for 2 disposal units denoted by the label “parent_inventory”.

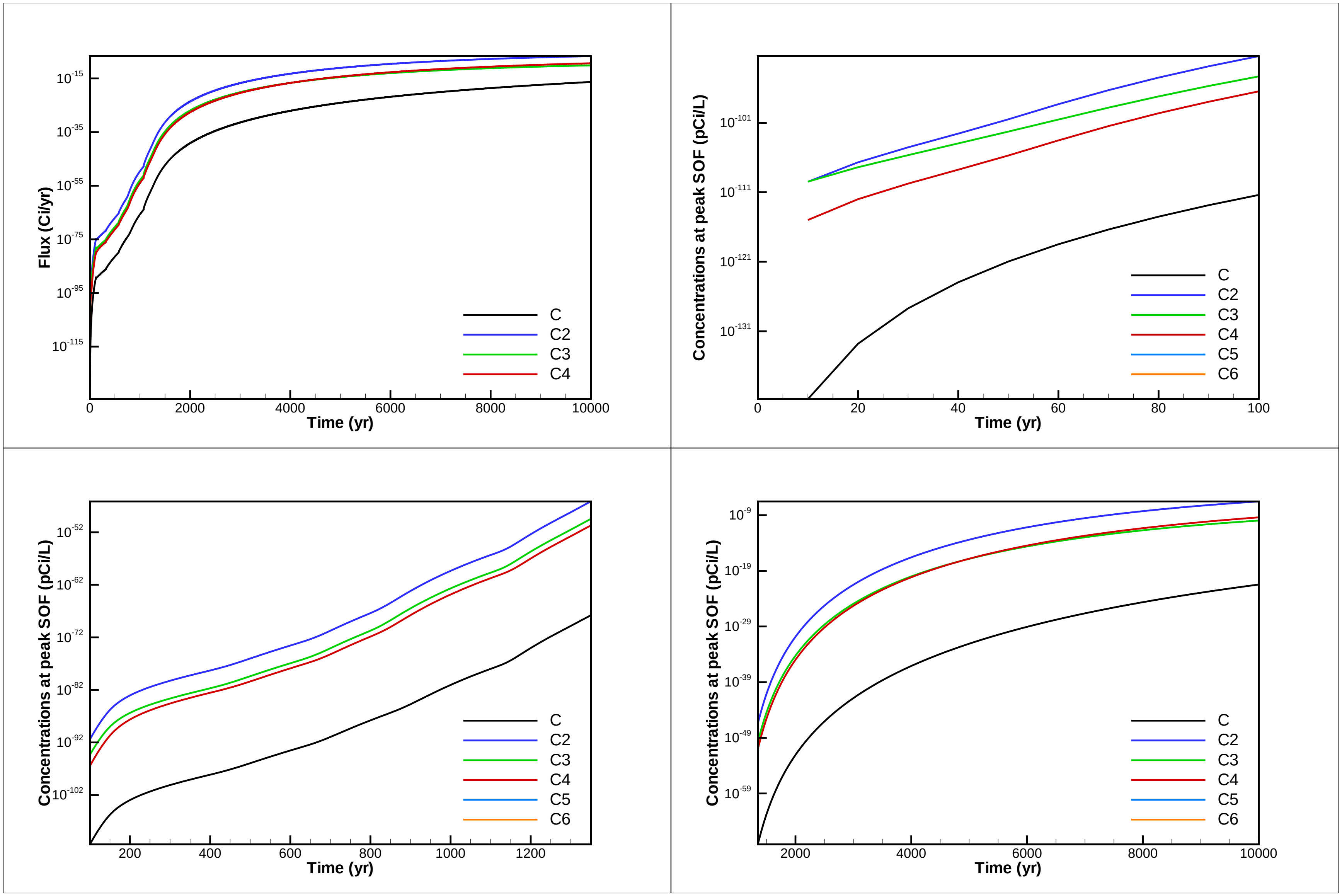


Figure A-8. Flux and concentration results for case Am-243_0.001: Am-243 Pu-239 Pu-239_56 U-234

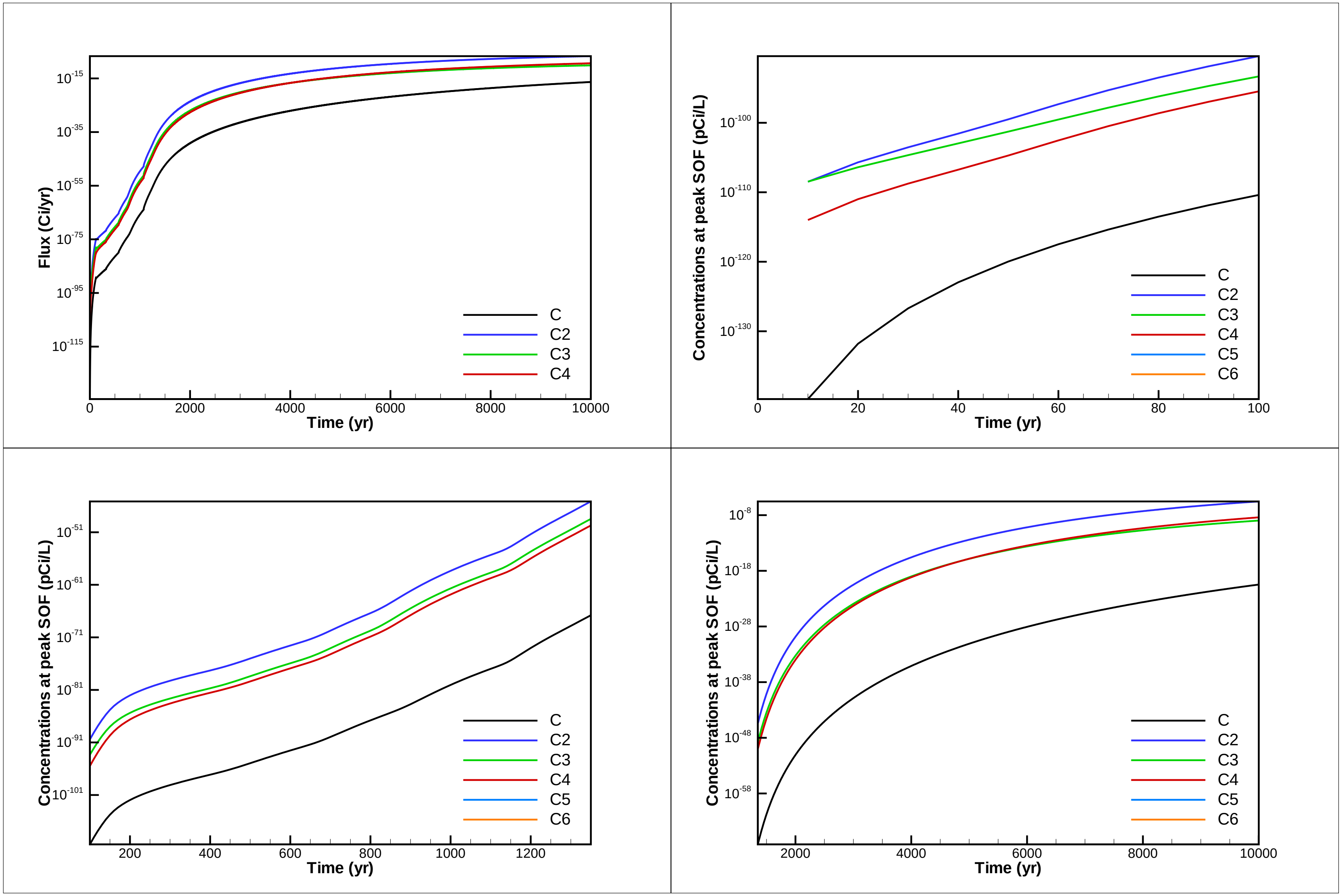


Figure A-9. Flux and concentration results for case Am-243_0.01: Am-243 Pu-239 Pu-239_56 U-234

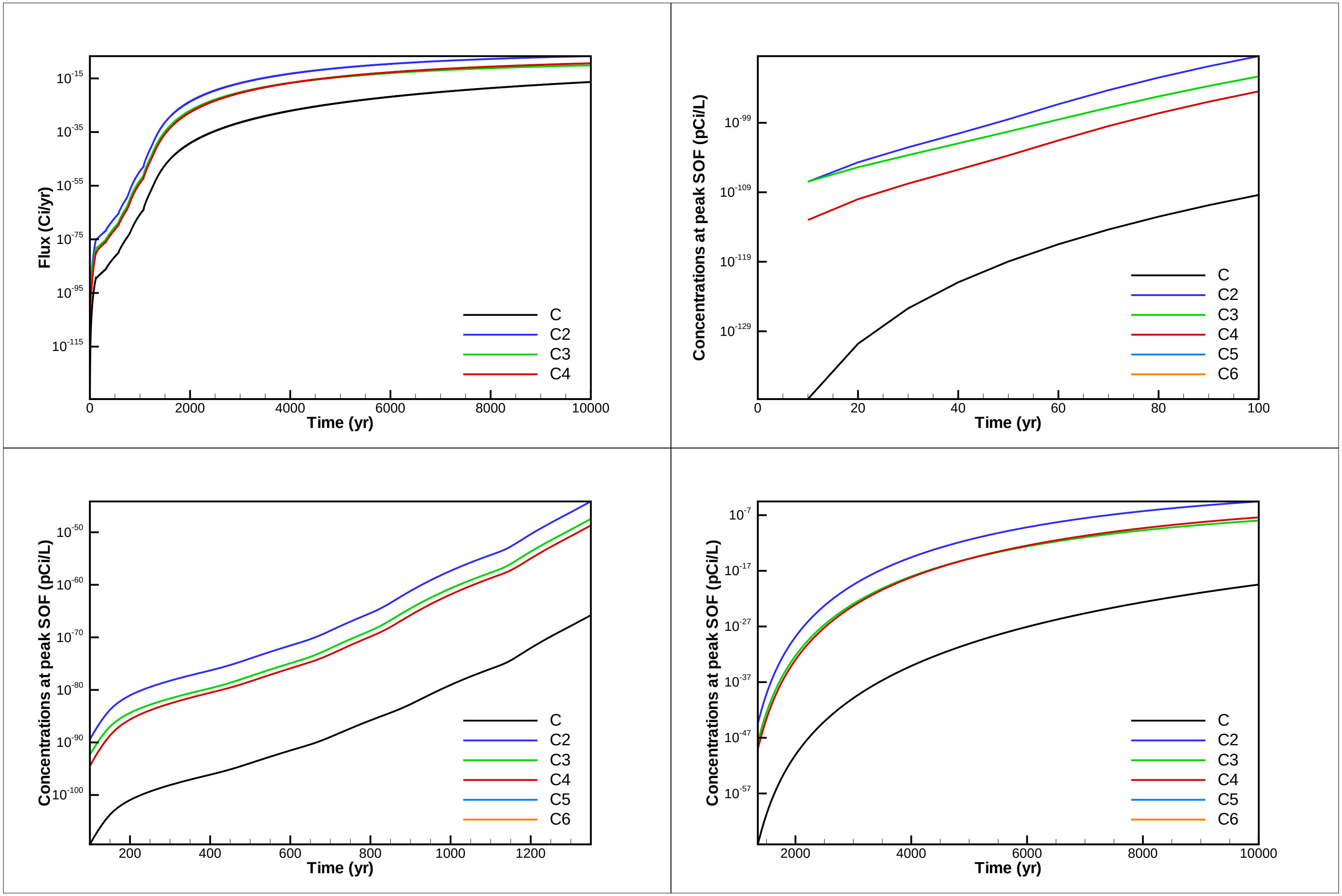


Figure A-10. Flux and concentration results for case Am-243_0.1: Am-243 Pu-239 Pu-239_56 U-234

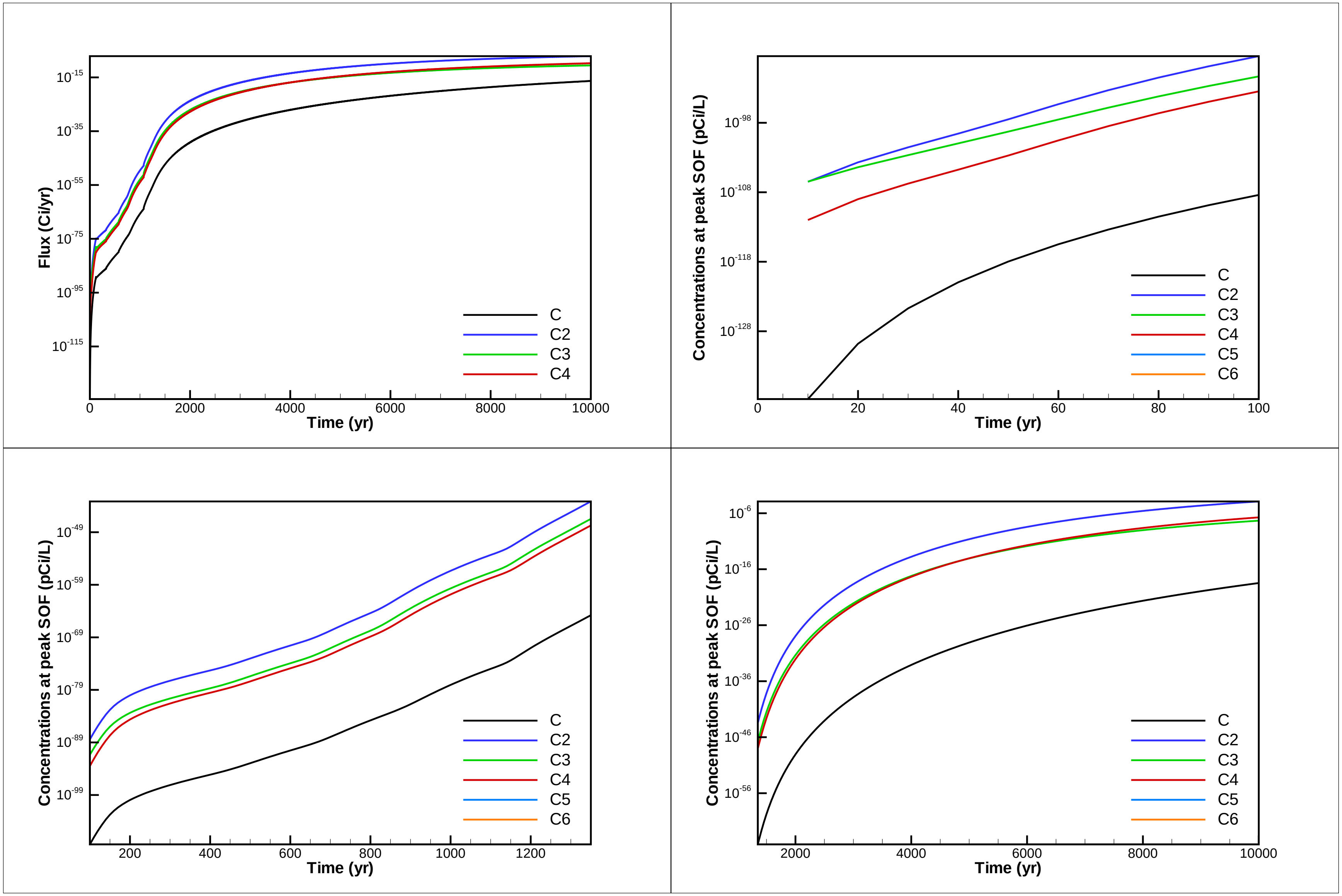


Figure A-11. Flux and concentration results for case Am-243_1: Am-243 Pu-239 Pu-239_56 U-234

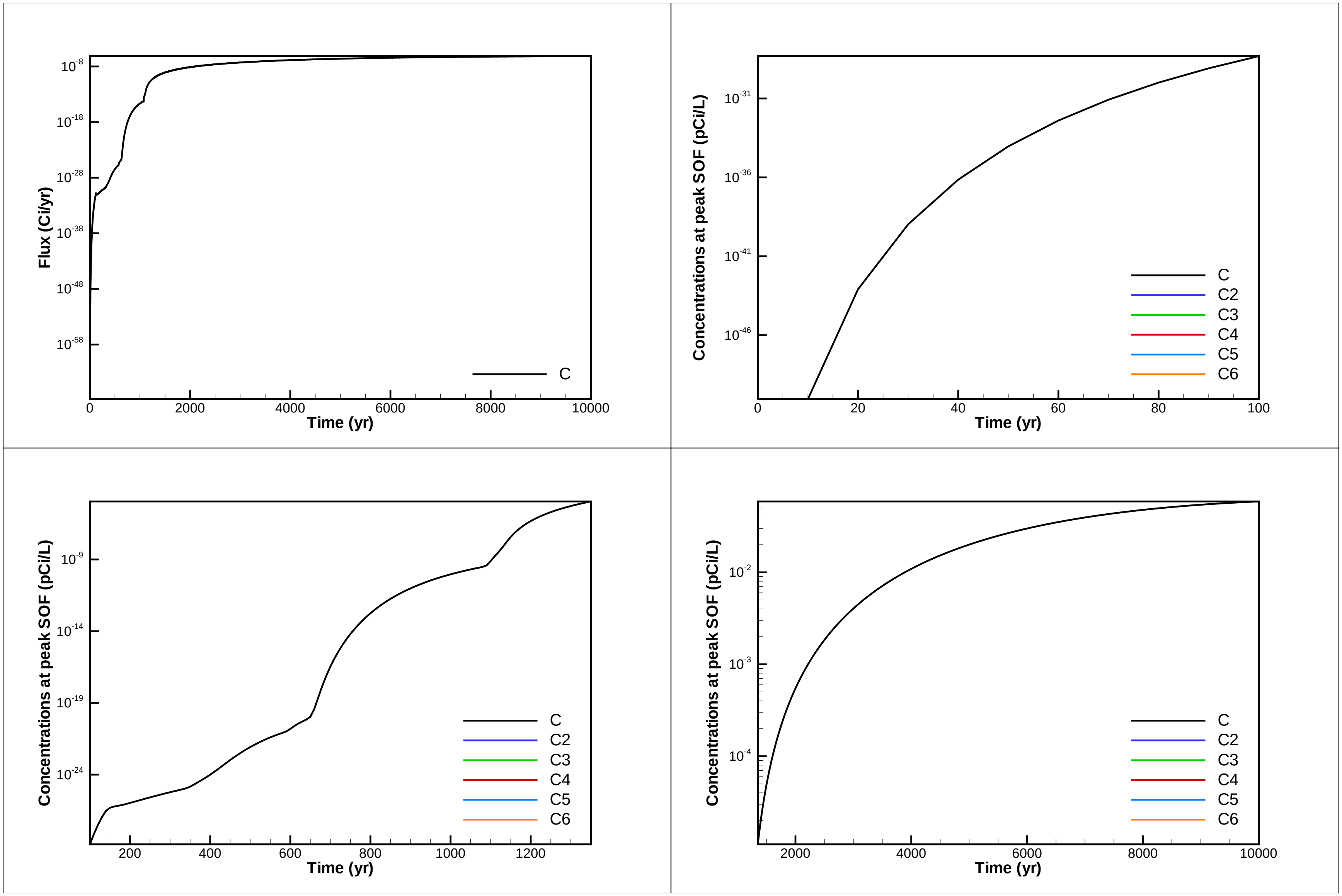


Figure A-12. Flux and concentration results for case C-14_1: C-14

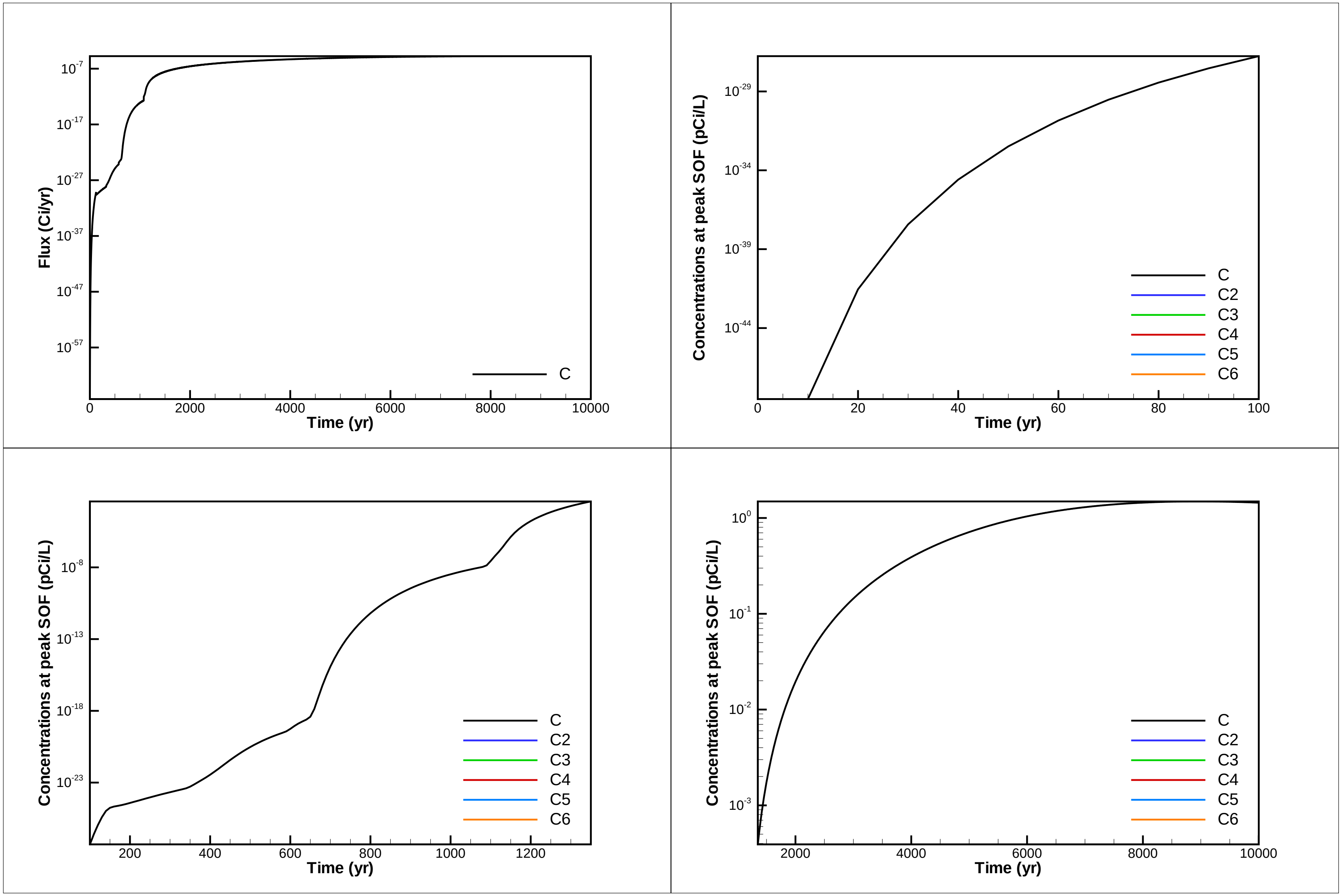


Figure A-13. Flux and concentration results for case C-14_KB_1: C-14_KB

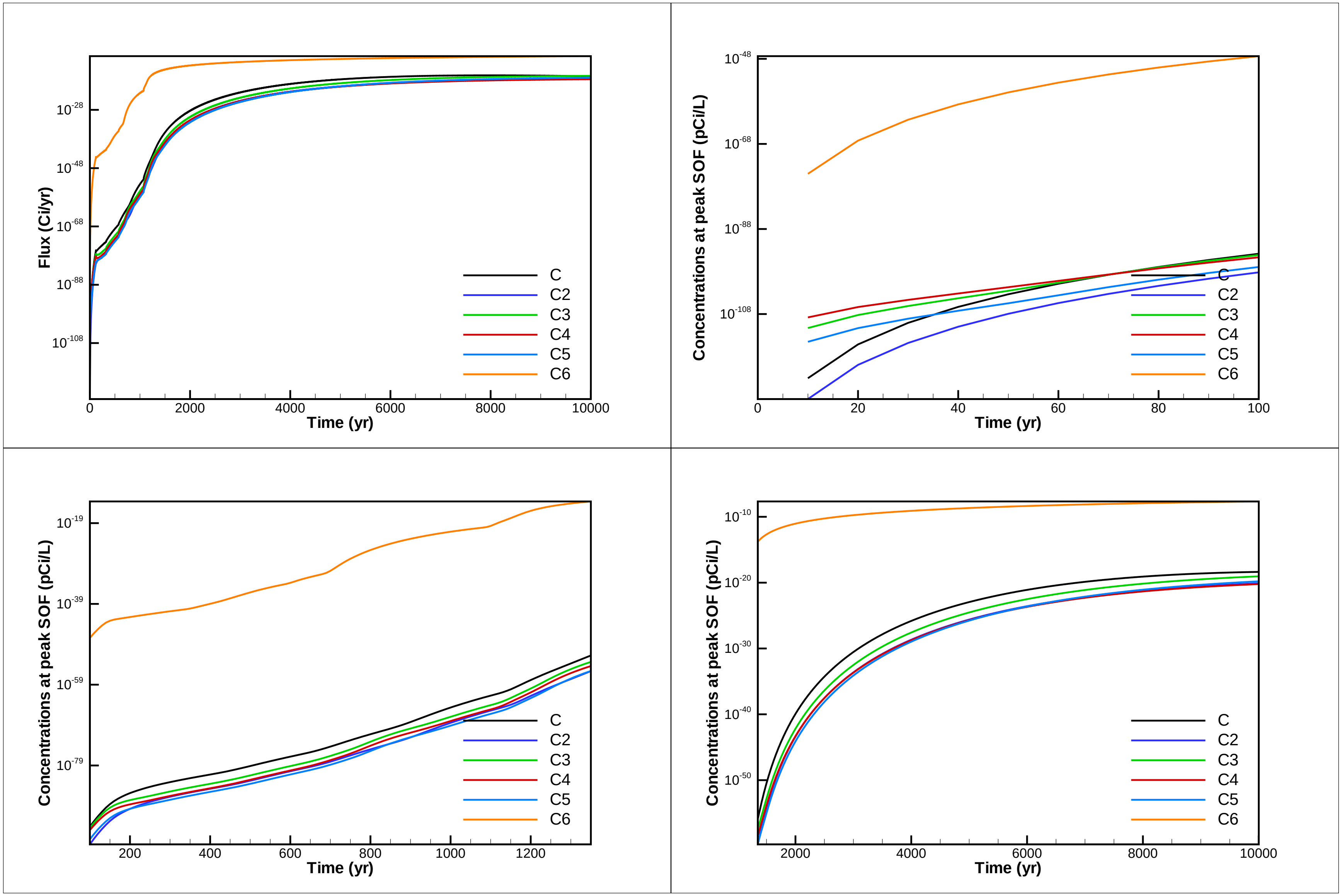


Figure A-14. Flux and concentration results for case Cf-249_0.001: Cf-249 Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

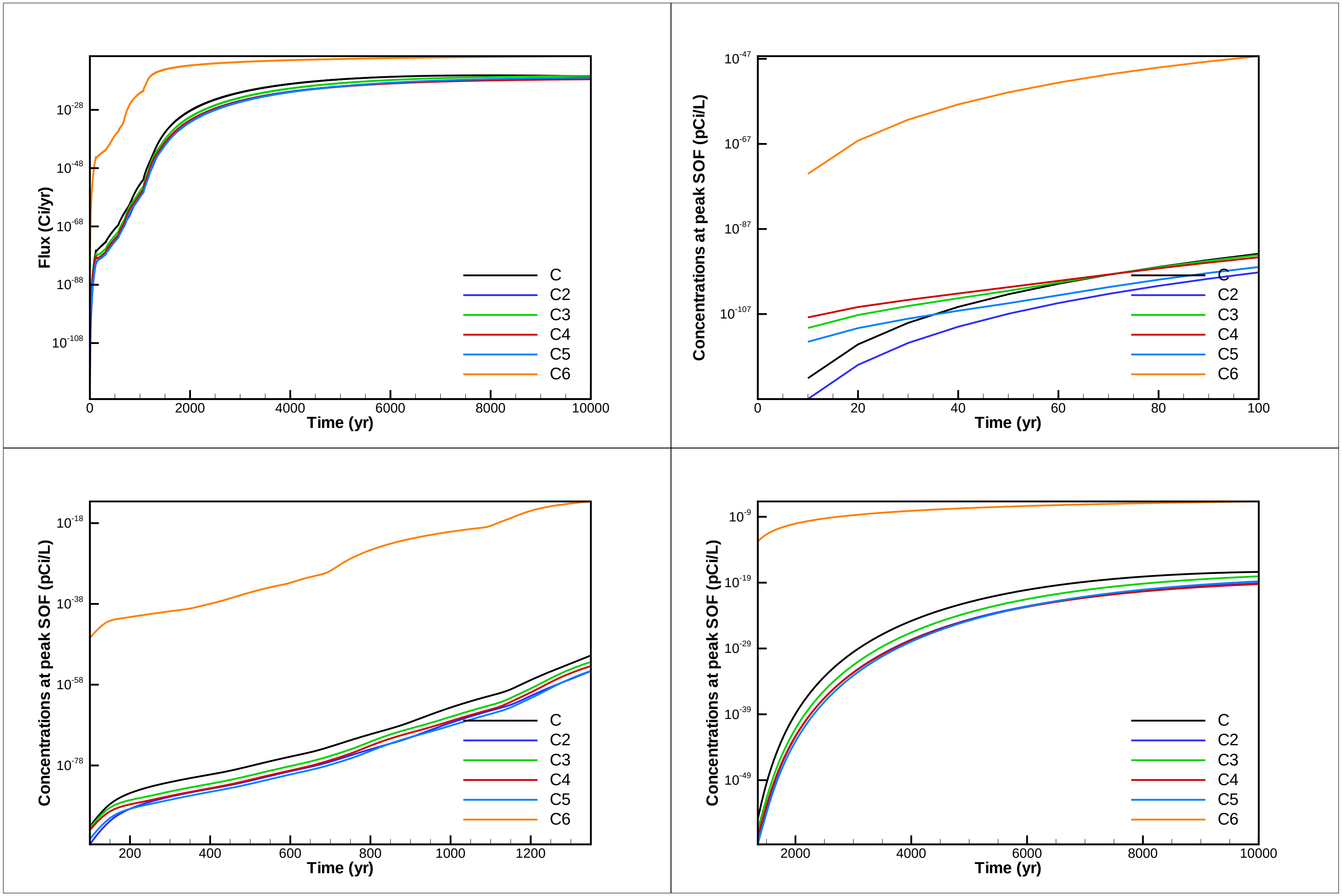


Figure A-15. Flux and concentration results for case Cf-249_0.01: Cf-249 Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

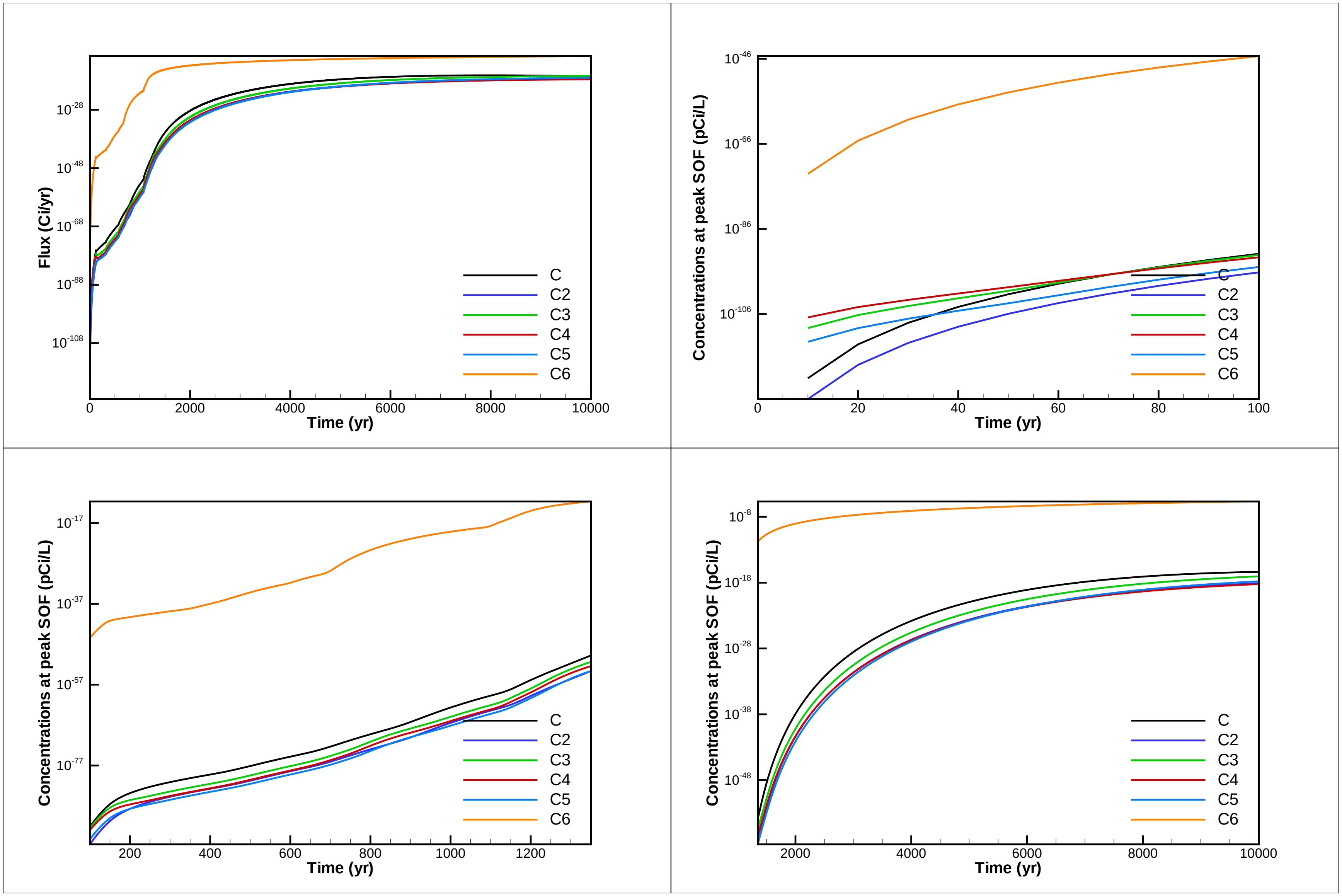


Figure A-16. Flux and concentration results for case Cf-249_0.1: Cf-249 Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

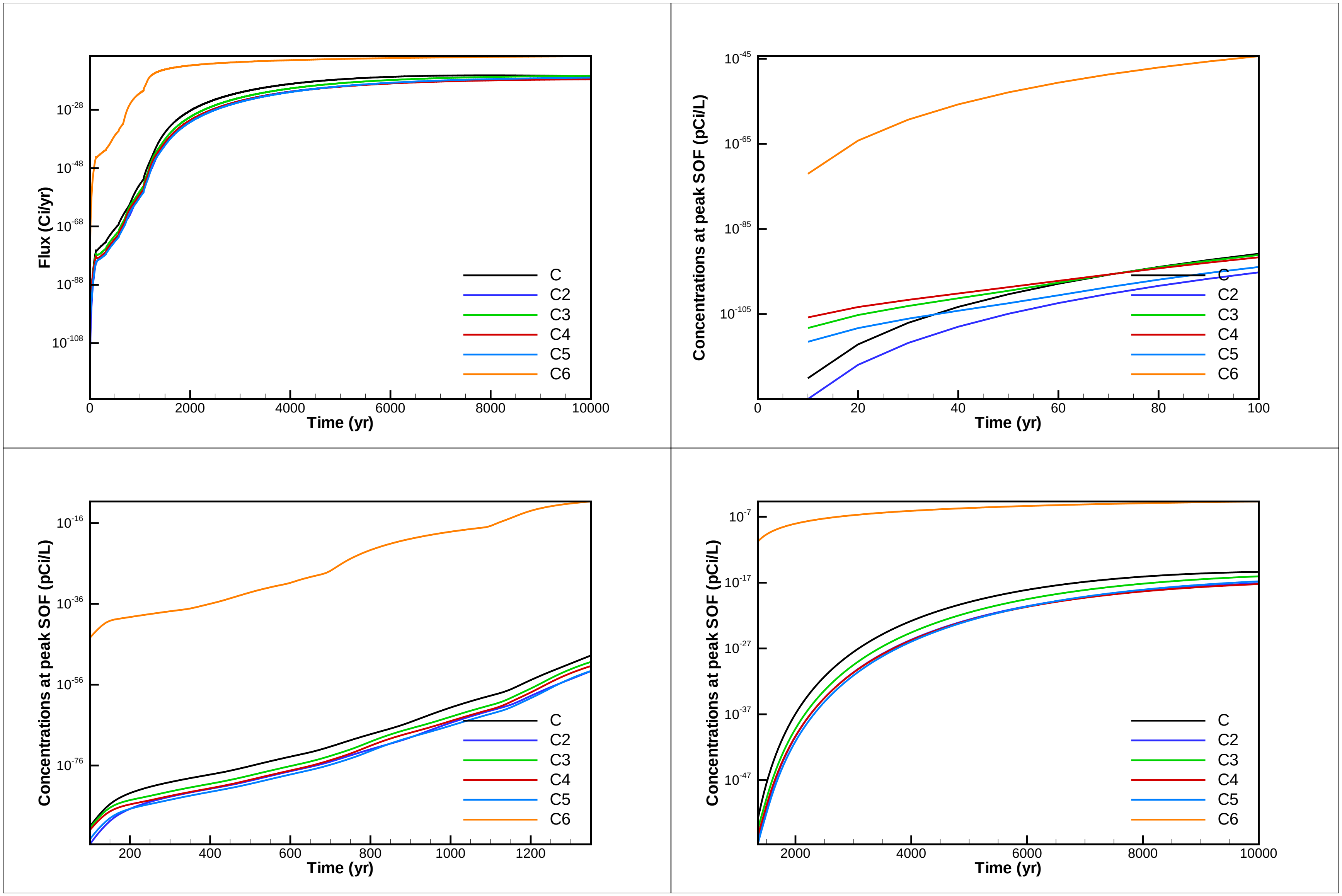


Figure A-17. Flux and concentration results for case Cf-249_1: Cf-249 Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

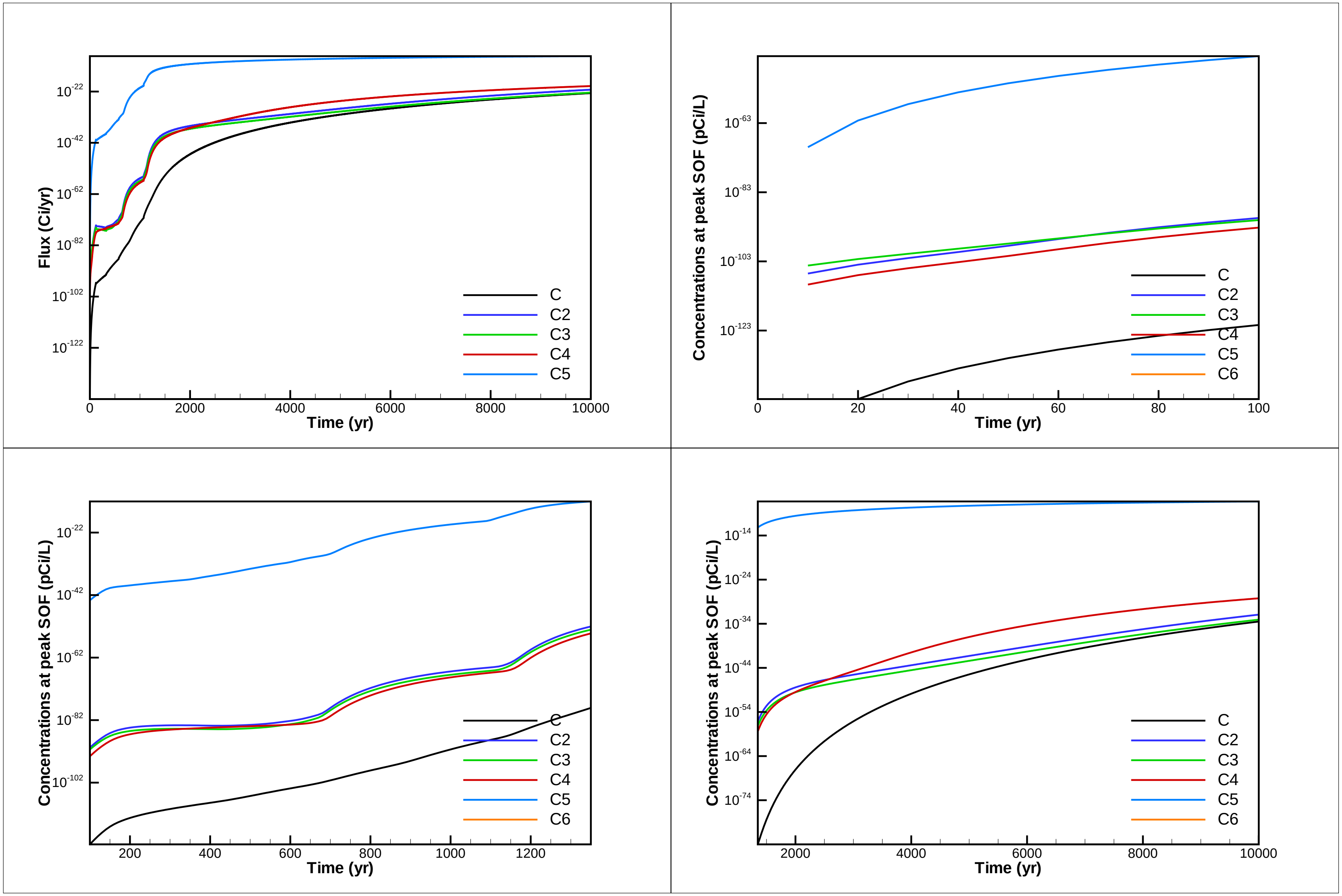


Figure A-18. Flux and concentration results for case Cm-245_0.001: Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

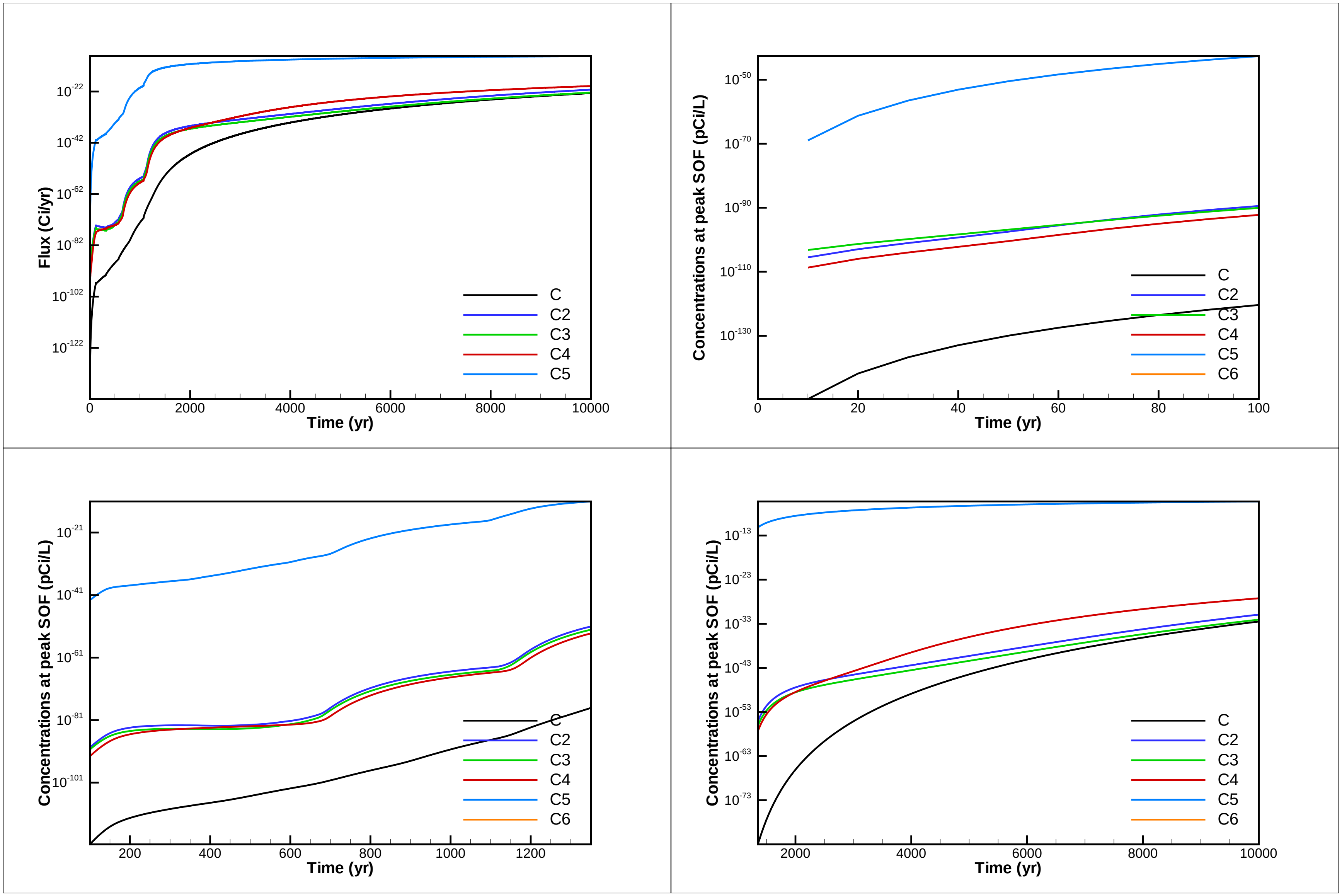


Figure A-19. Flux and concentration results for case Cm-245_0.01: Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

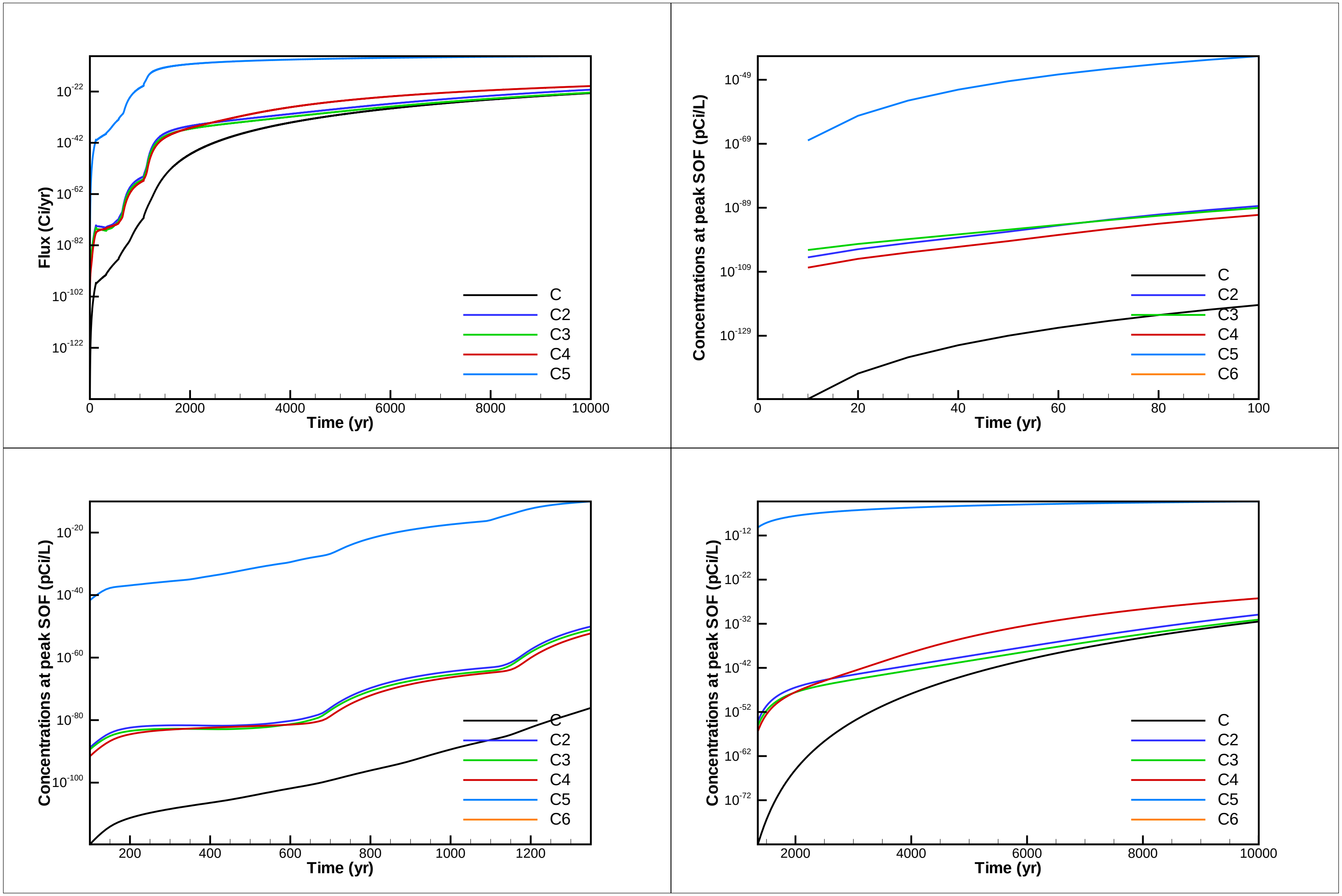


Figure A-20. Flux and concentration results for case Cm-245_0.1: Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

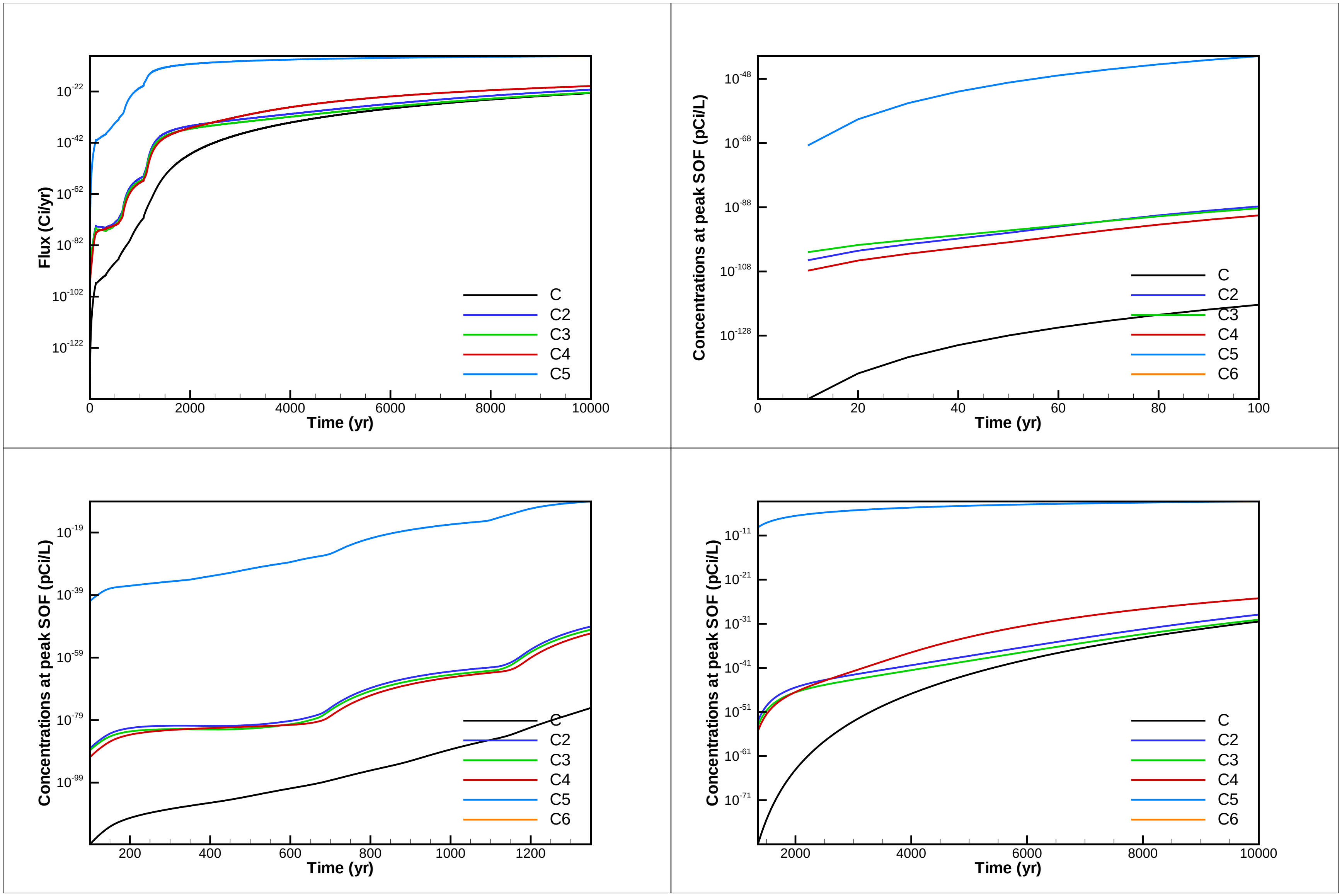


Figure A-21. Flux and concentration results for case Cm-245_1: Cm-245 Pu-241 Pu-241_56 Am-241 Np-237

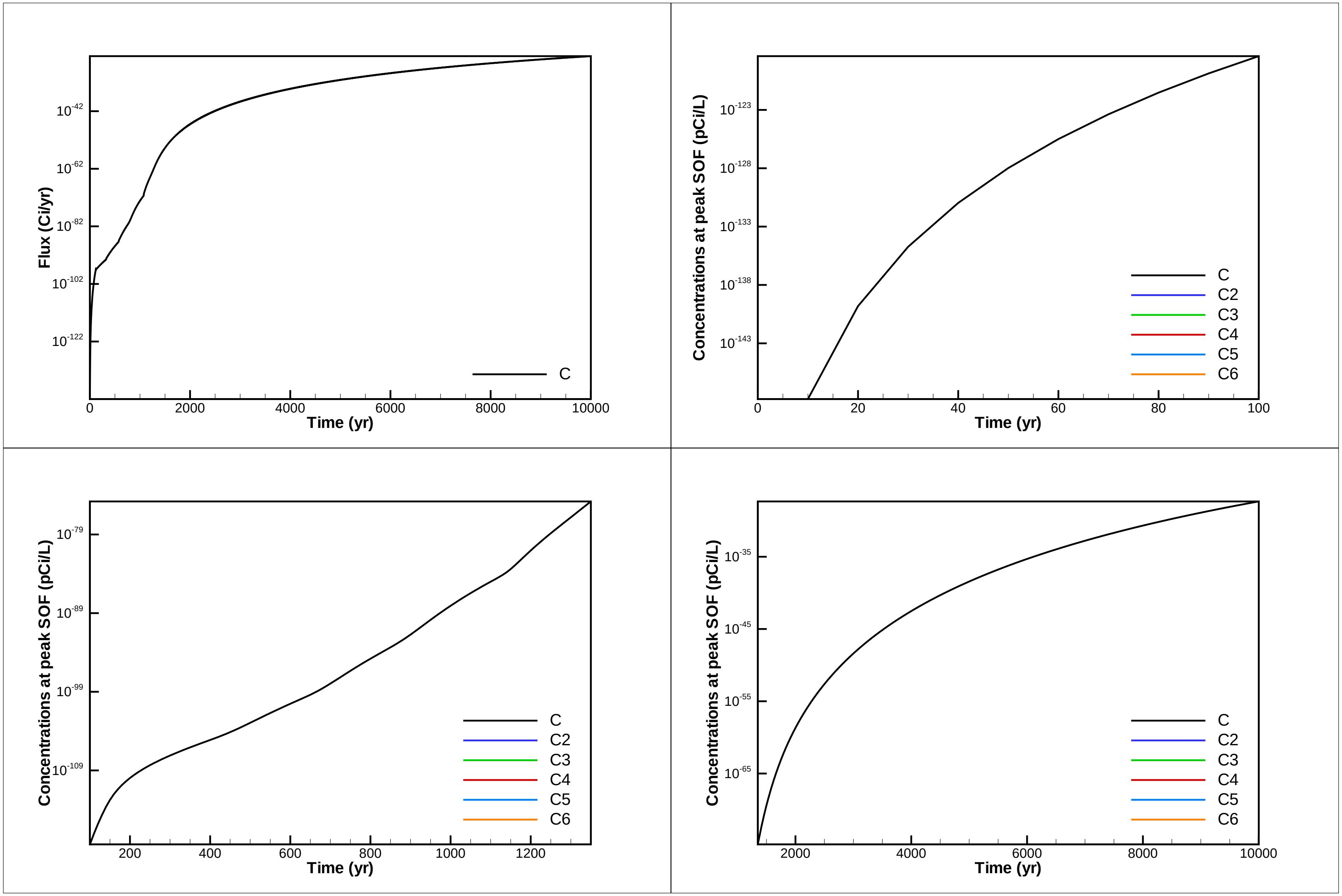


Figure A-22. Flux and concentration results for case Cm-246_1: Cm-246

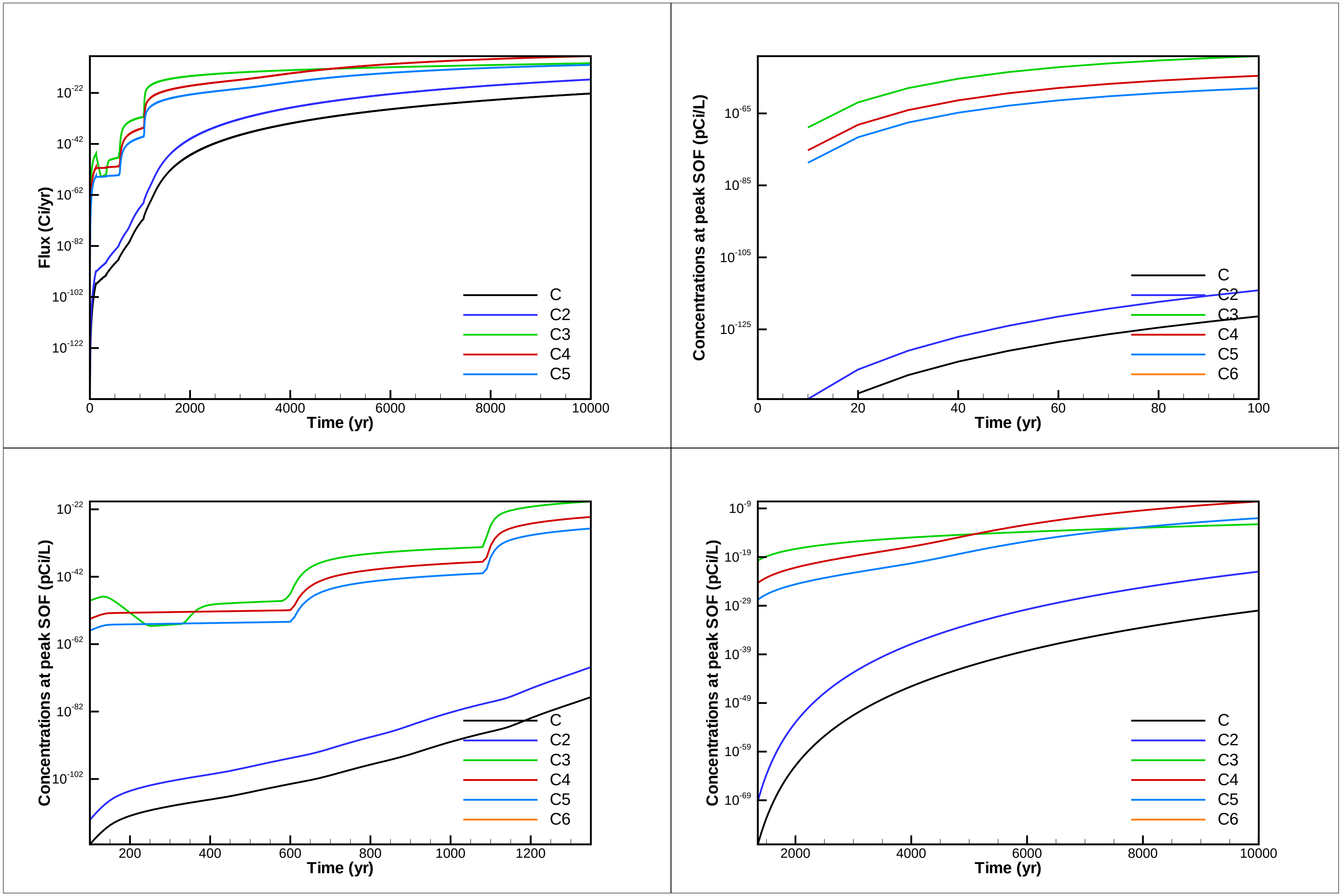


Figure A-23. Flux and concentration results for case Cm-247_0.001: Cm-247 Am-243 Np-239 Pu-239 Pu-239_56

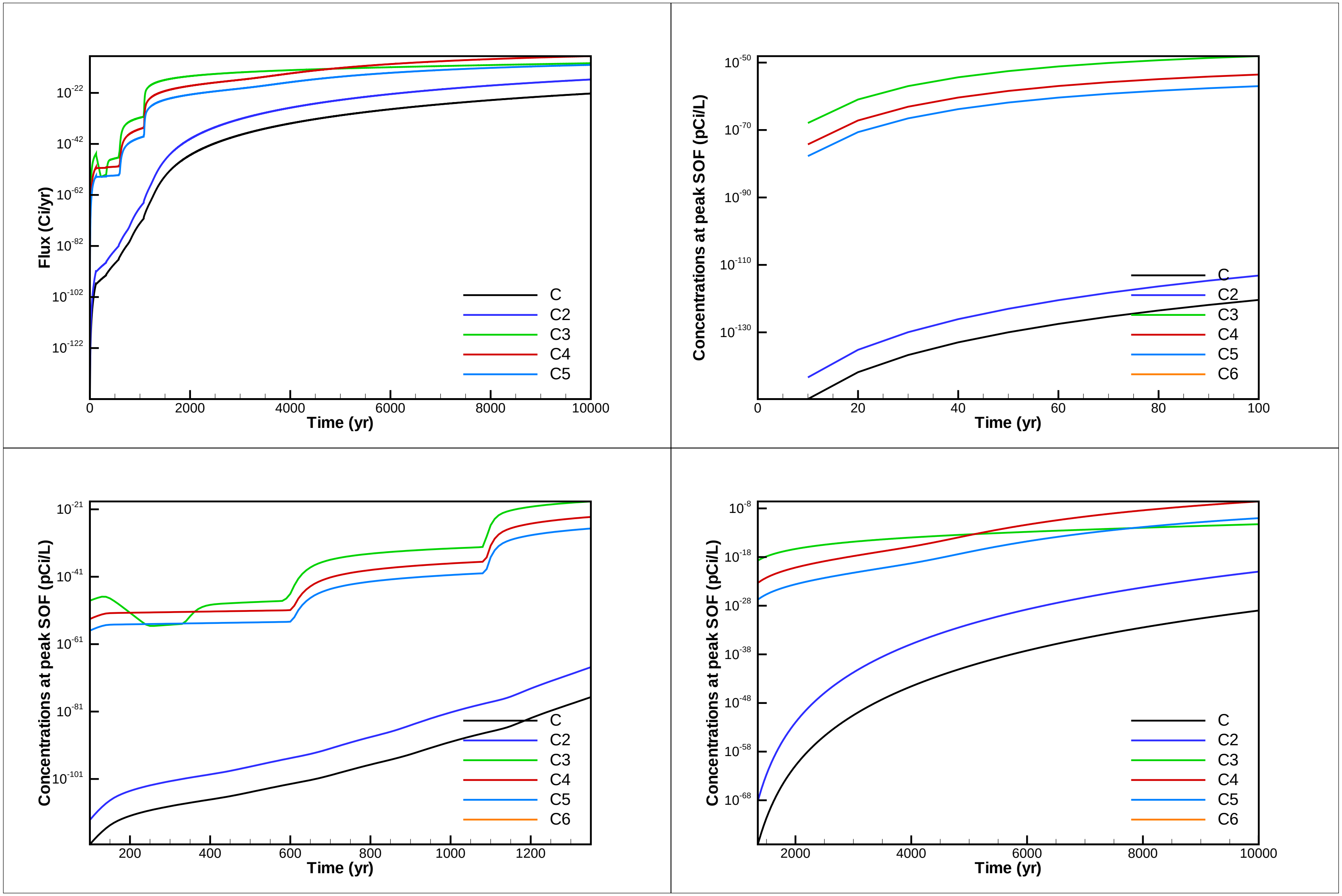


Figure A-24. Flux and concentration results for case Cm-247_0.01: Cm-247 Am-243 Np-239 Pu-239 Pu-239_56

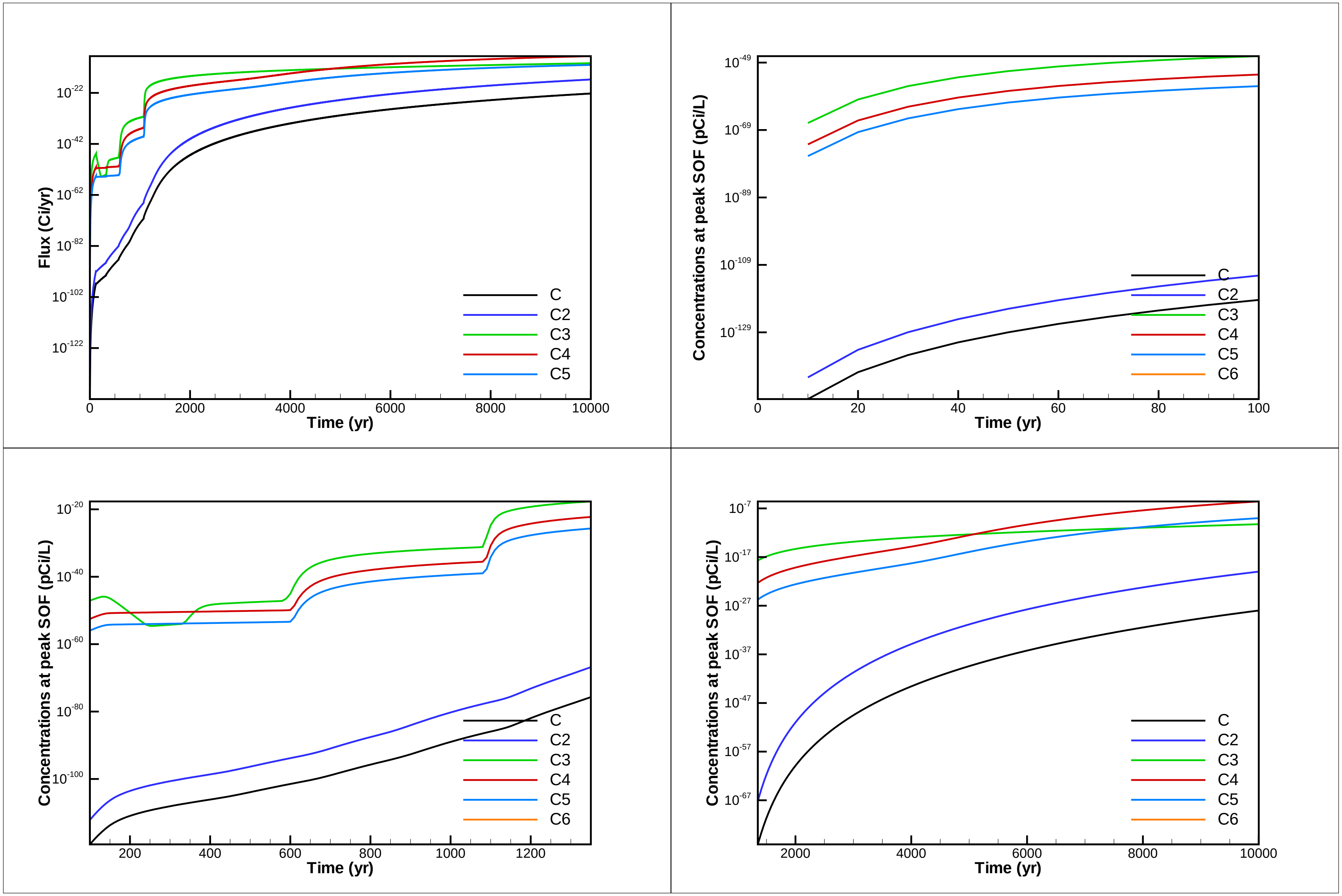


Figure A-25. Flux and concentration results for case Cm-247_0.1: Cm-247 Am-243 Np-239 Pu-239 Pu-239_56

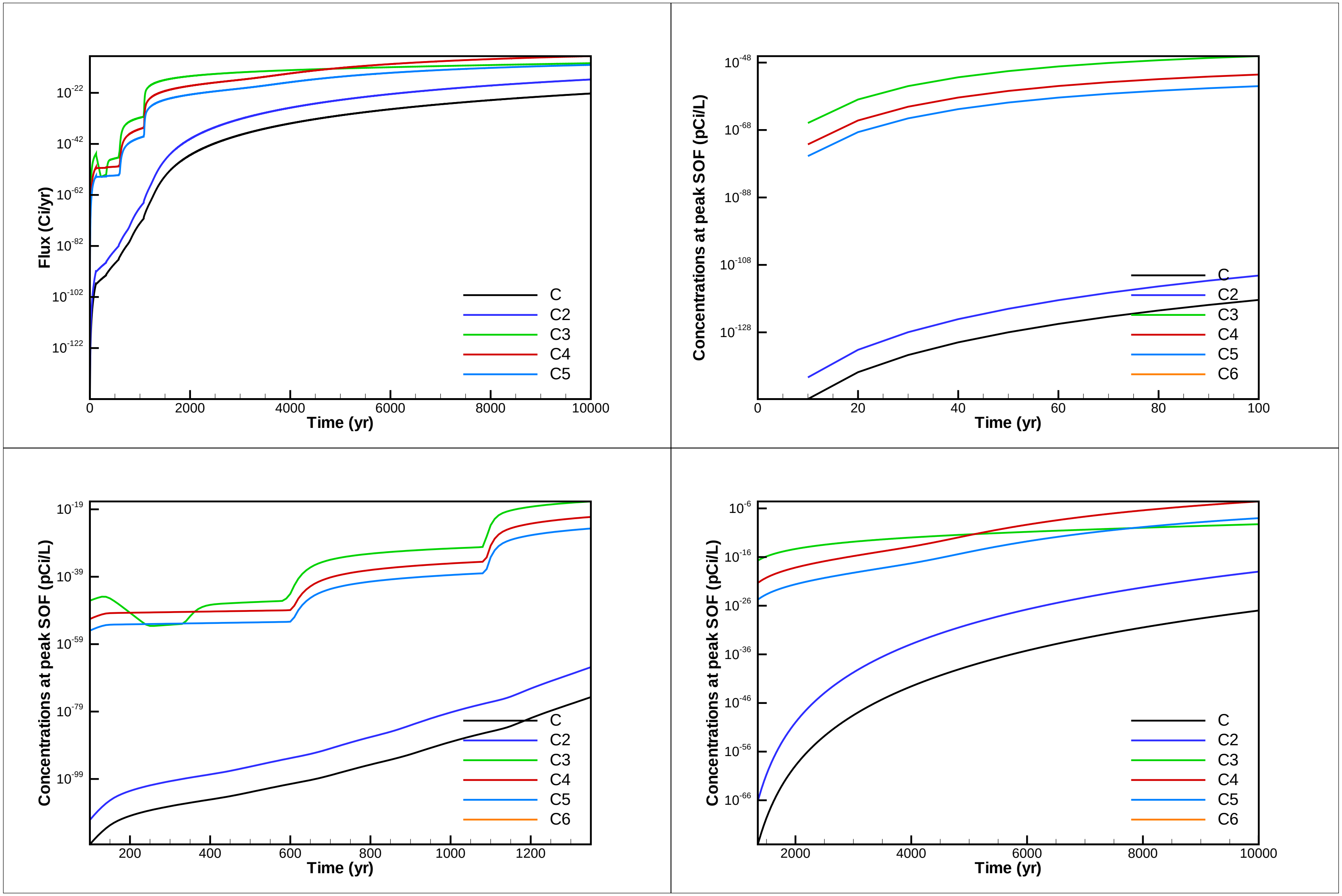


Figure A-26. Flux and concentration results for case Cm-247_1: Cm-247 Am-243 Np-239 Pu-239 Pu-239_56

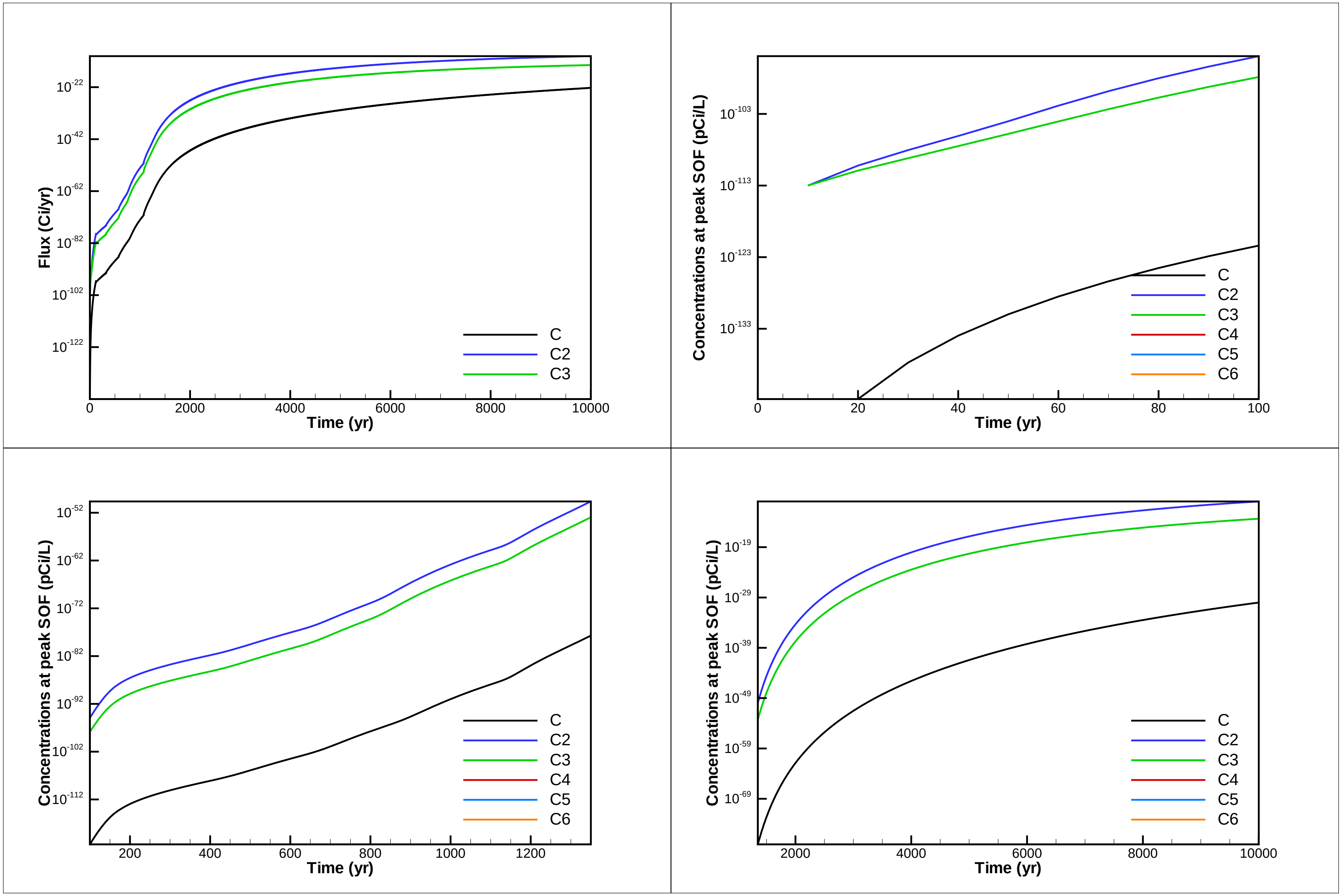


Figure A-27. Flux and concentration results for case Cm-248_0.001: Cm-248 Pu-244 Pu-244_56

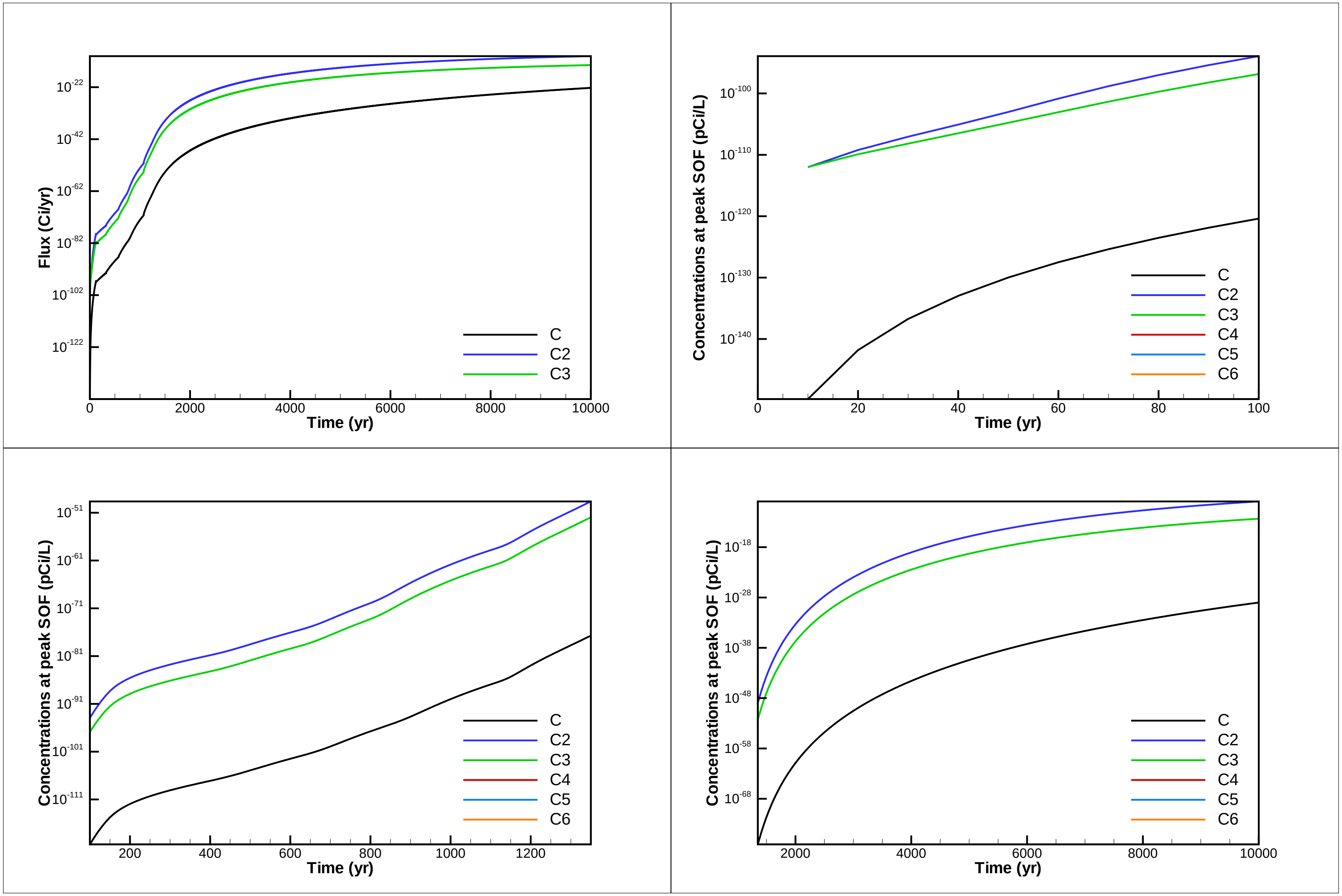


Figure A-28. Flux and concentration results for case Cm-248_0.01: Cm-248 Pu-244 Pu-244_56

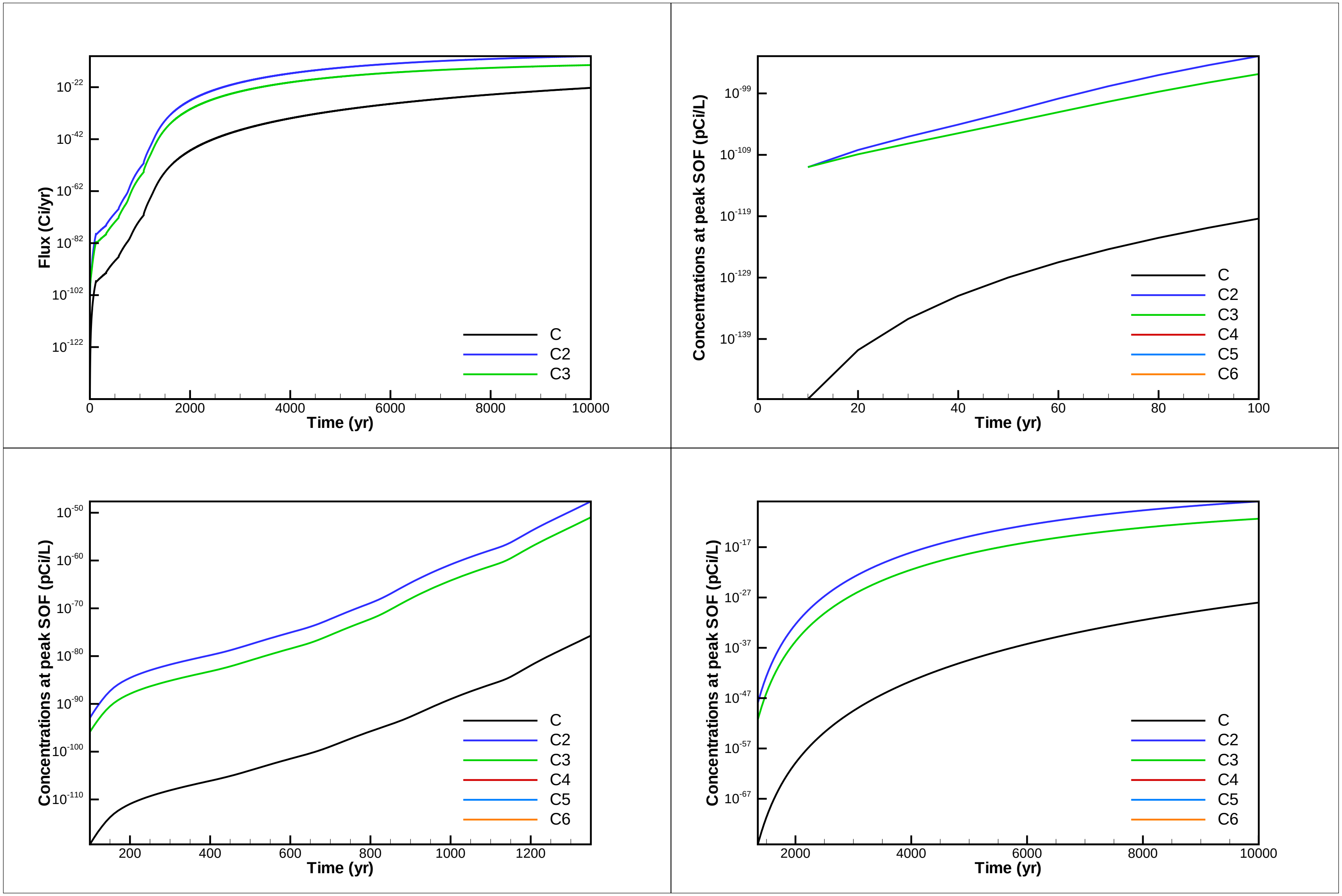


Figure A-29. Flux and concentration results for case Cm-248_0.1: Cm-248 Pu-244 Pu-244_56

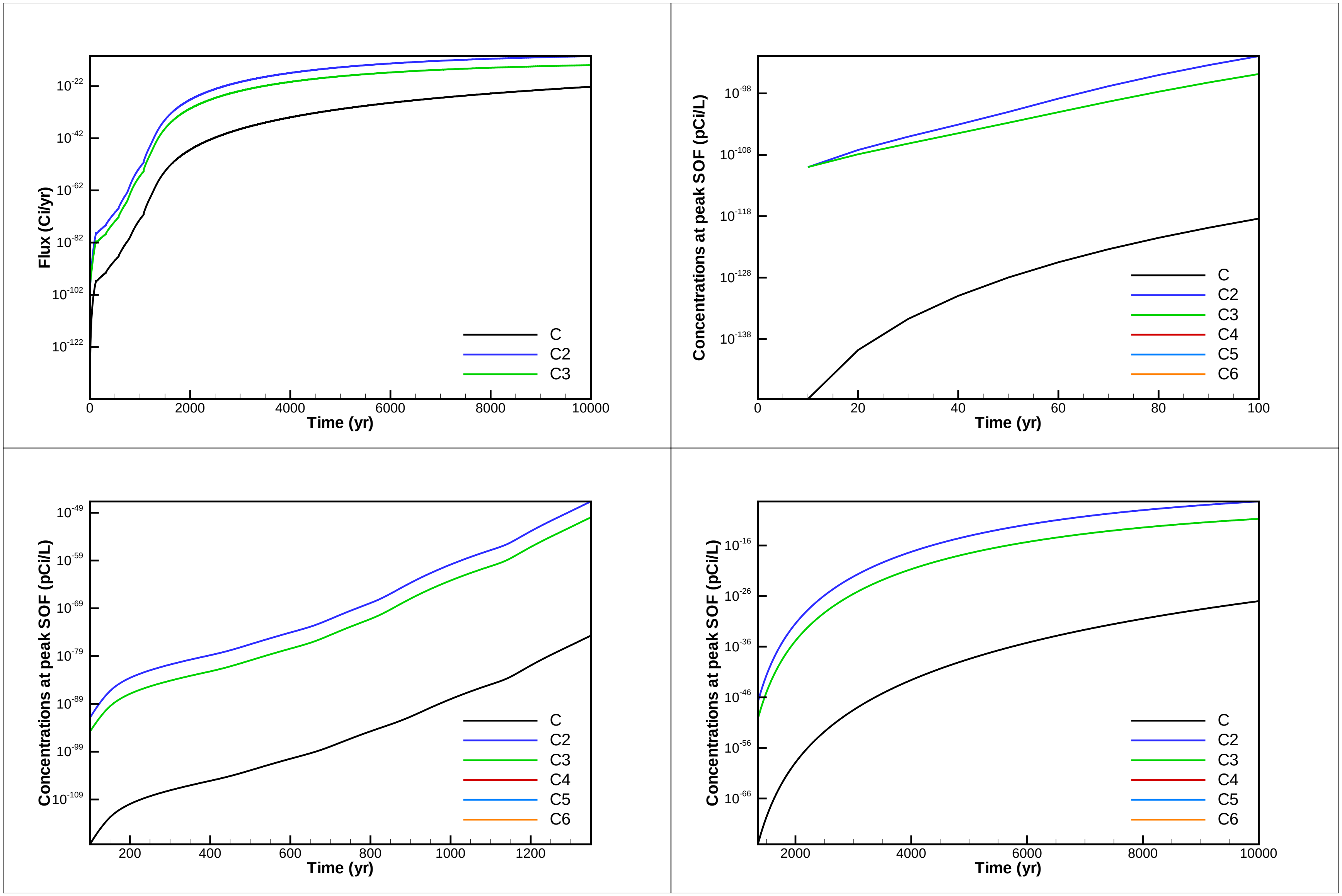


Figure A-30. Flux and concentration results for case Cm-248_1: Cm-248 Pu-244 Pu-244_56

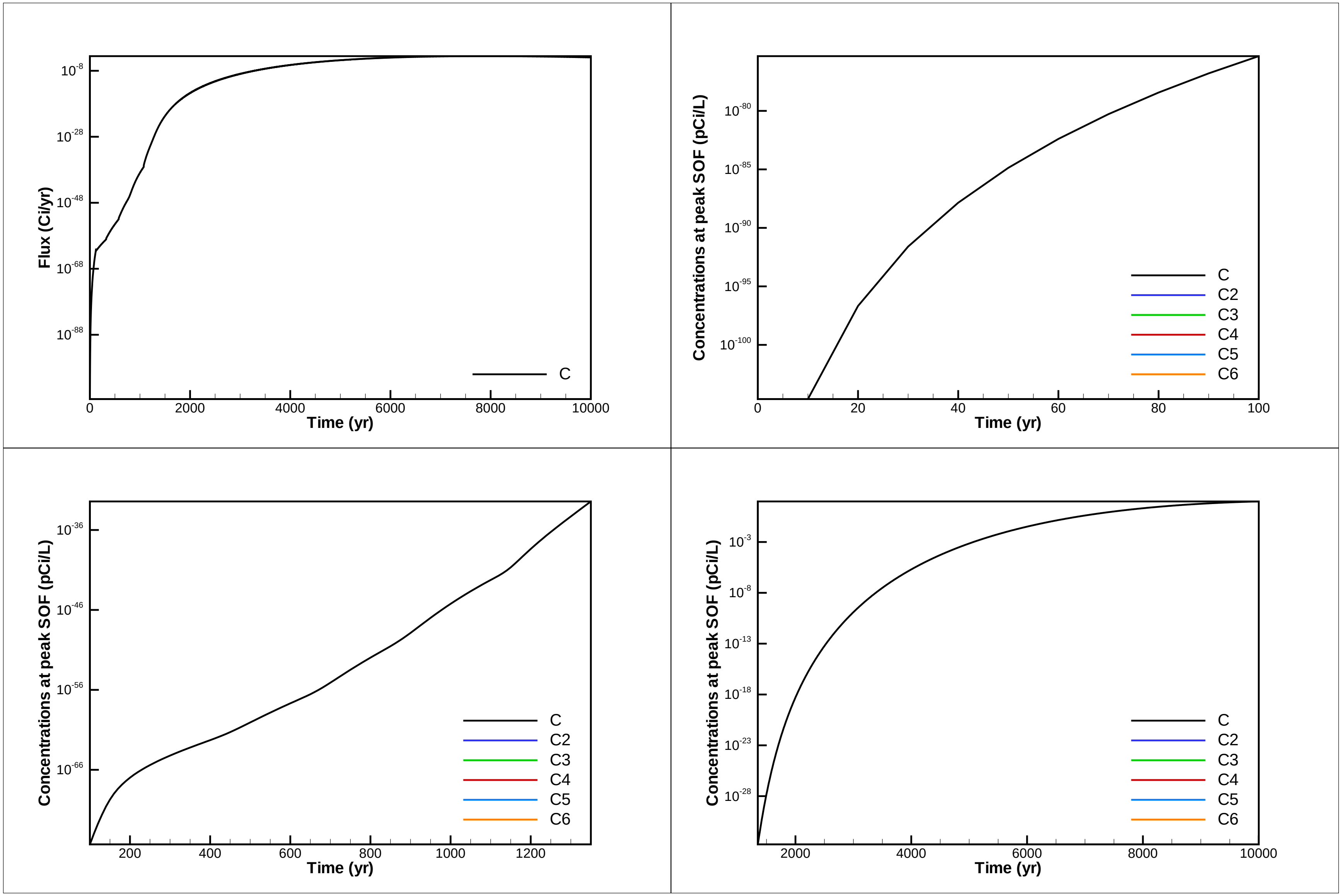


Figure A-31. Flux and concentration results for case Cs-135_1: Cs-135

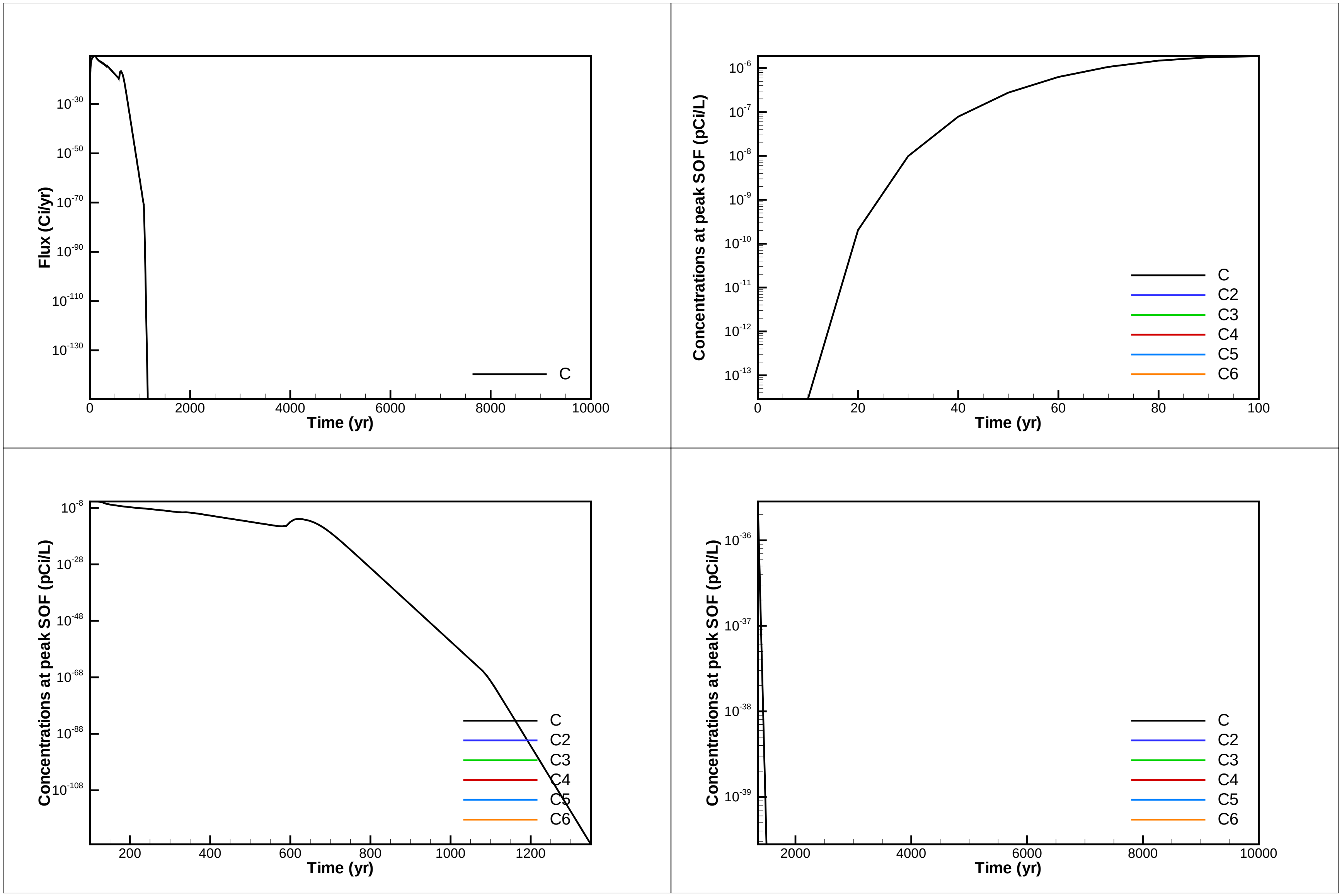


Figure A-32. Flux and concentration results for case H-3_1: H-3

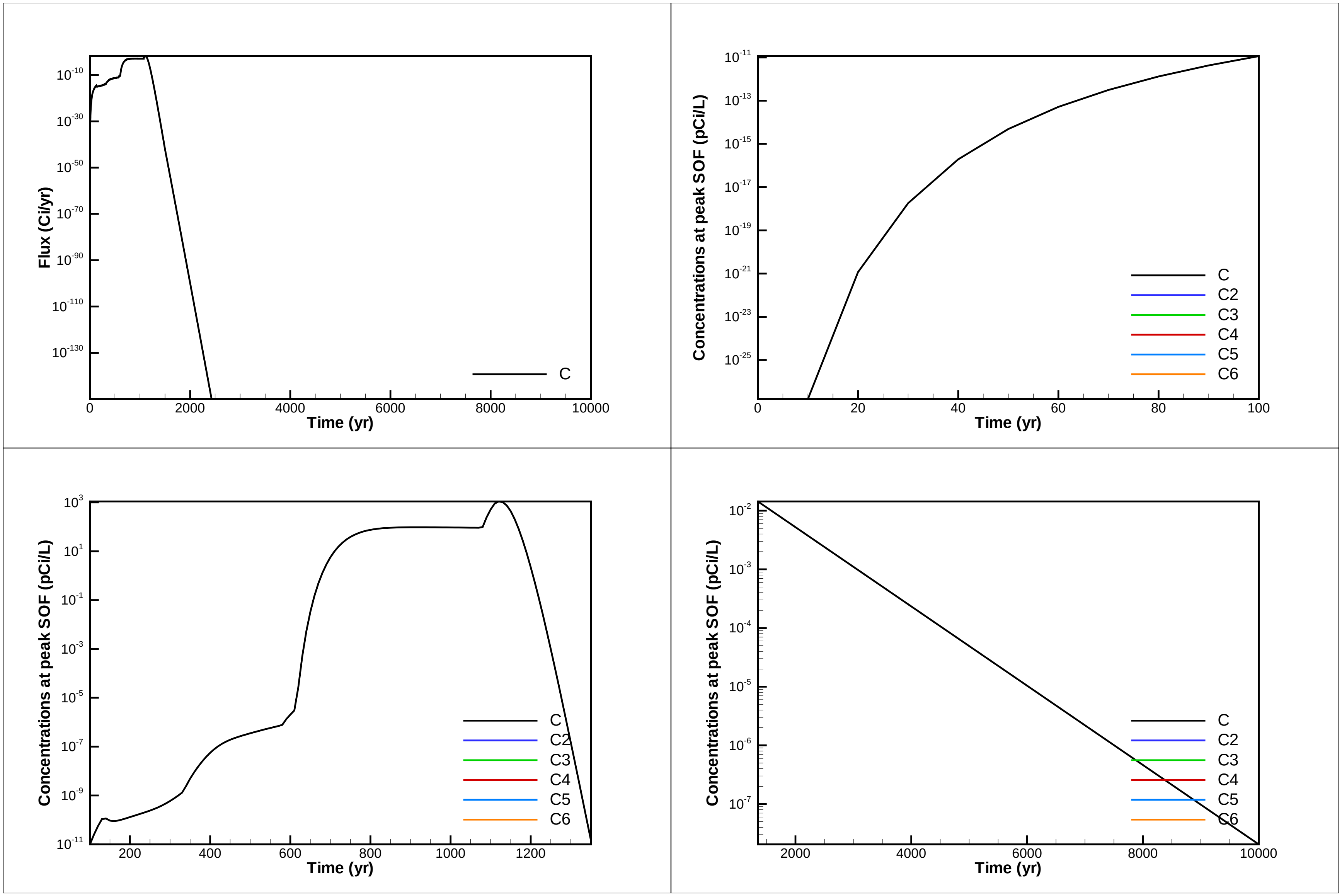


Figure A-33. Flux and concentration results for case I-129_1: I-129

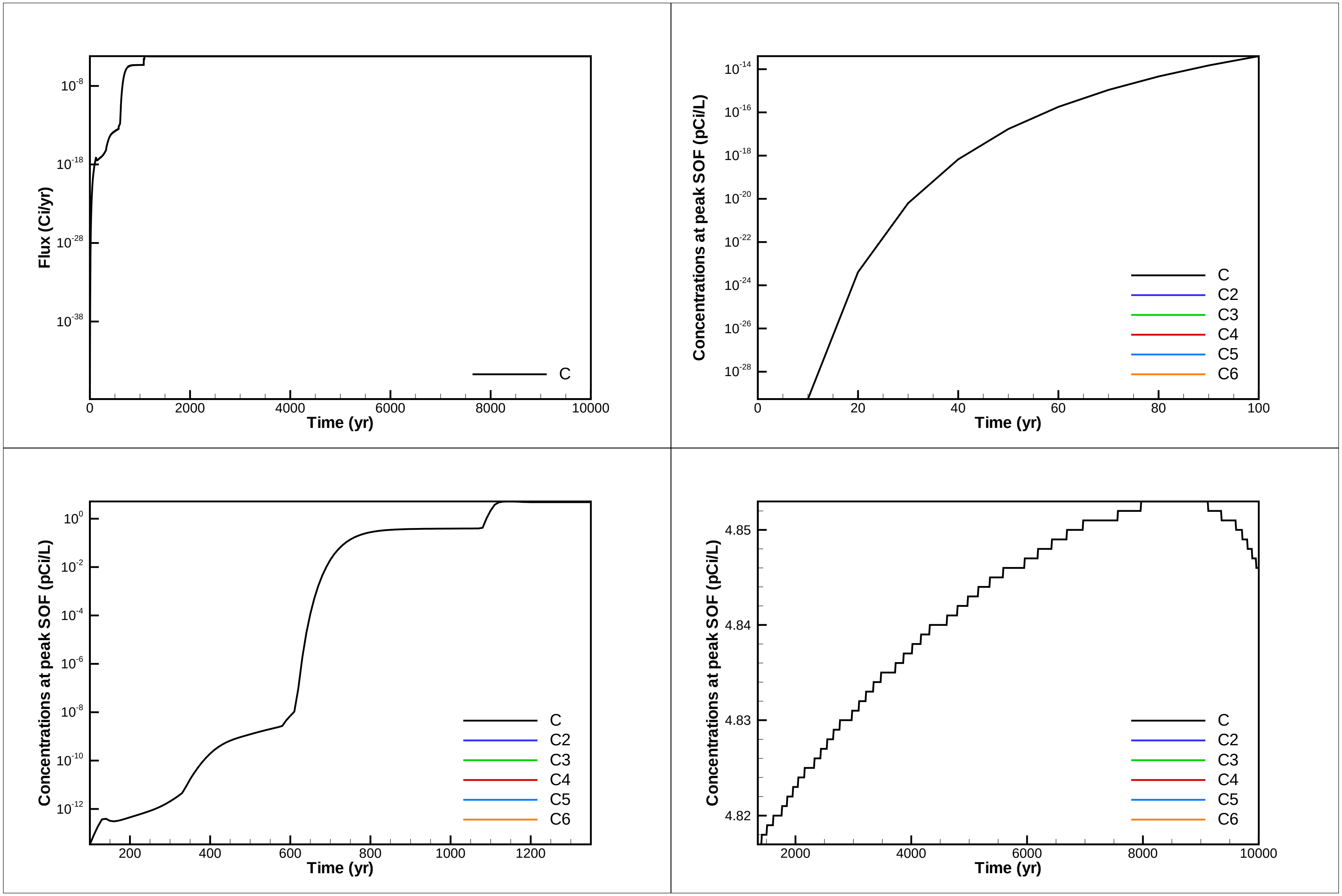


Figure A-34. Flux and concentration results for case I-129_ETF-Carbon_1: I-129_ETF-Carbon

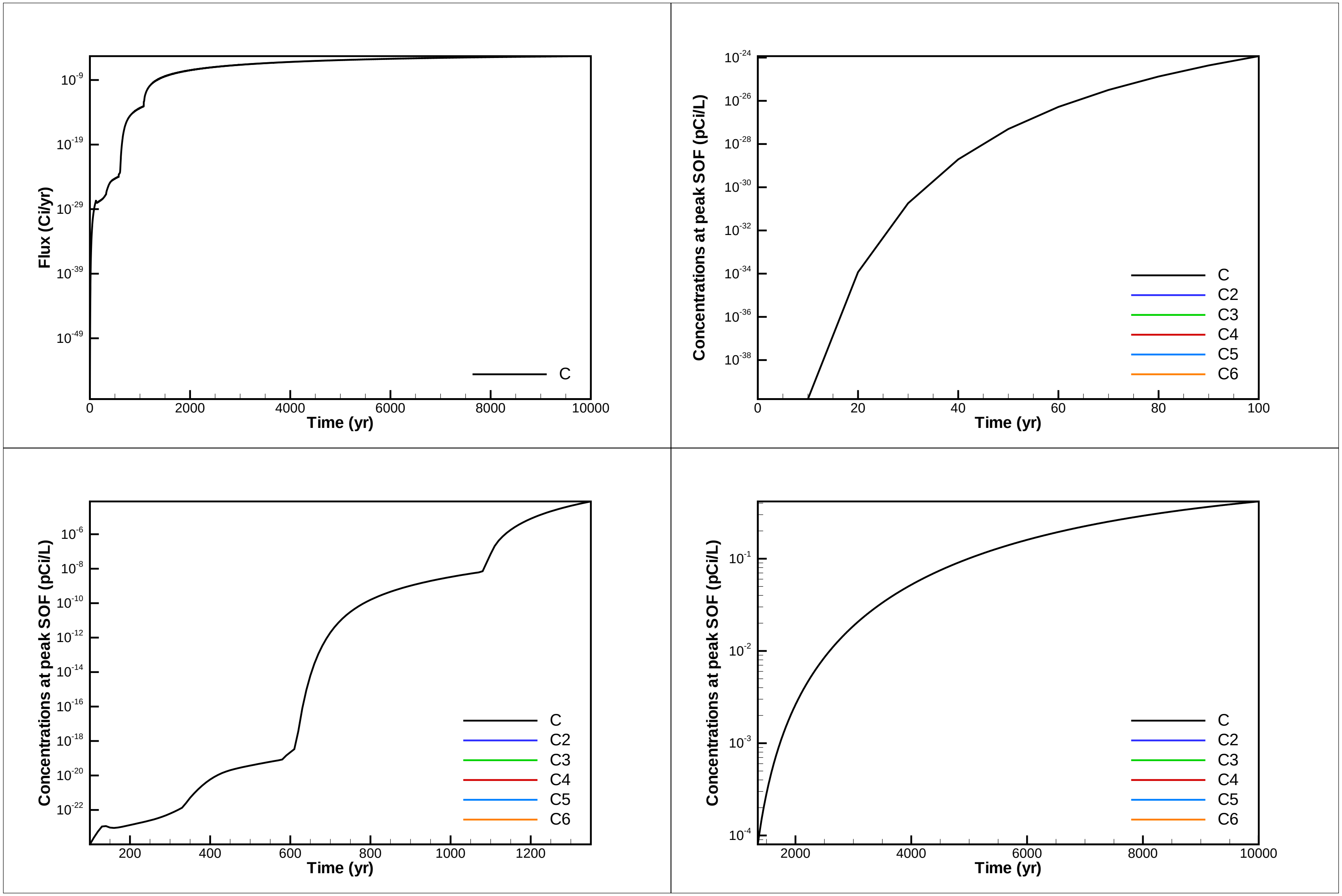


Figure A-35. Flux and concentration results for case I-129_KB_1: I-129_KB

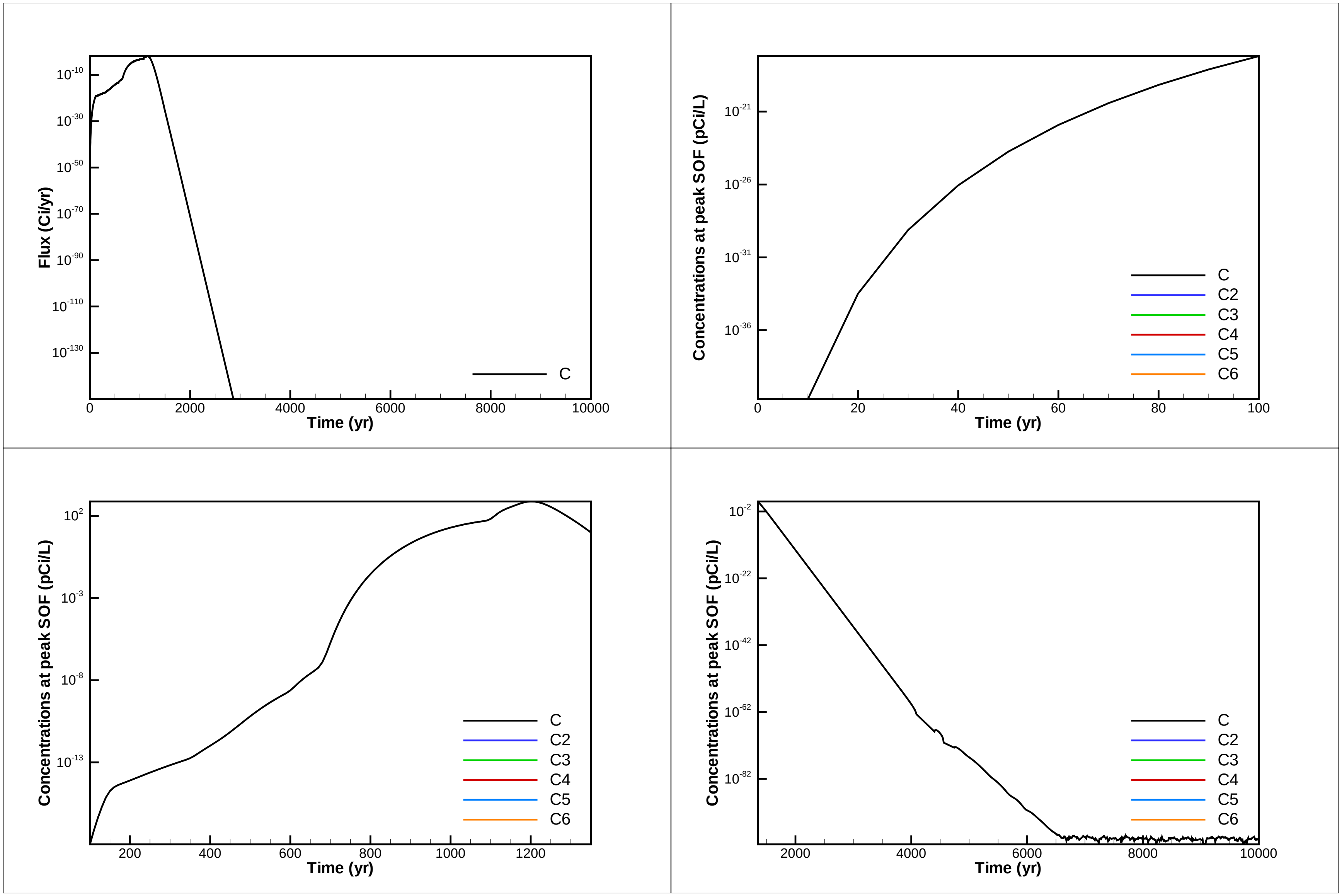


Figure A-36. Flux and concentration results for case K-40_1: K-40

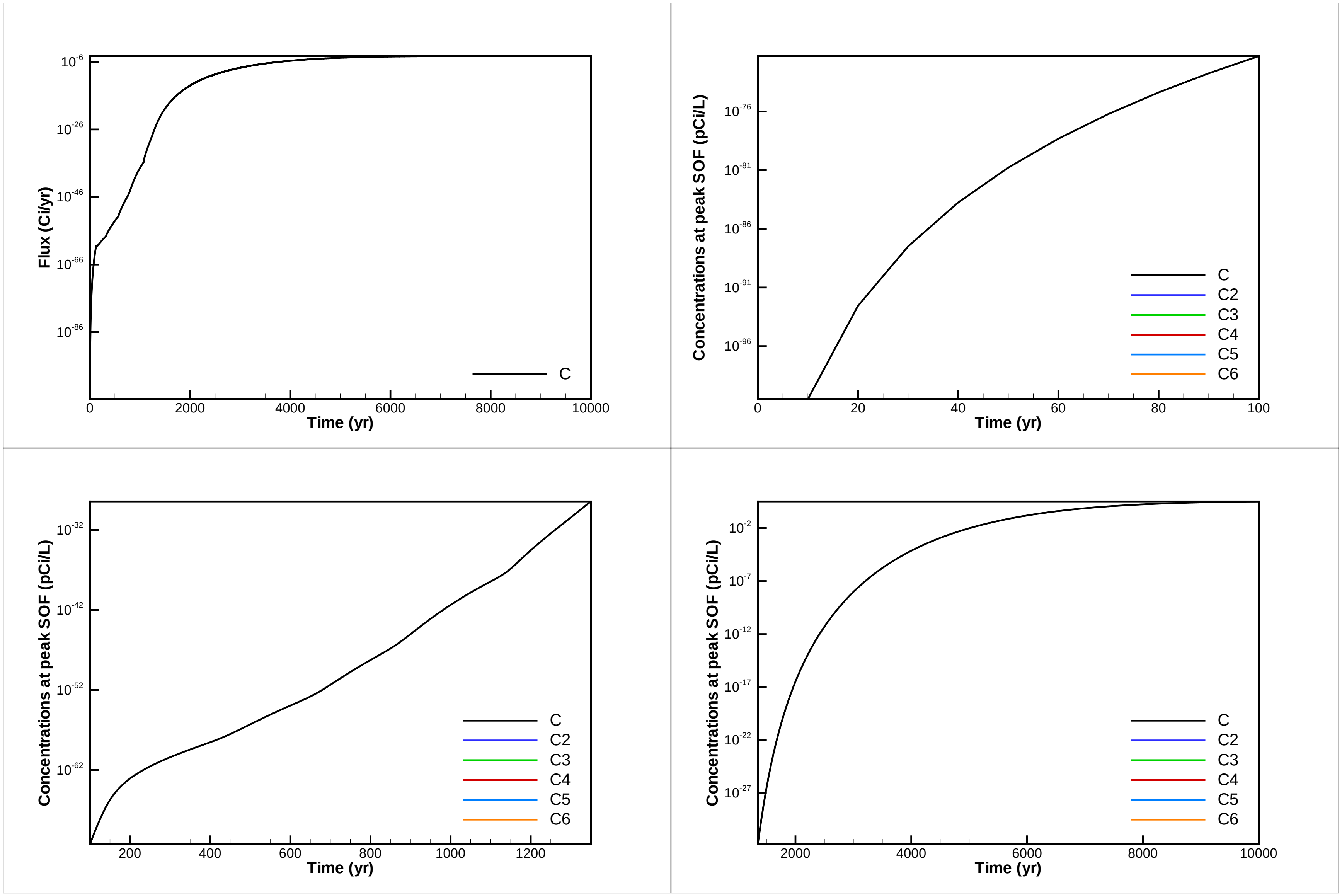


Figure A-37. Flux and concentration results for case Nb-94_1: Nb-94

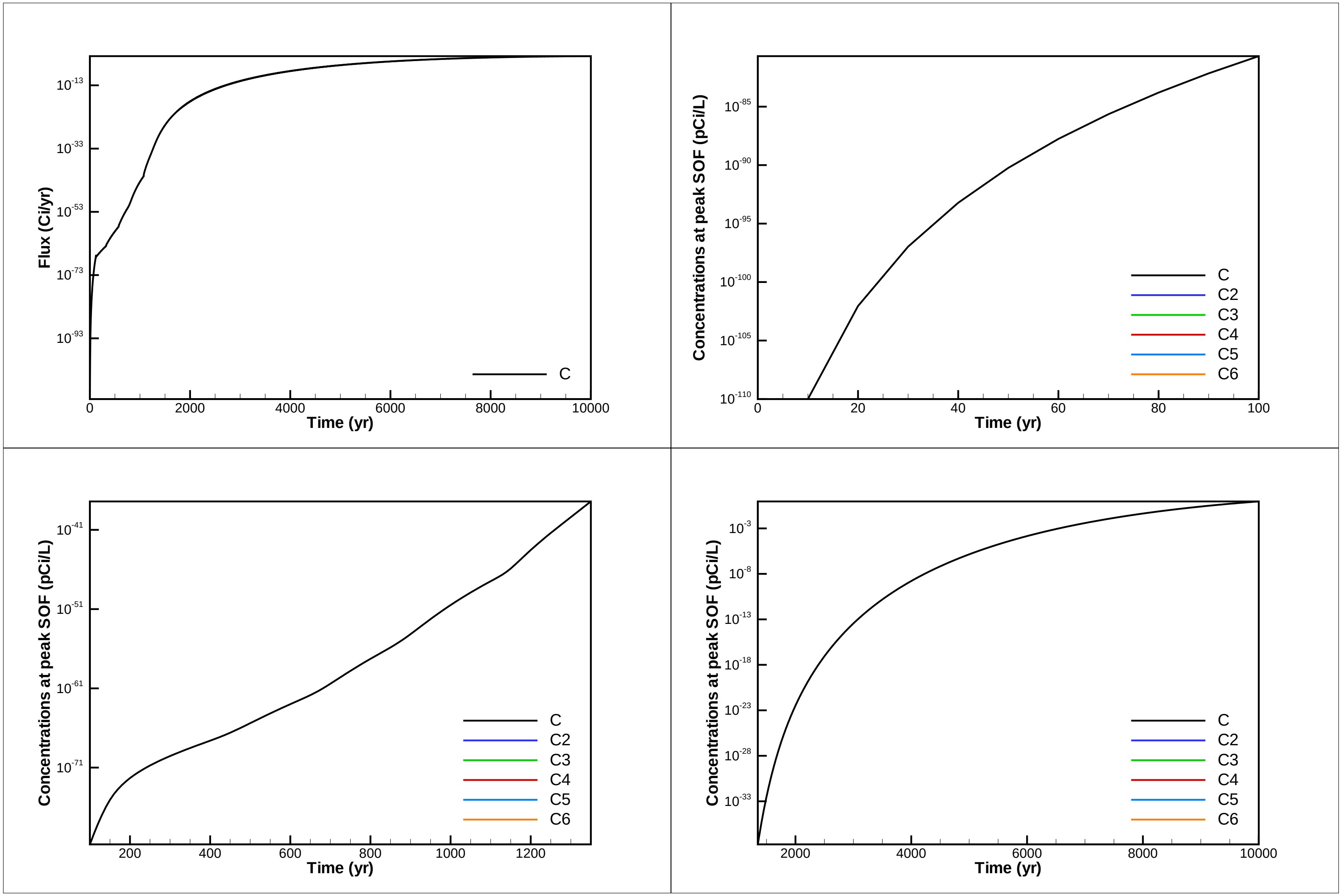


Figure A-38. Flux and concentration results for case Ni-59_1: Ni-59

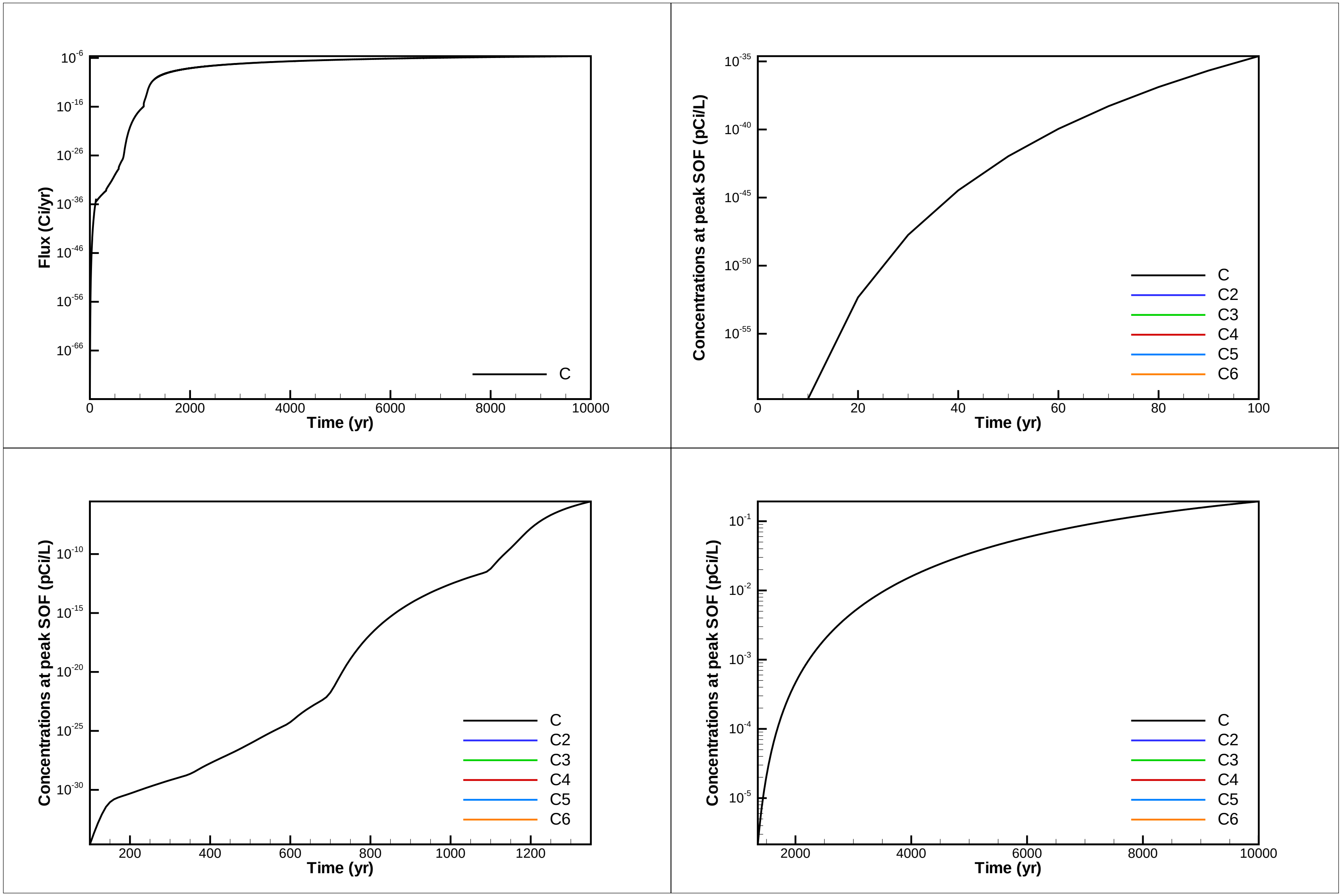


Figure A-39. Flux and concentration results for case Np-237_1: Np-237

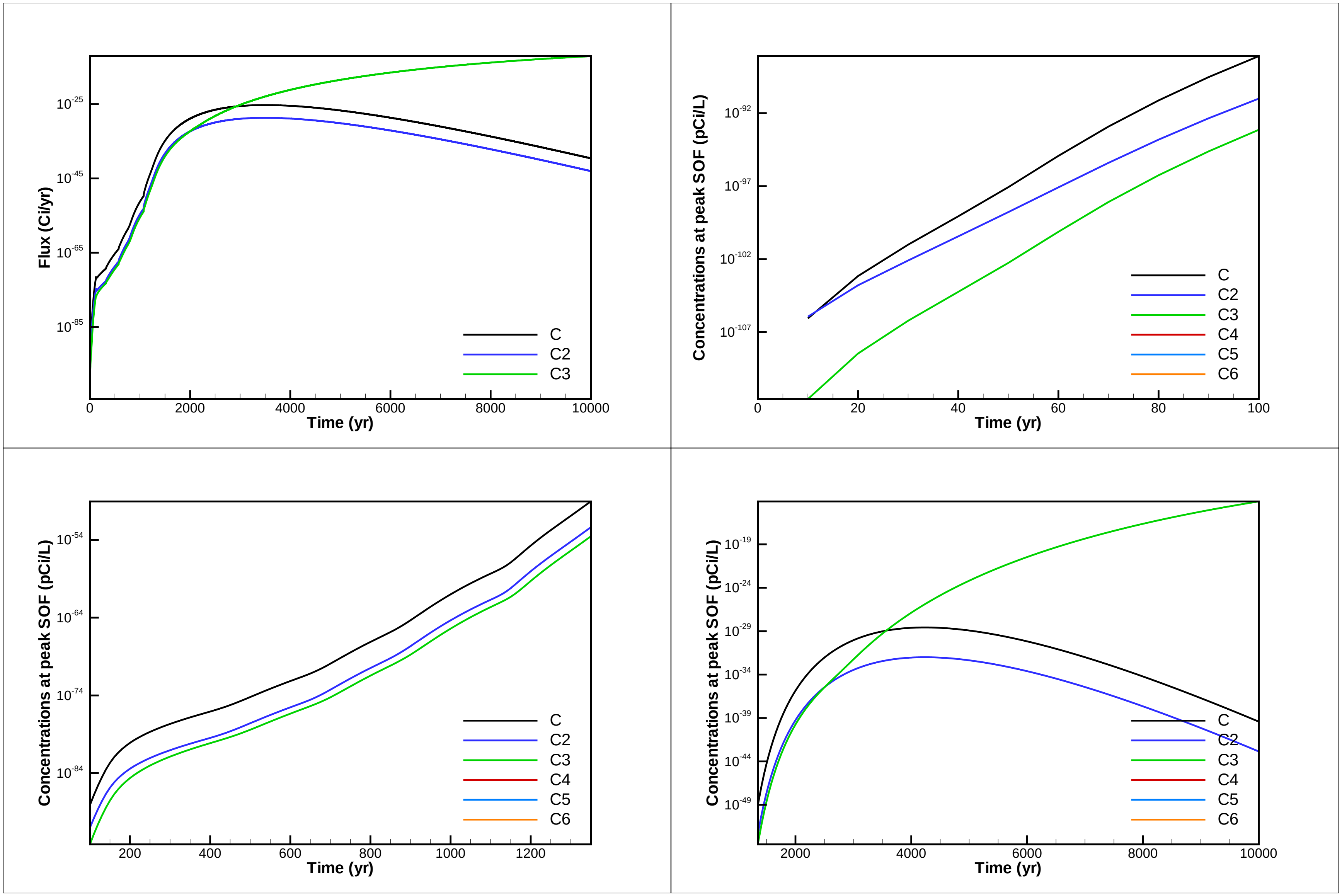


Figure A-40. Flux and concentration results for case Pu-238_0.001: Pu-238 Pu-238_56 U-234

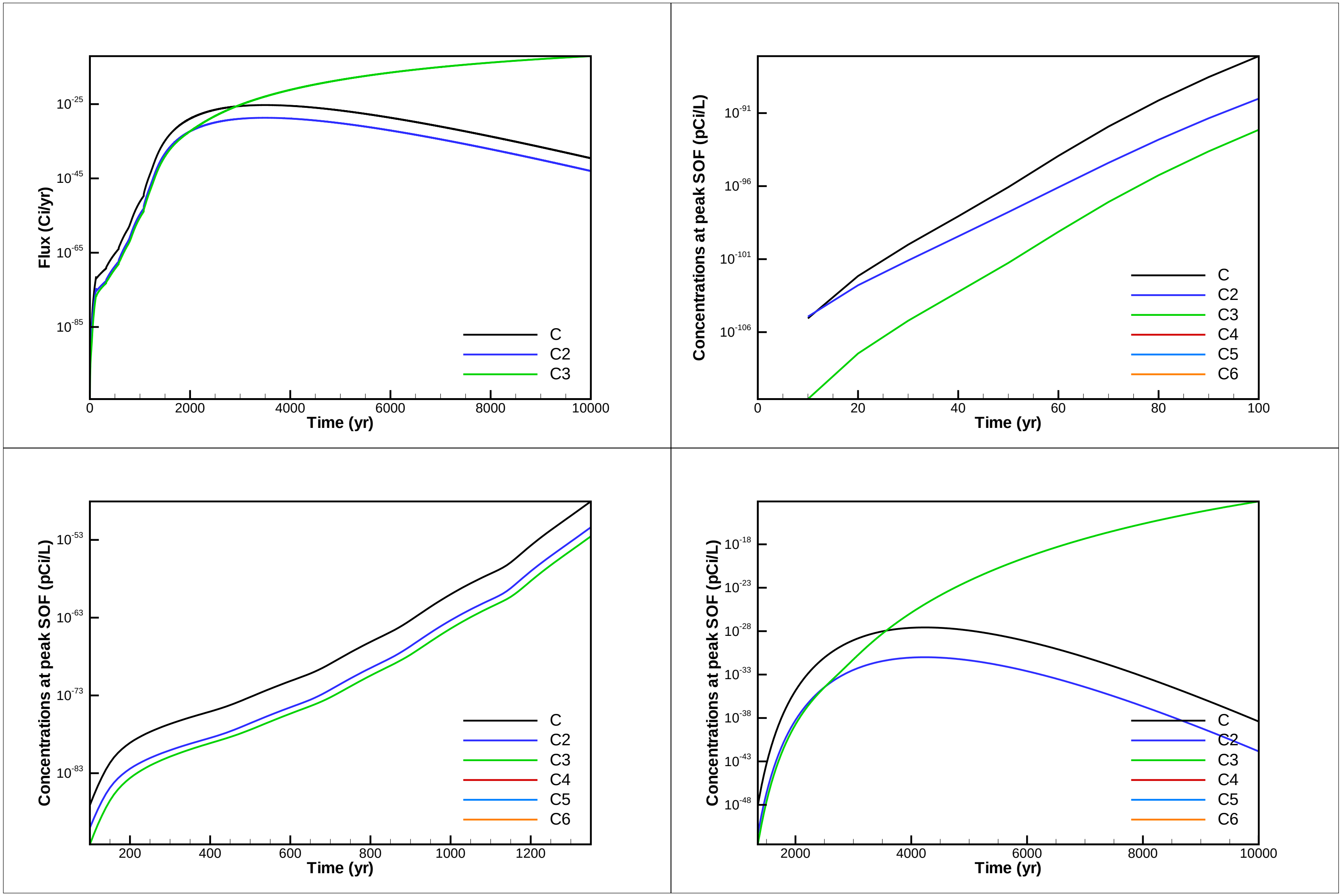


Figure A-41. Flux and concentration results for case Pu-238_0.01: Pu-238 Pu-238_56 U-234

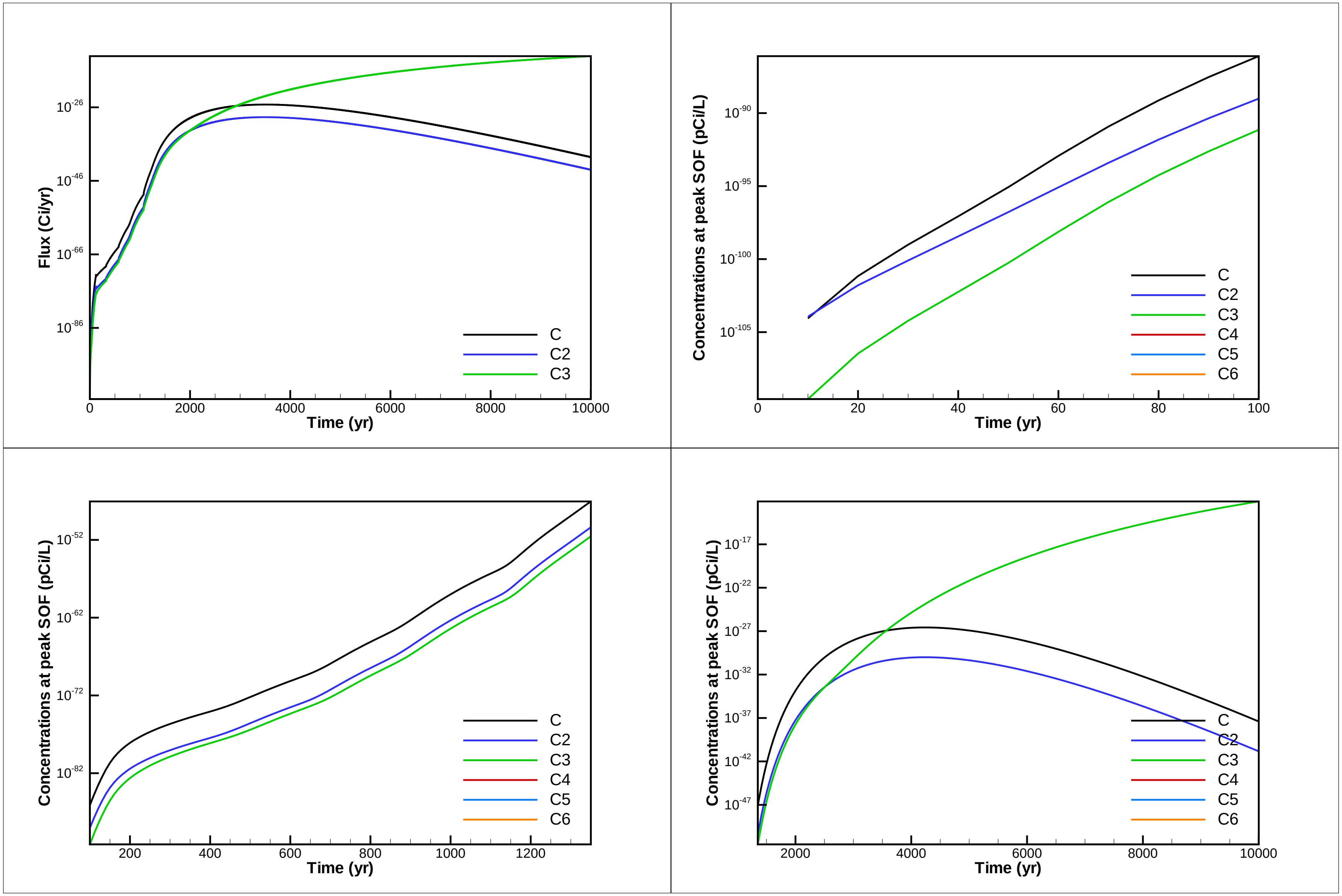


Figure A-42. Flux and concentration results for case Pu-238_0.1: Pu-238 Pu-238_56 U-234

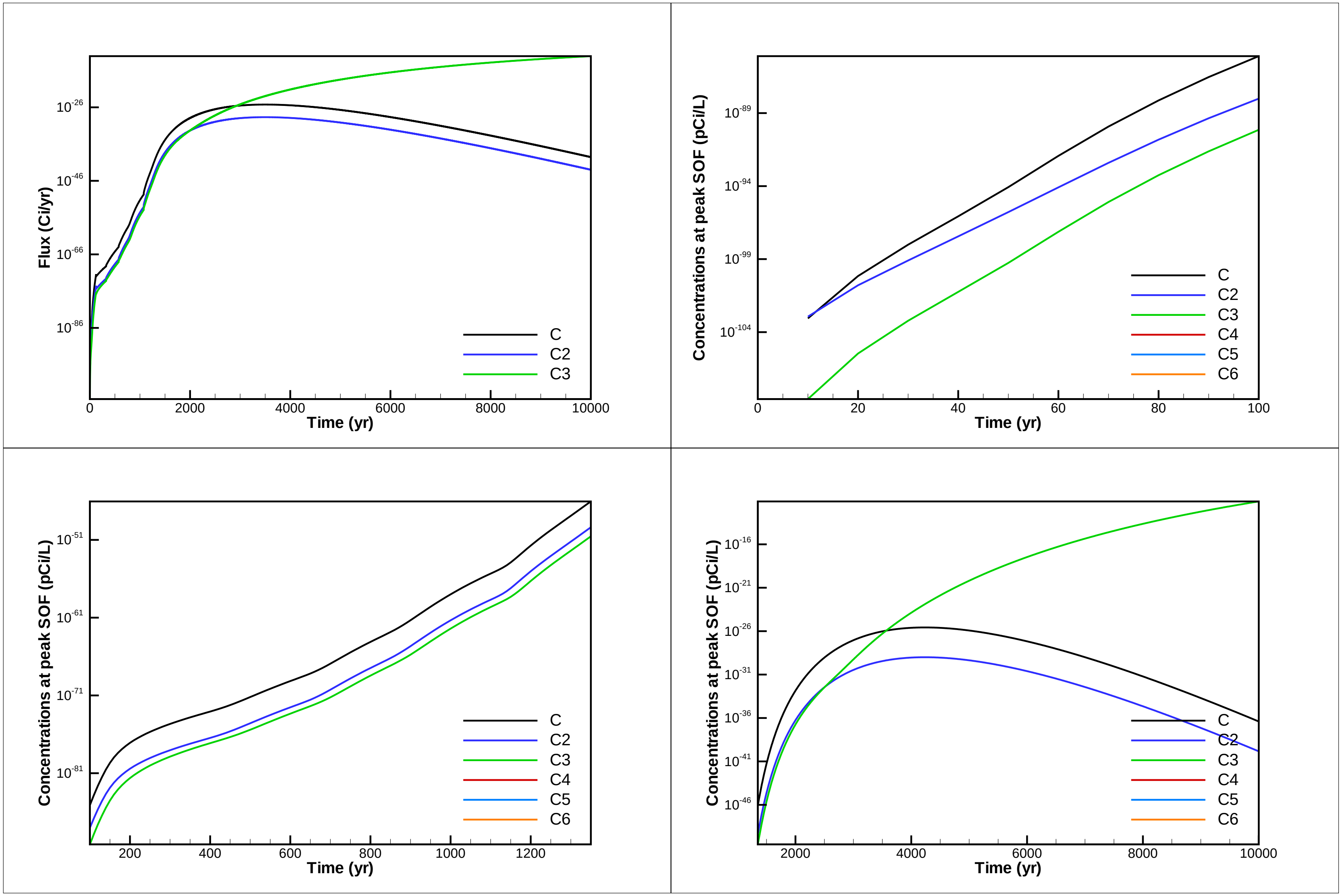


Figure A-43. Flux and concentration results for case Pu-238_1: Pu-238 Pu-238_56 U-234

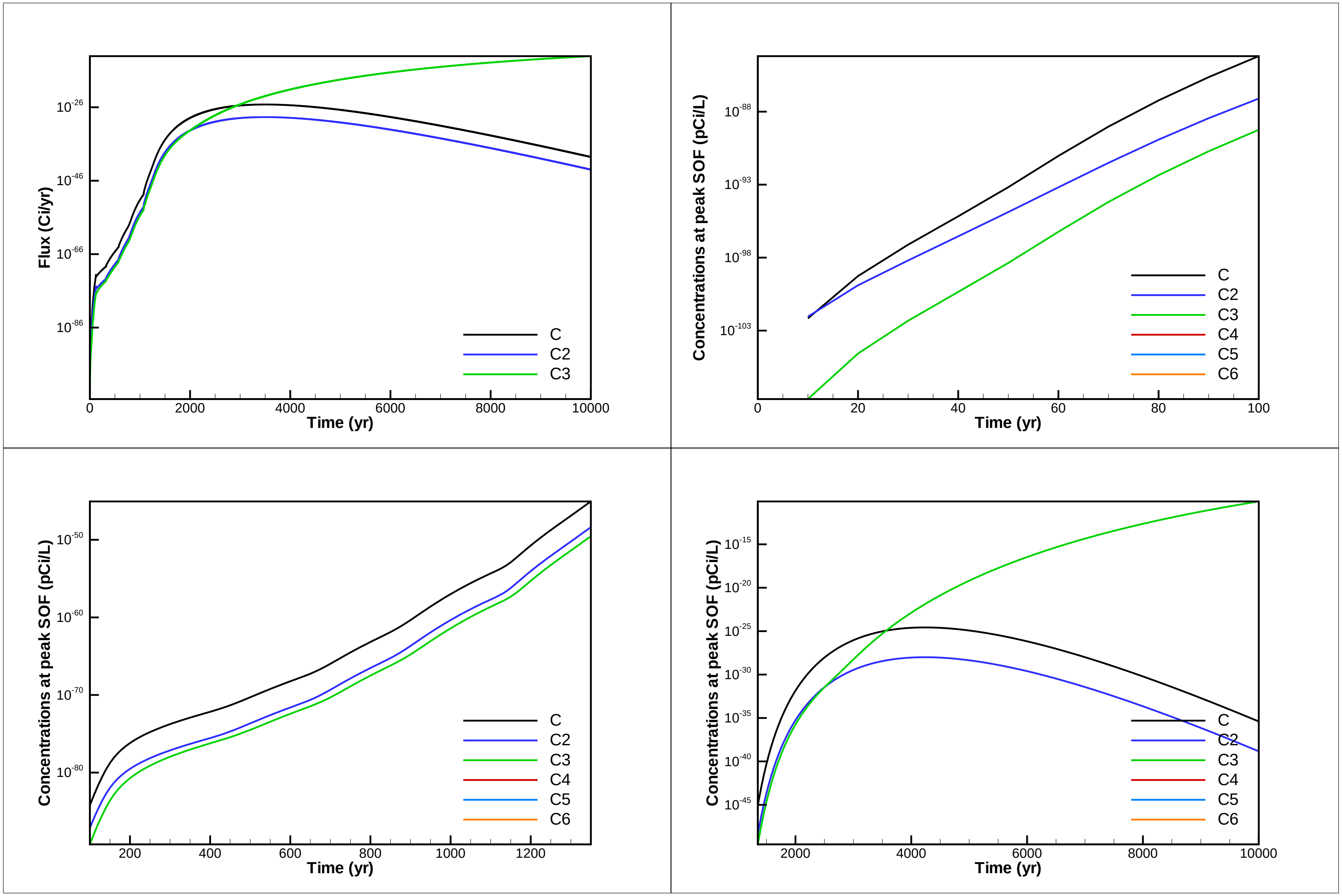


Figure A-44. Flux and concentration results for case Pu-238_10: Pu-238 Pu-238_56 U-234

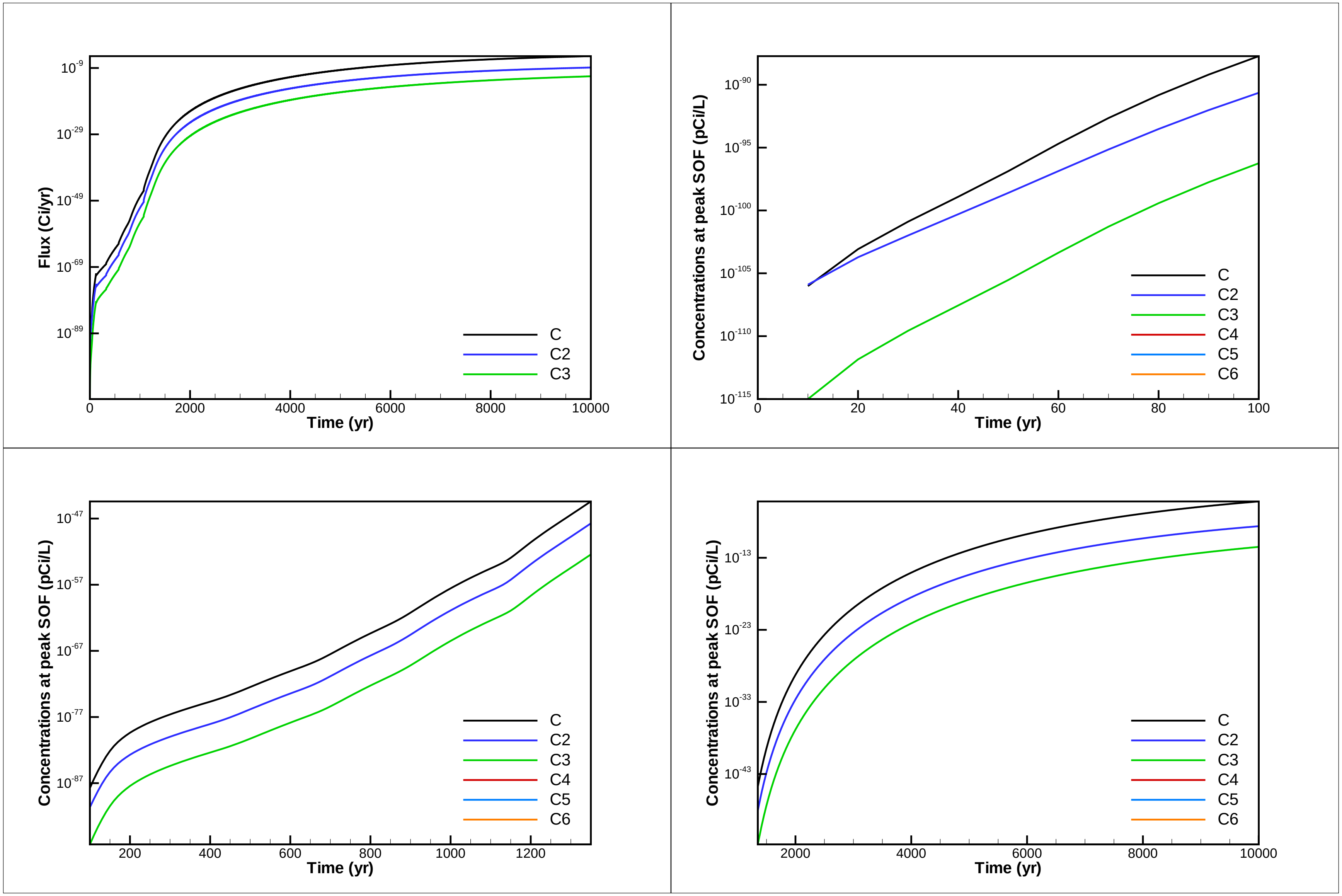


Figure A-45. Flux and concentration results for case Pu-239_0.001: Pu-239 Pu-239_56 U-235

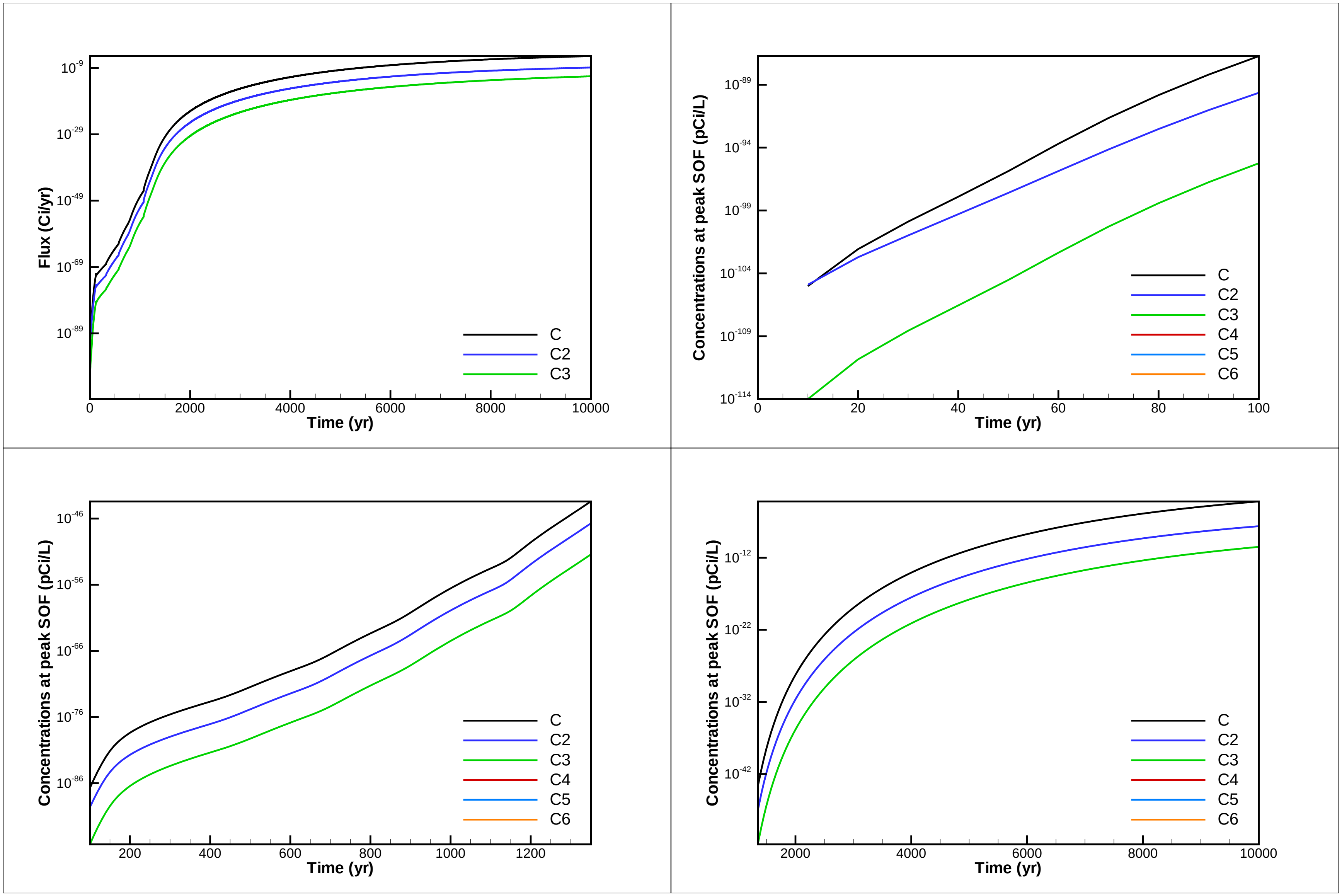


Figure A-46. Flux and concentration results for case Pu-239_0.01: Pu-239 Pu-239_56 U-235

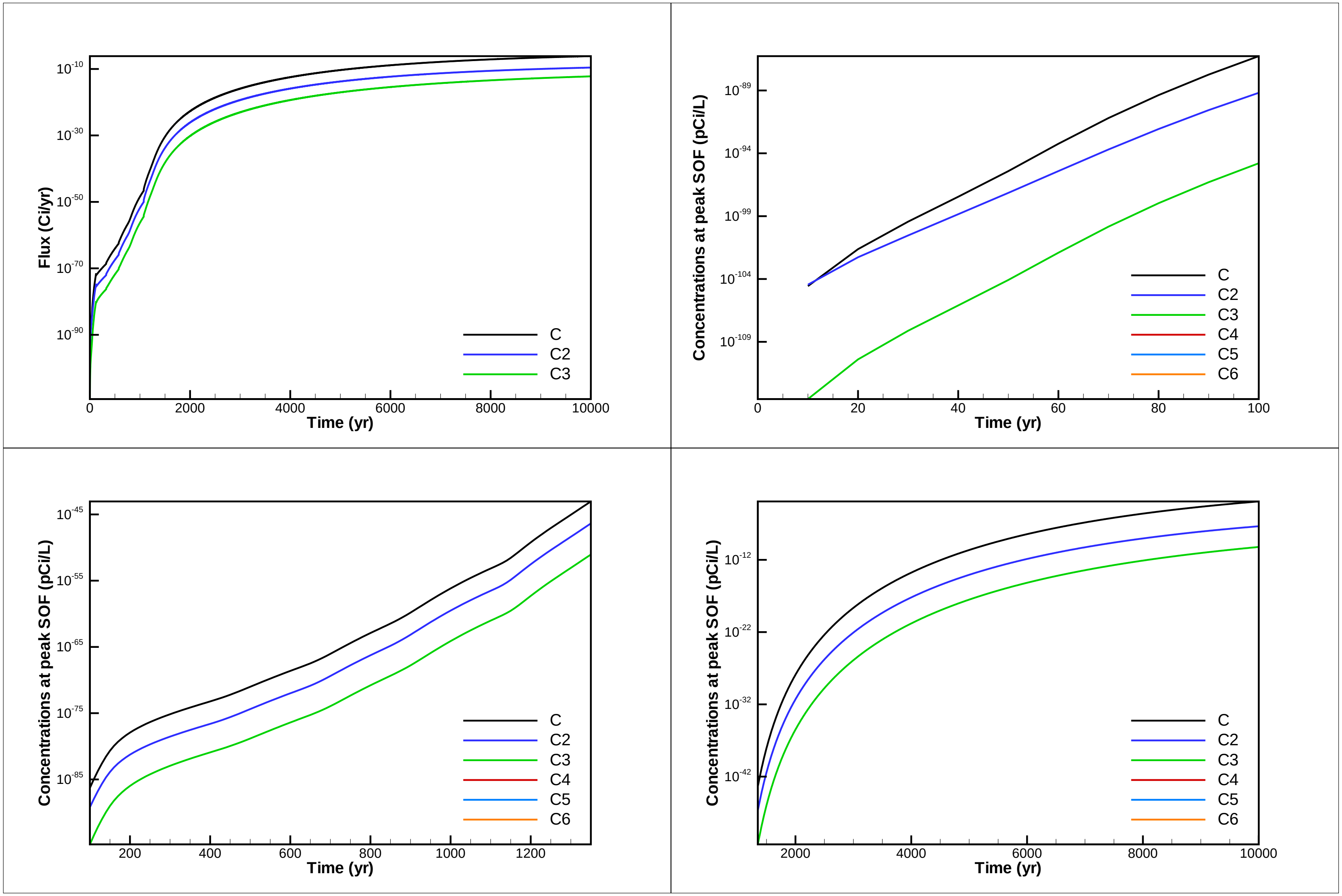


Figure A-47. Flux and concentration results for case Pu-239_0.1: Pu-239 Pu-239_56 U-235

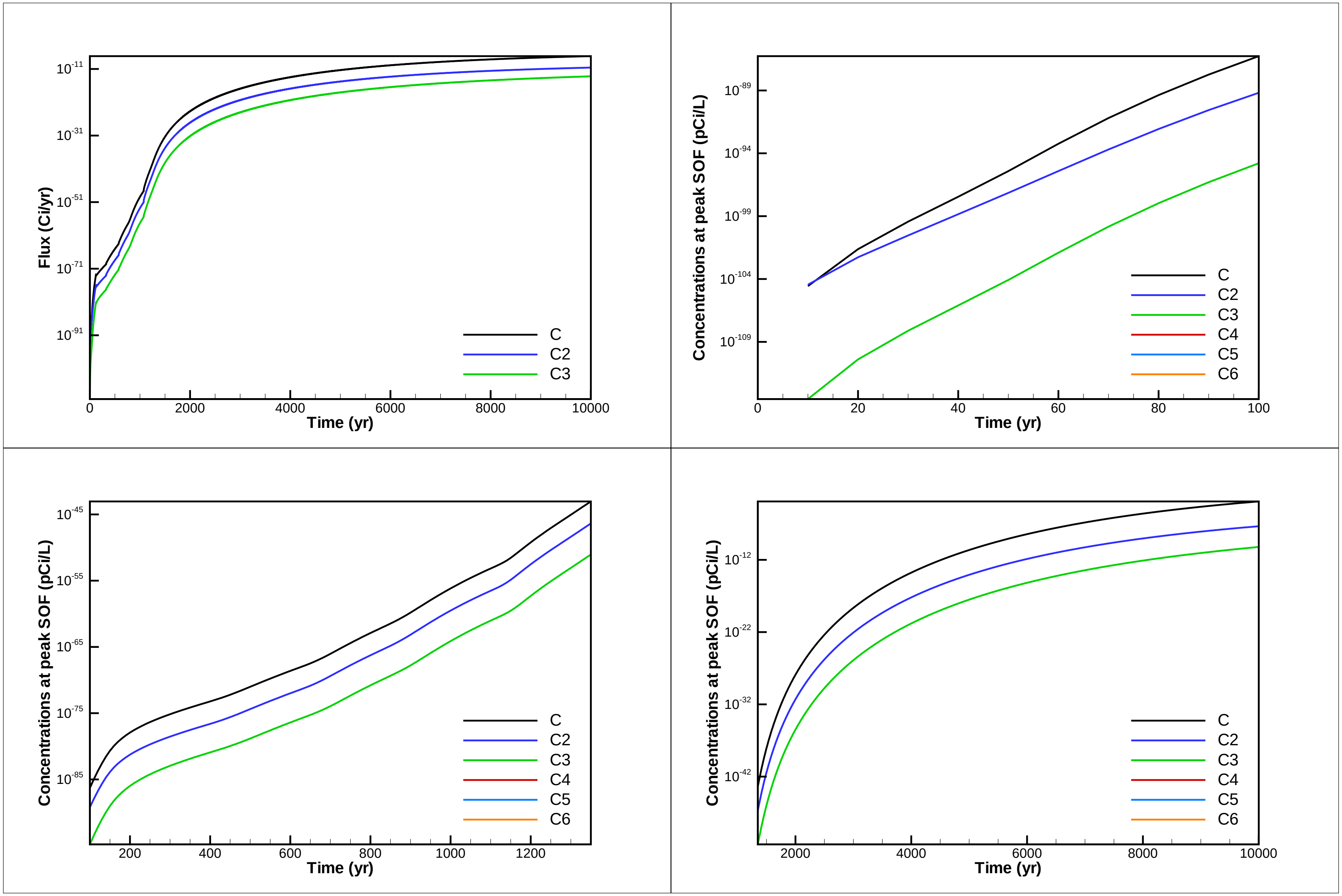


Figure A-48. Flux and concentration results for case Pu-239_1: Pu-239 Pu-239_56 U-235

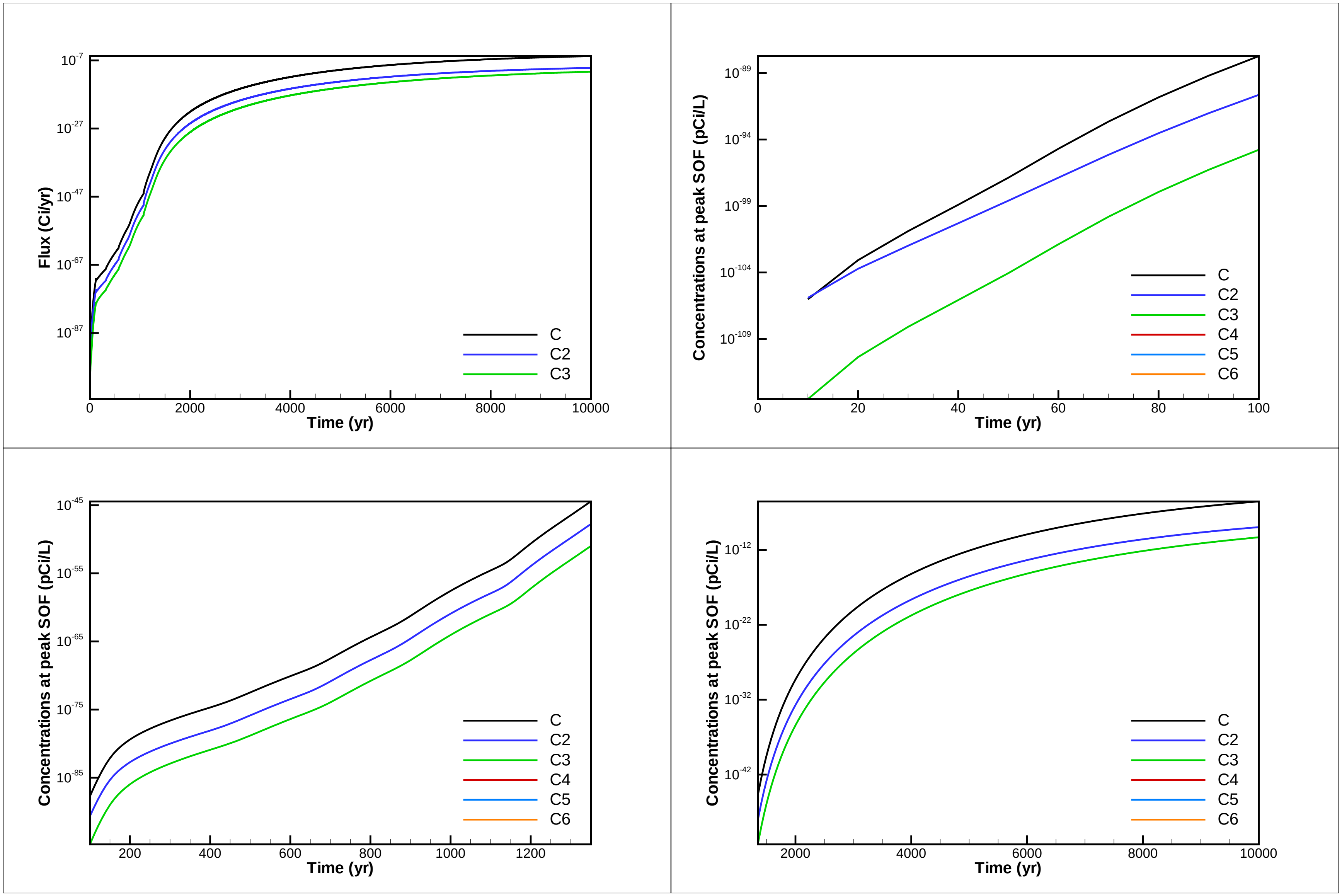


Figure A-49. Flux and concentration results for case Pu-240_0.001: Pu-240 Pu-240_56 U-236

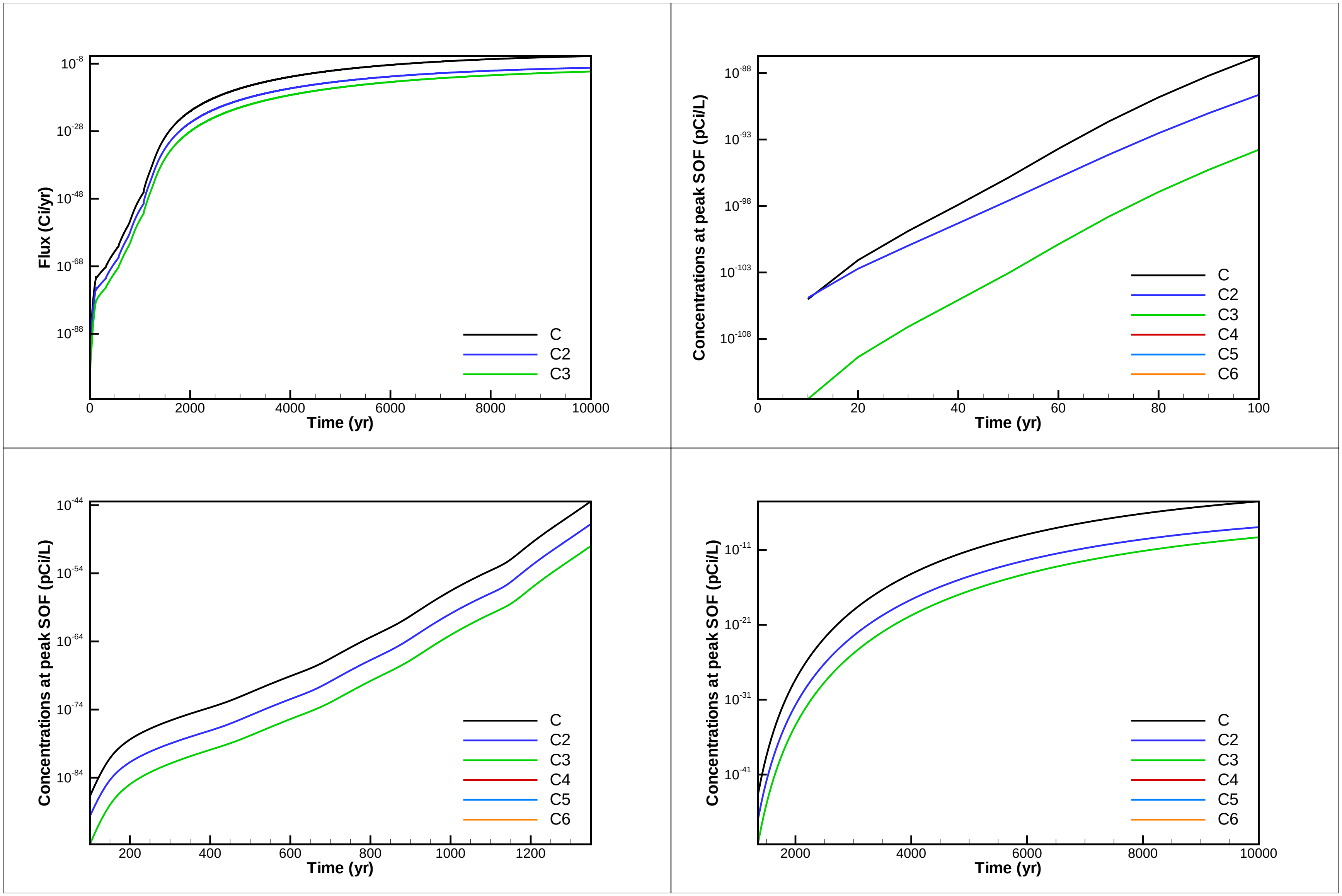


Figure A-50. Flux and concentration results for case Pu-240_0.01: Pu-240 Pu-240_56 U-236

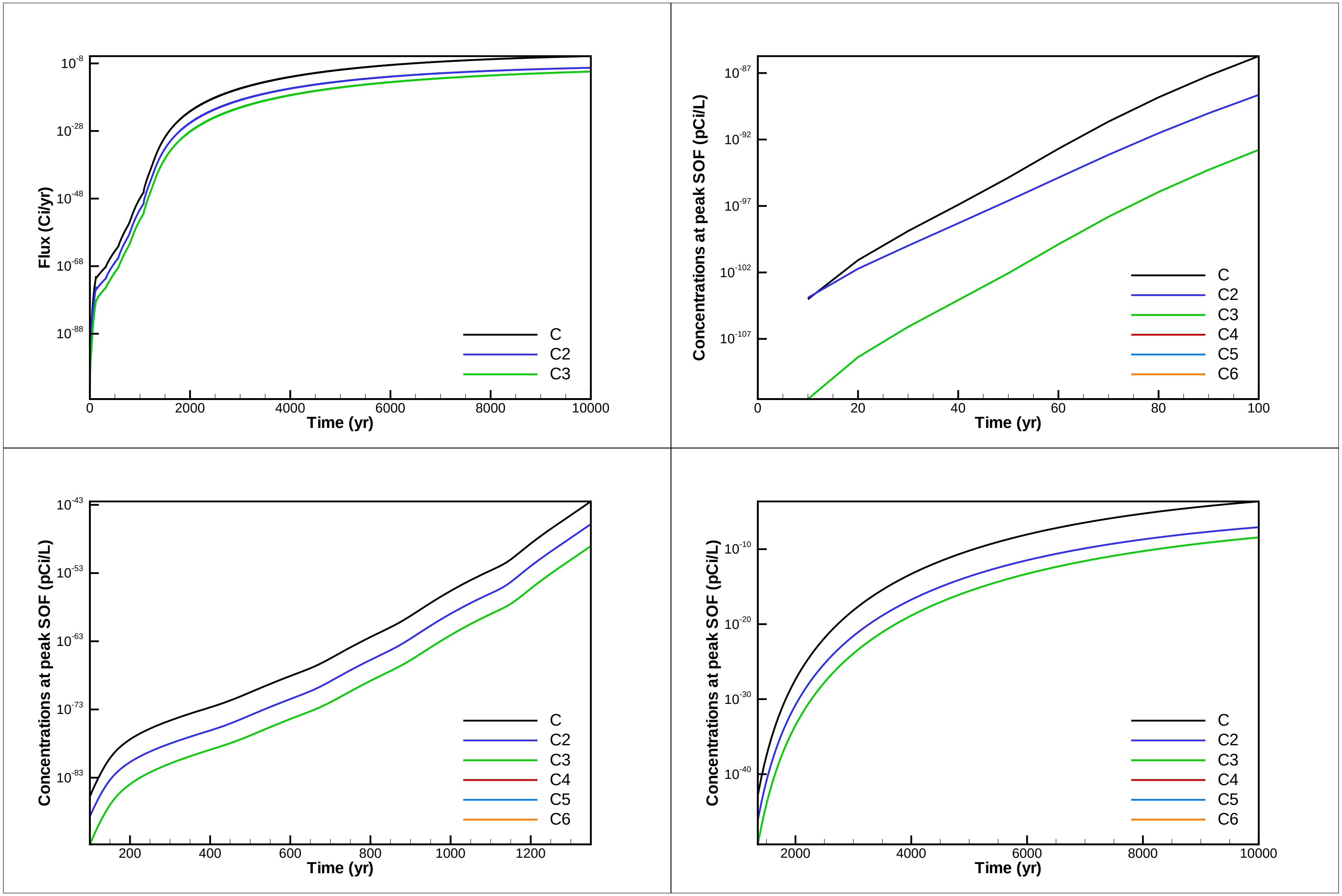


Figure A-51. Flux and concentration results for case Pu-240_0.1: Pu-240 Pu-240_56 U-236

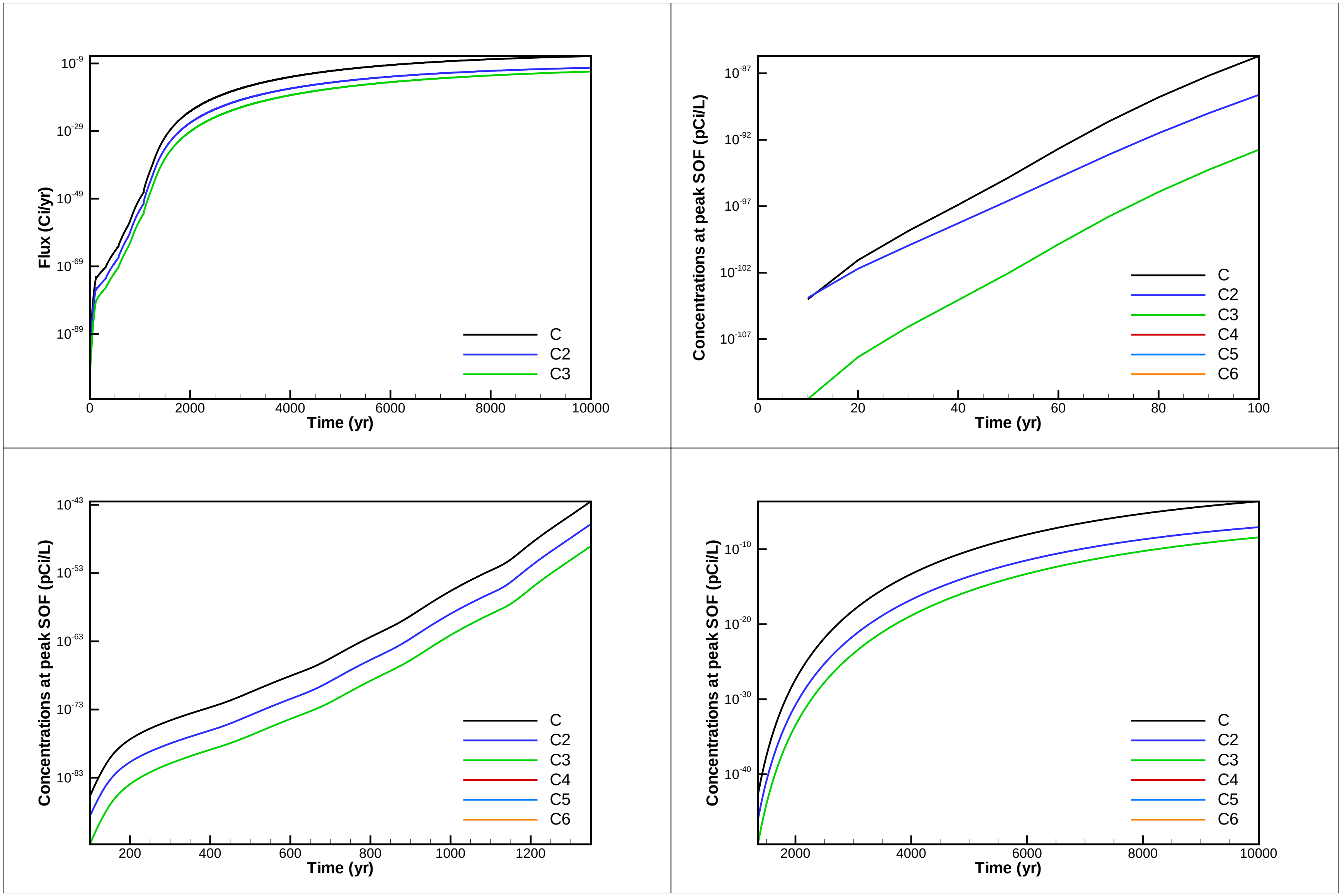


Figure A-52. Flux and concentration results for case Pu-240_1: Pu-240 Pu-240_56 U-236

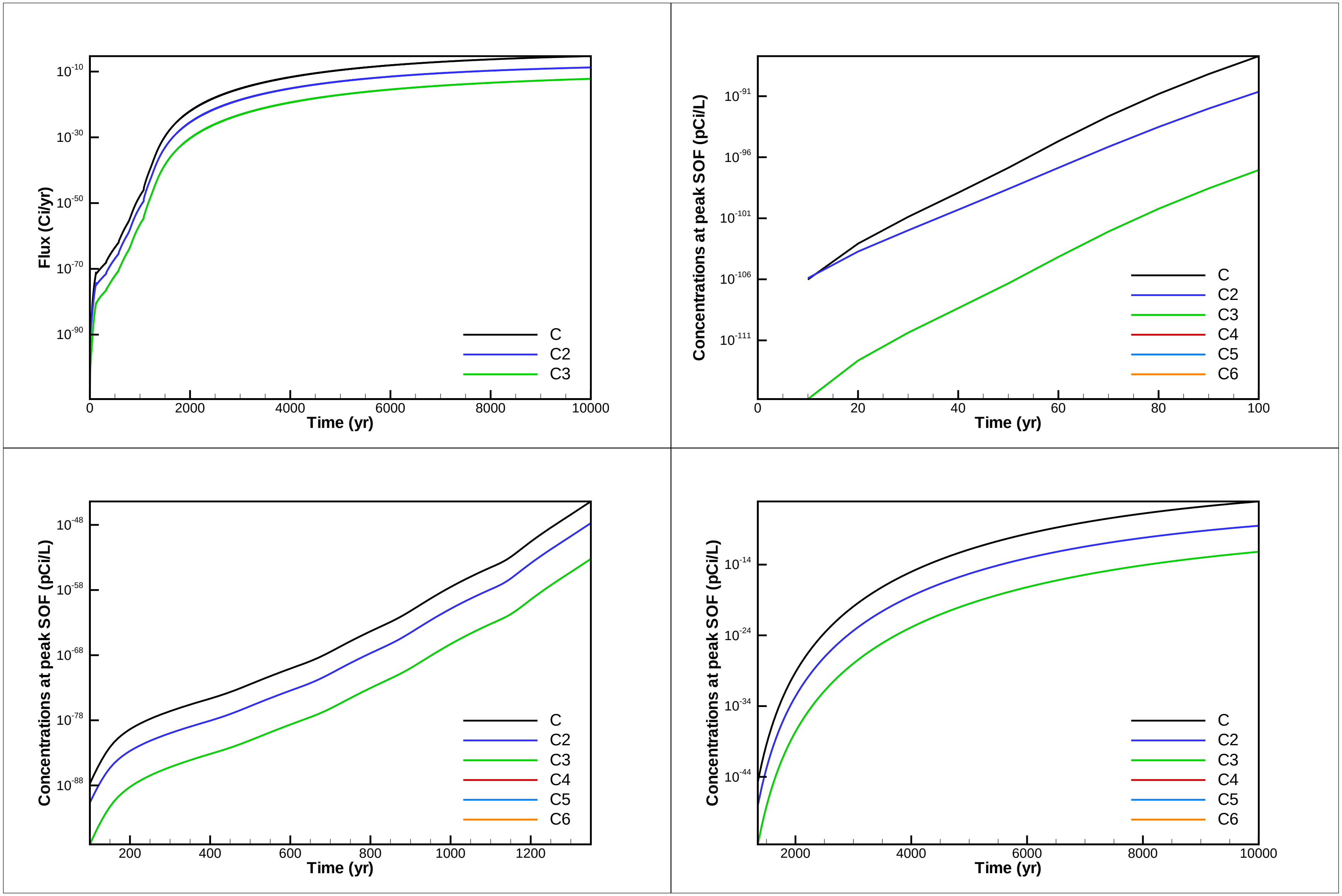


Figure A-53. Flux and concentration results for case Pu-242_0.001: Pu-242 Pu-242_56 U-238

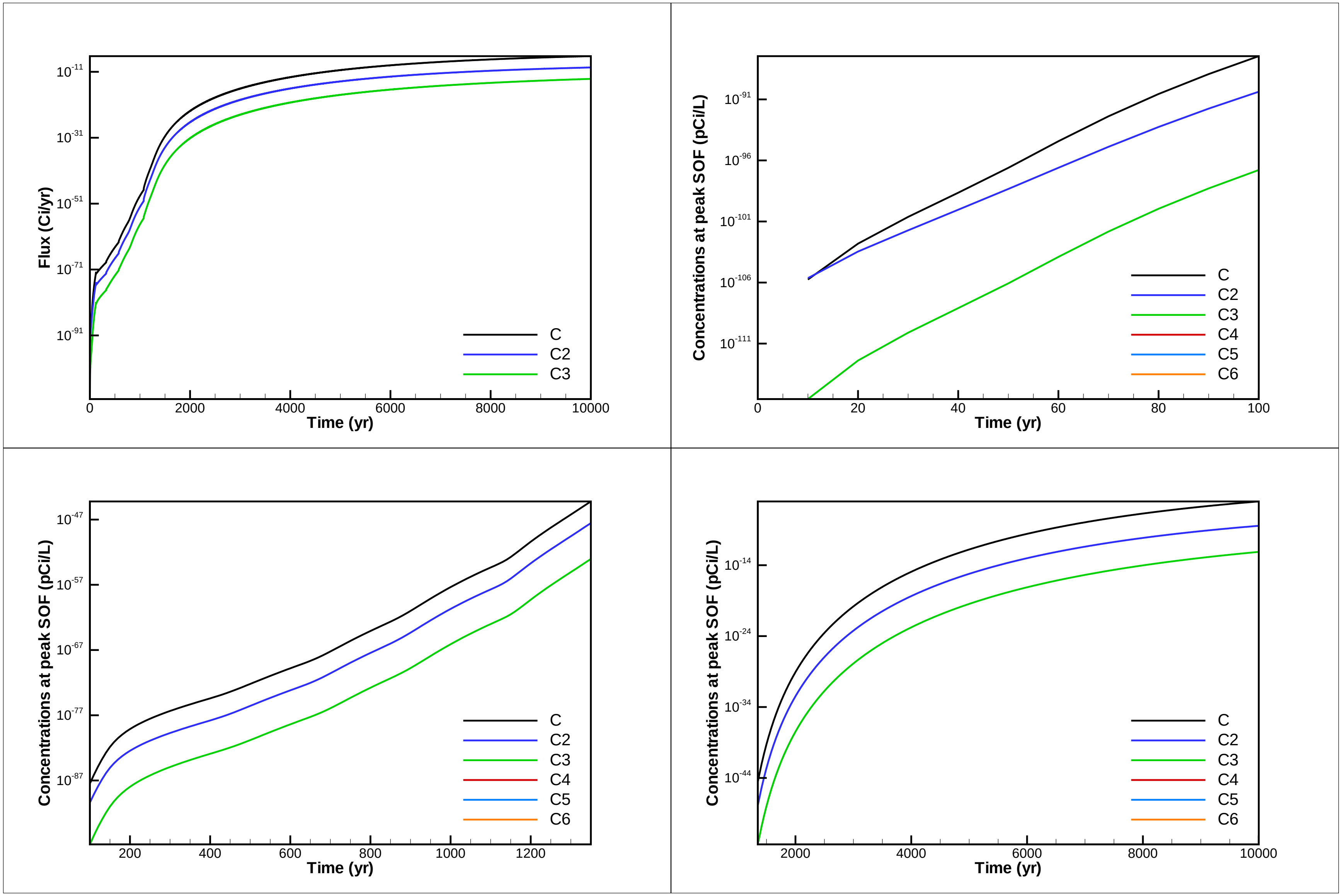


Figure A-54. Flux and concentration results for case Pu-242_0.01: Pu-242 Pu-242_56 U-238

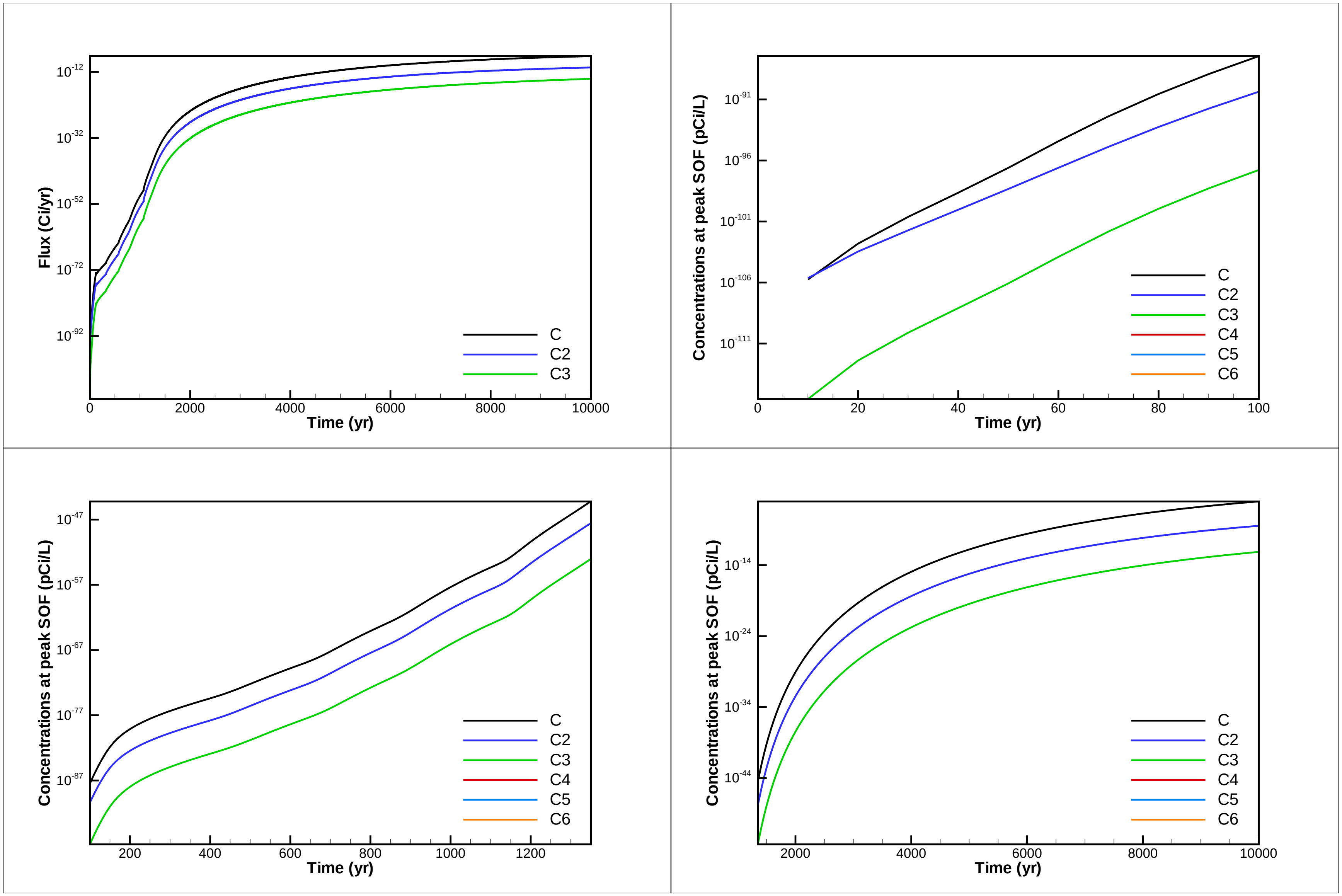


Figure A-55. Flux and concentration results for case Pu-242_0.1: Pu-242 Pu-242_56 U-238

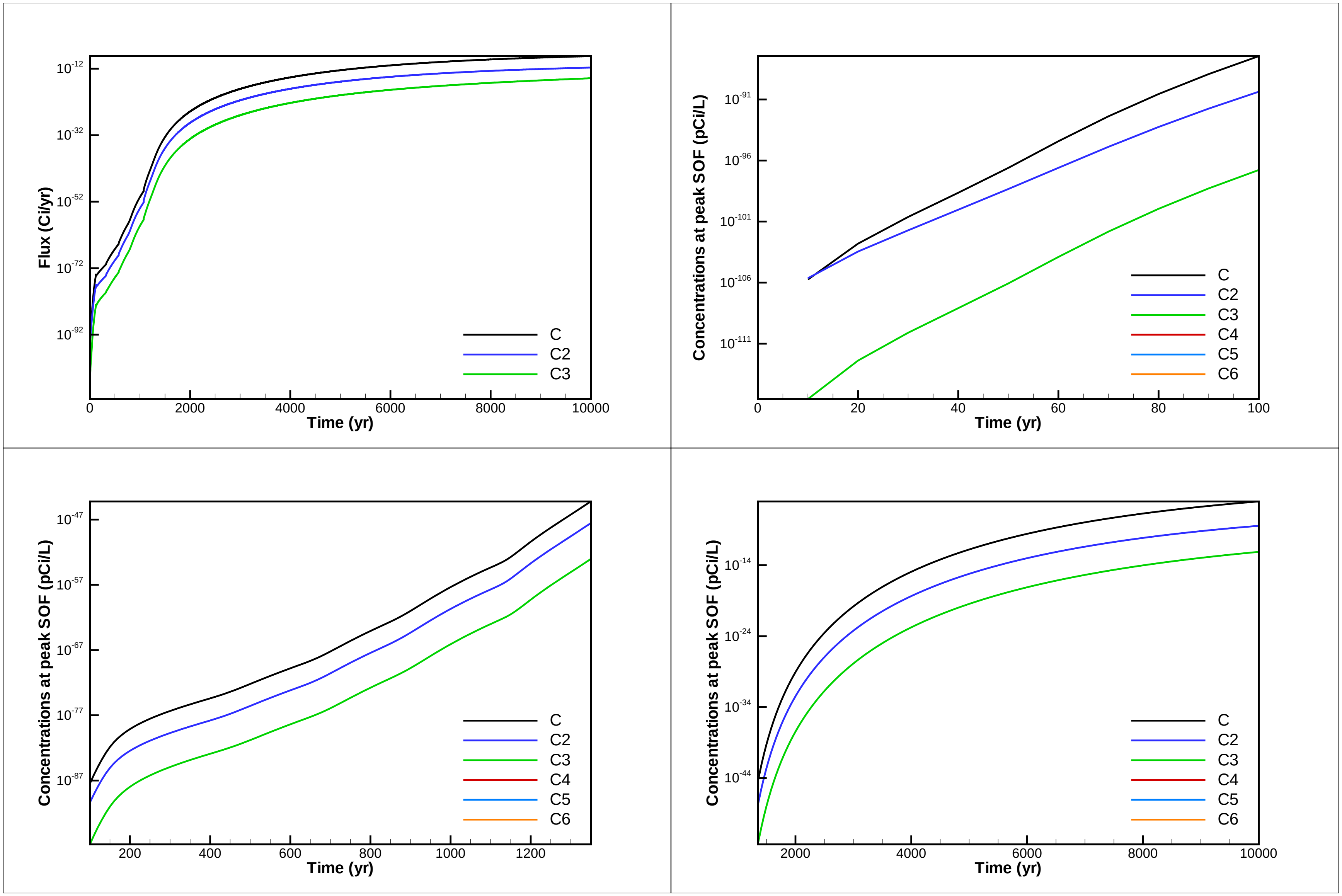


Figure A-56. Flux and concentration results for case Pu-242_1: Pu-242 Pu-242_56 U-238

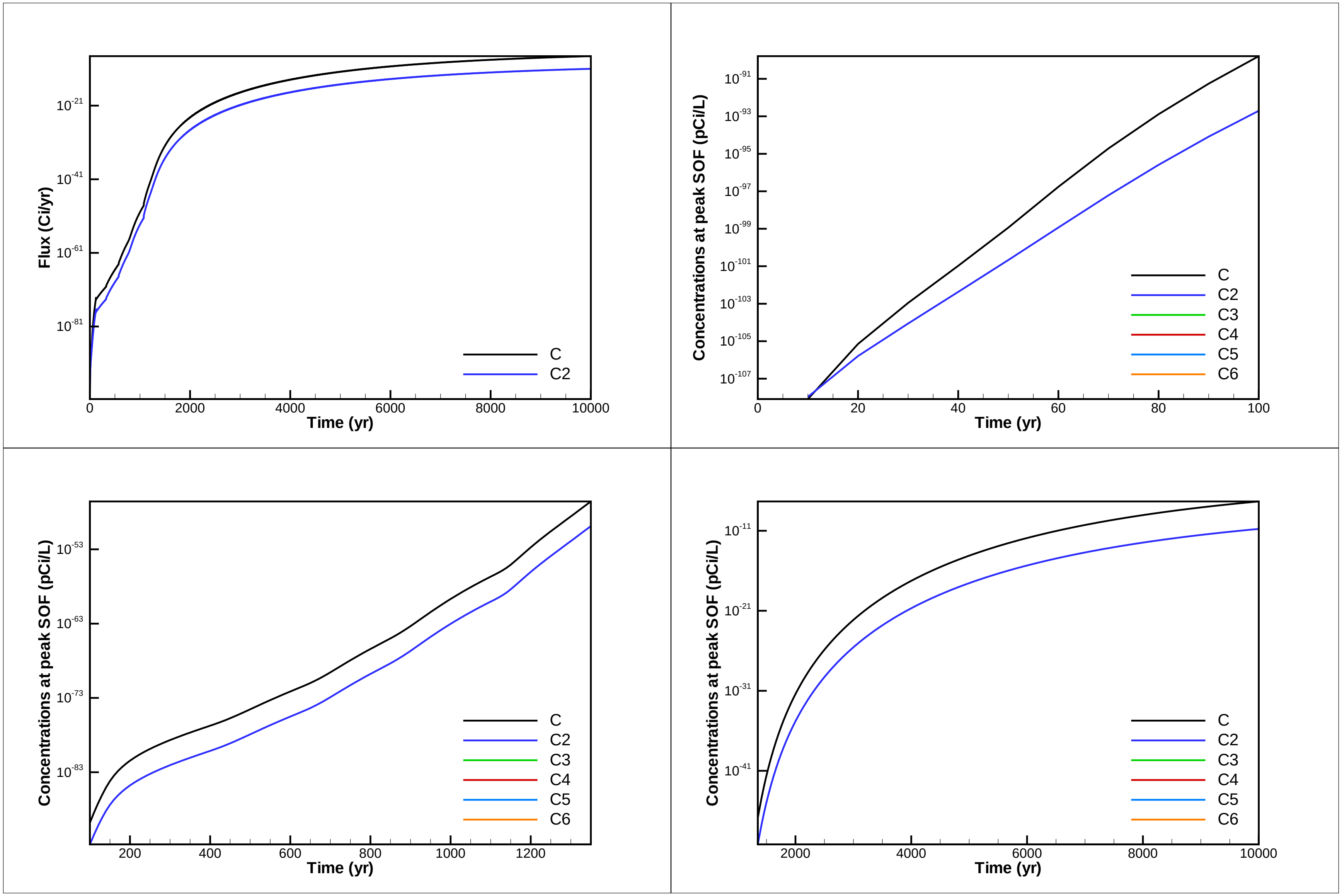


Figure A-57. Flux and concentration results for case Pu-244_0.001: Pu-244 Pu-244_56

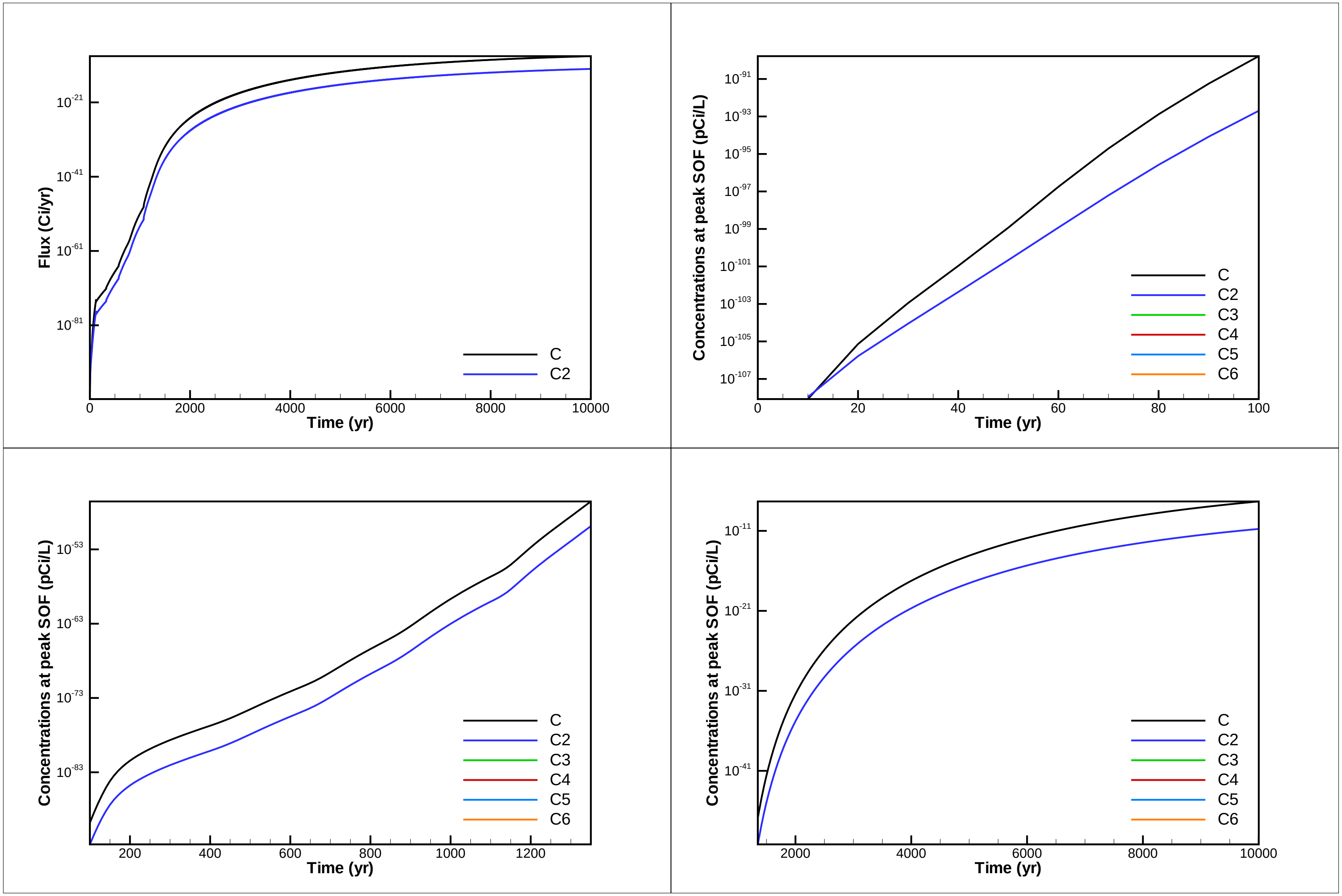


Figure A-58. Flux and concentration results for case Pu-244_0.01: Pu-244 Pu-244_56

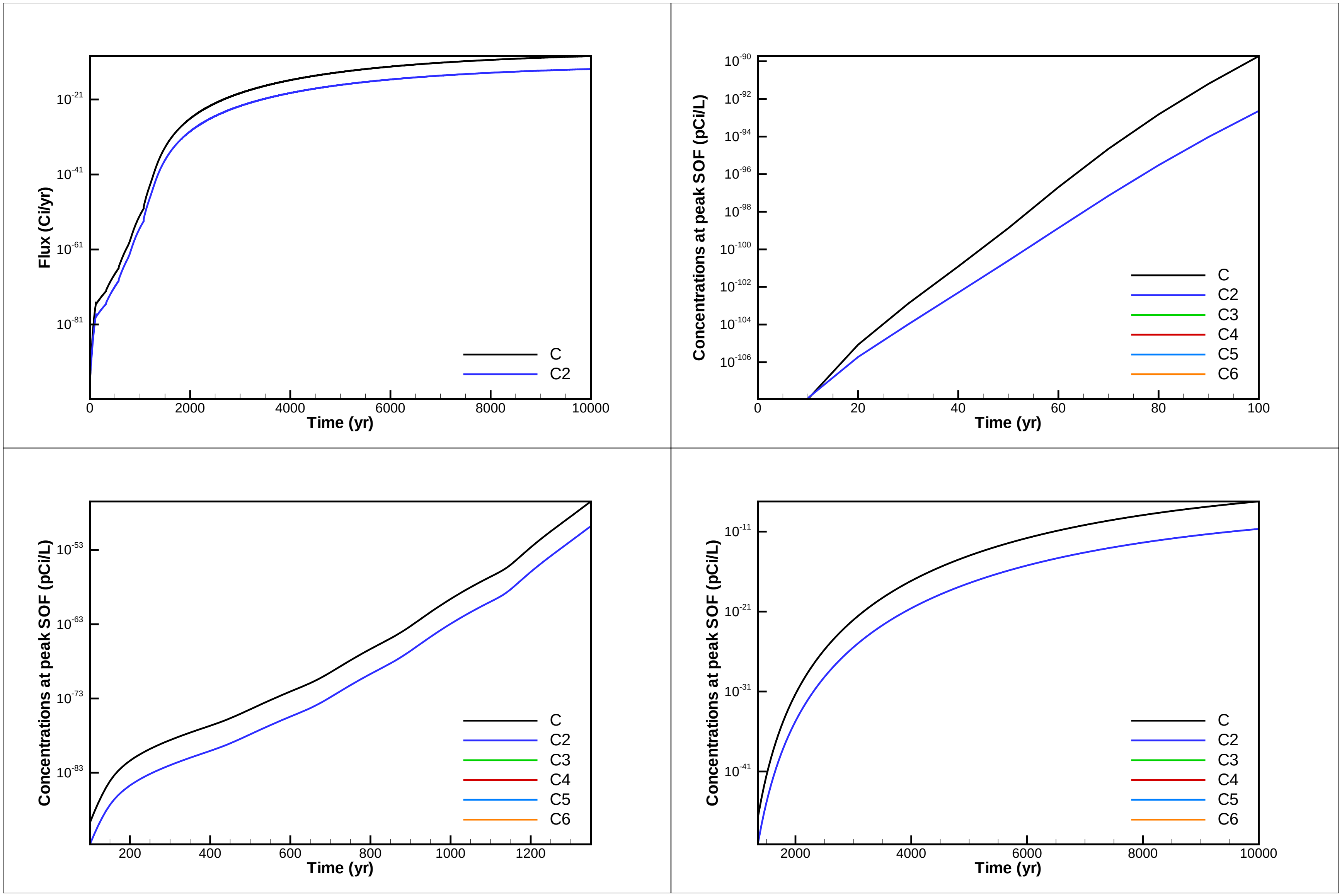


Figure A-59. Flux and concentration results for case Pu-244_0.1: Pu-244 Pu-244_56

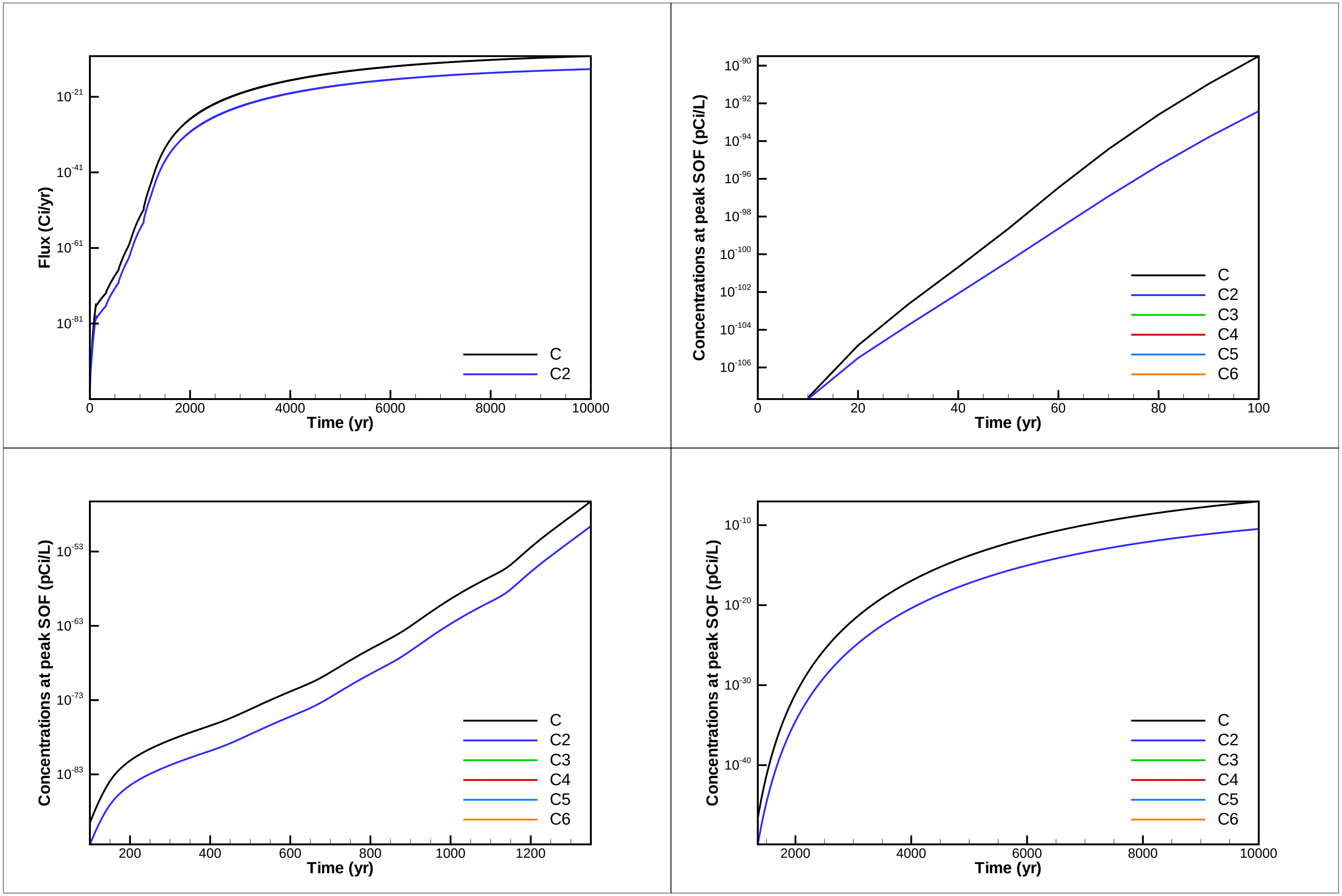


Figure A-60. Flux and concentration results for case Pu-244_1: Pu-244 Pu-244_56

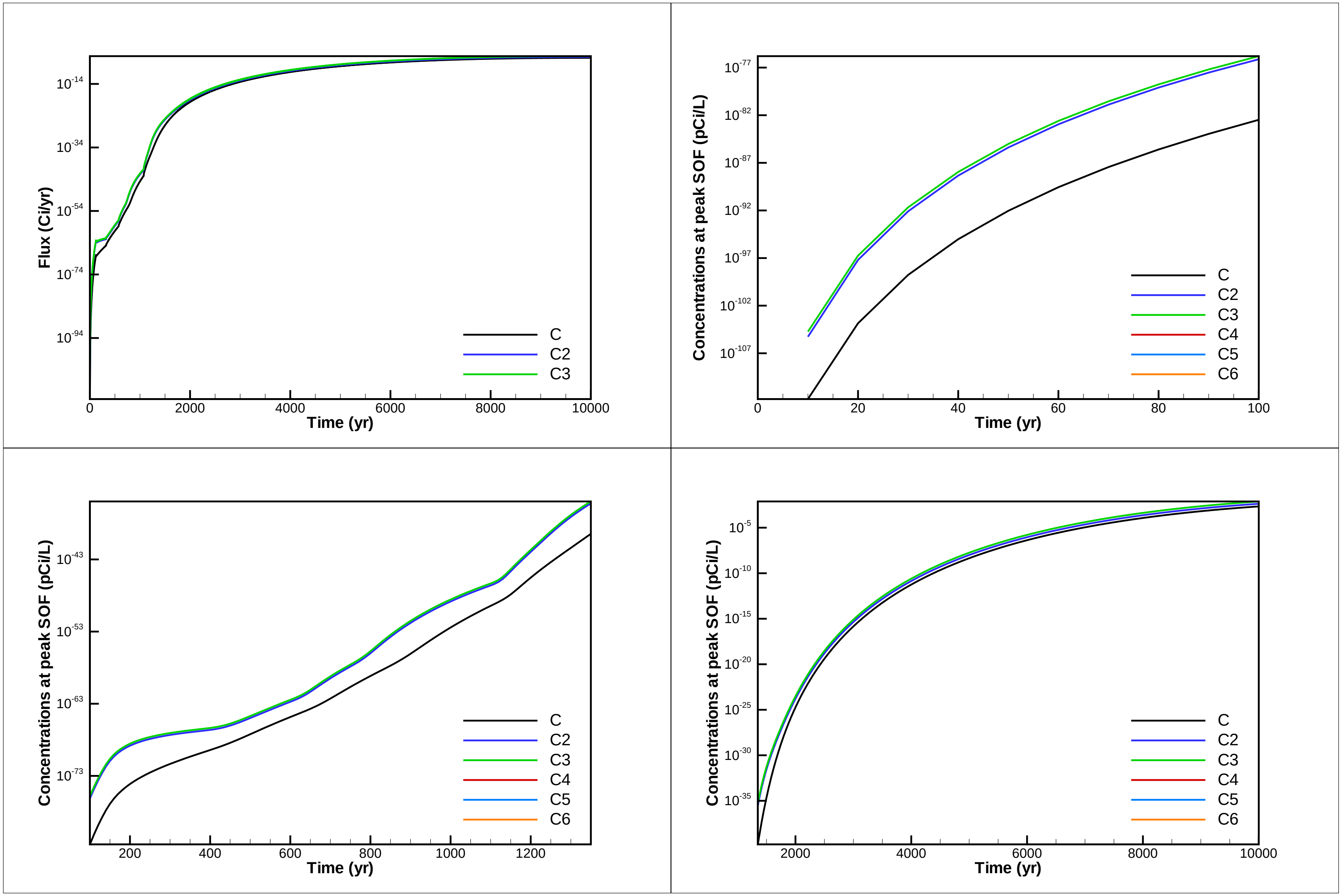


Figure A-61. Flux and concentration results for case Ra-226_1: Ra-226 Pb-210 Po-210

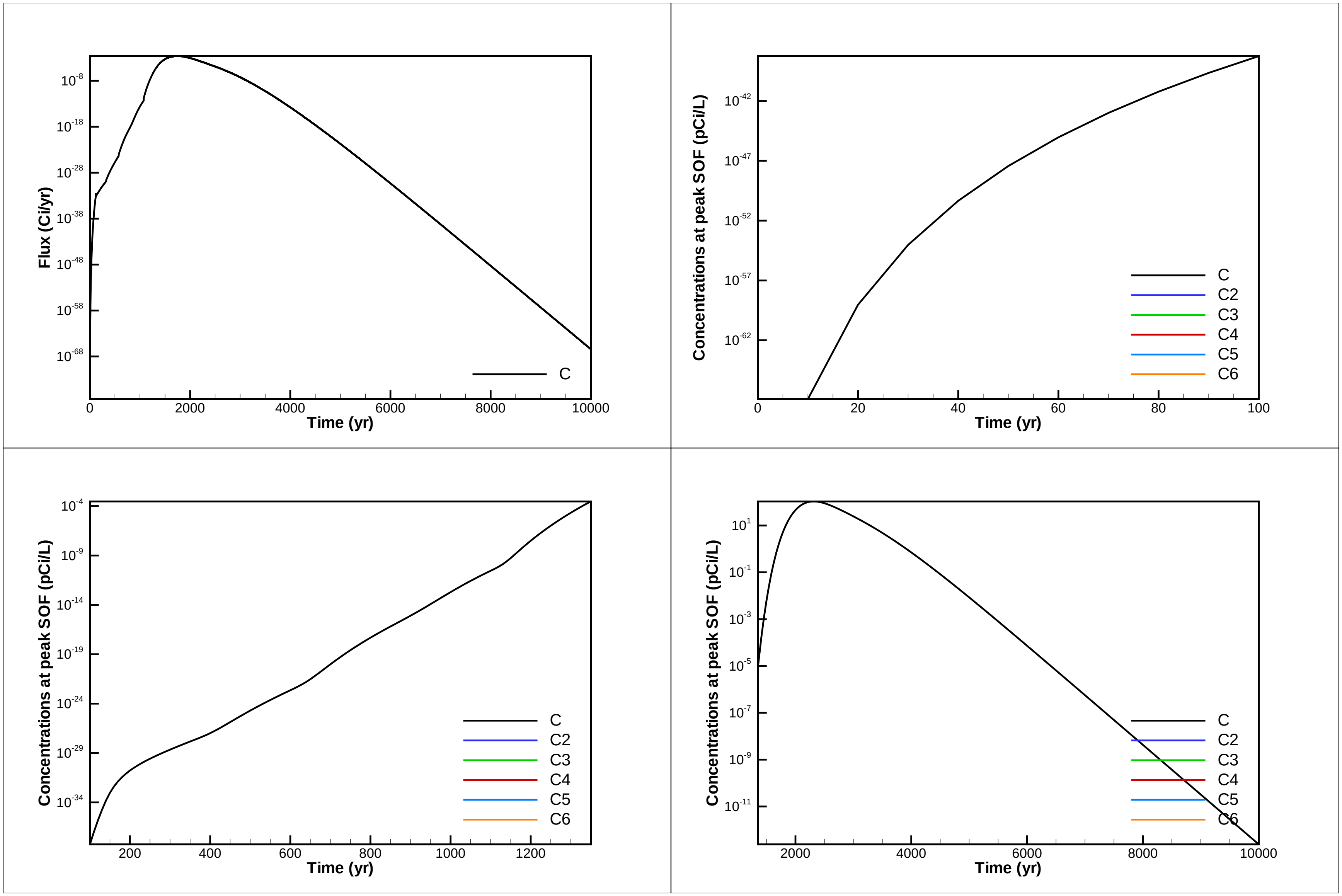


Figure A-62. Flux and concentration results for case Se-79_1: Se-79

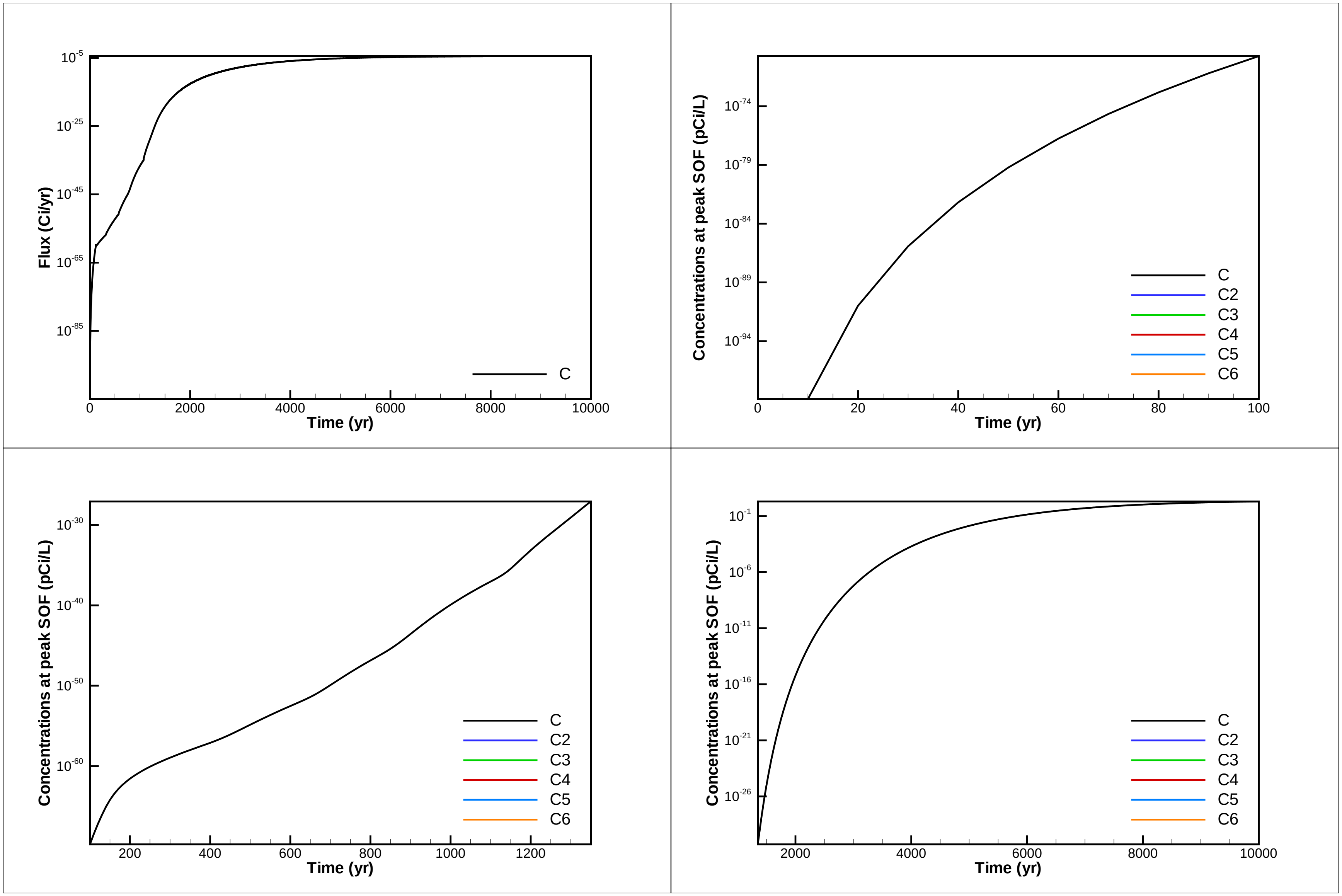


Figure A-63. Flux and concentration results for case Sn-126_1: Sn-126

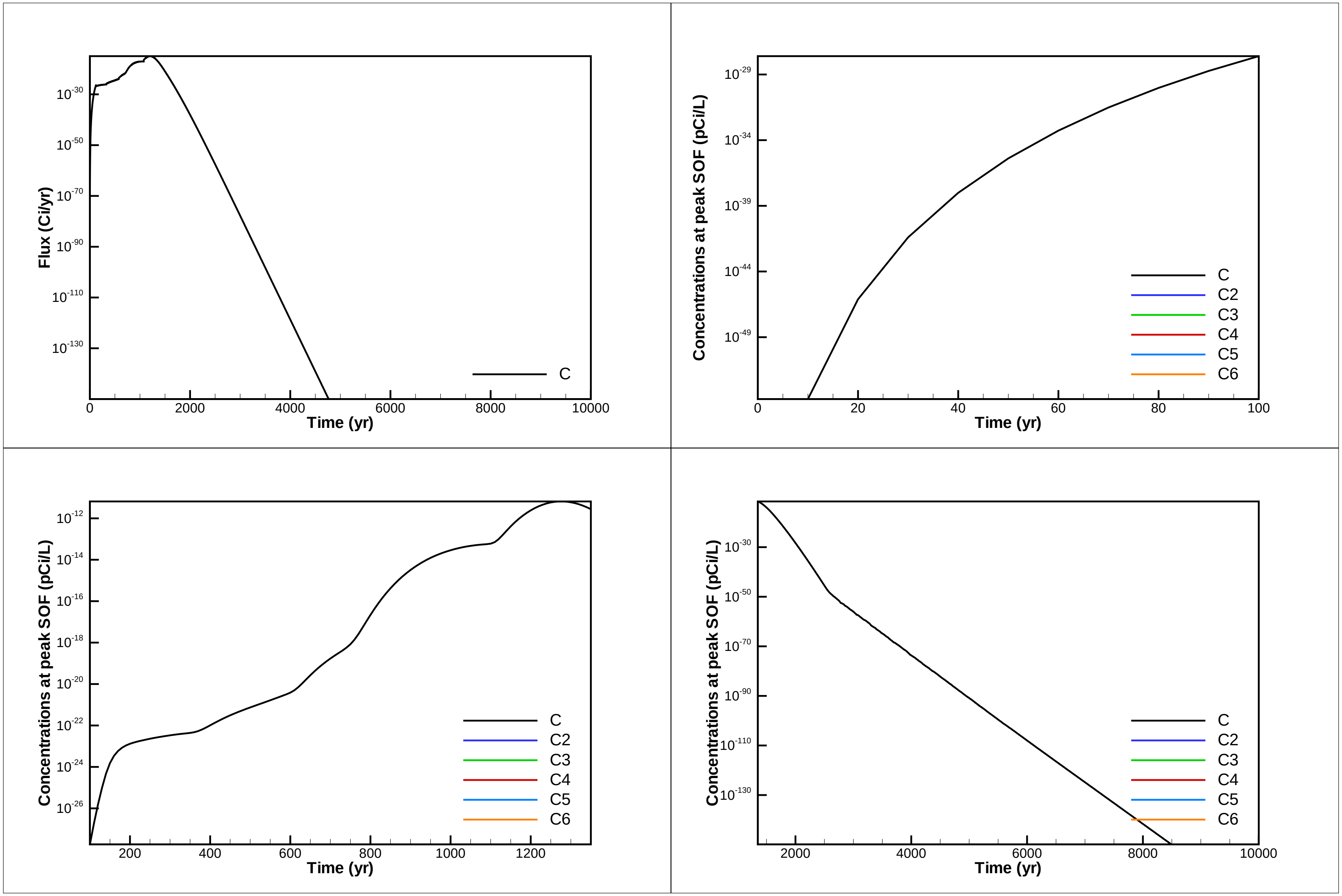


Figure A-64. Flux and concentration results for case Sr-90_1: Sr-90

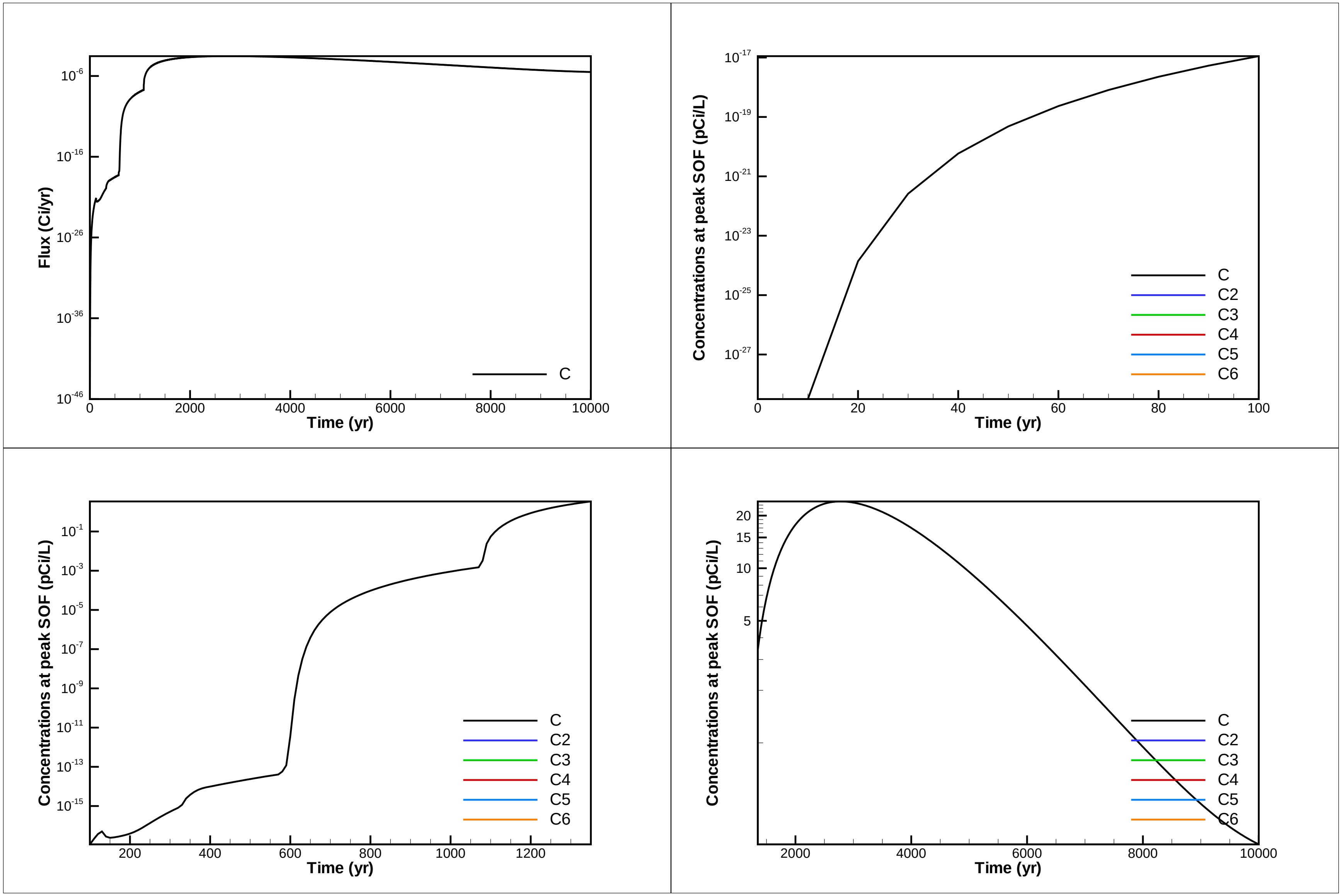


Figure A-65. Flux and concentration results for case Tc-99_1: Tc-99

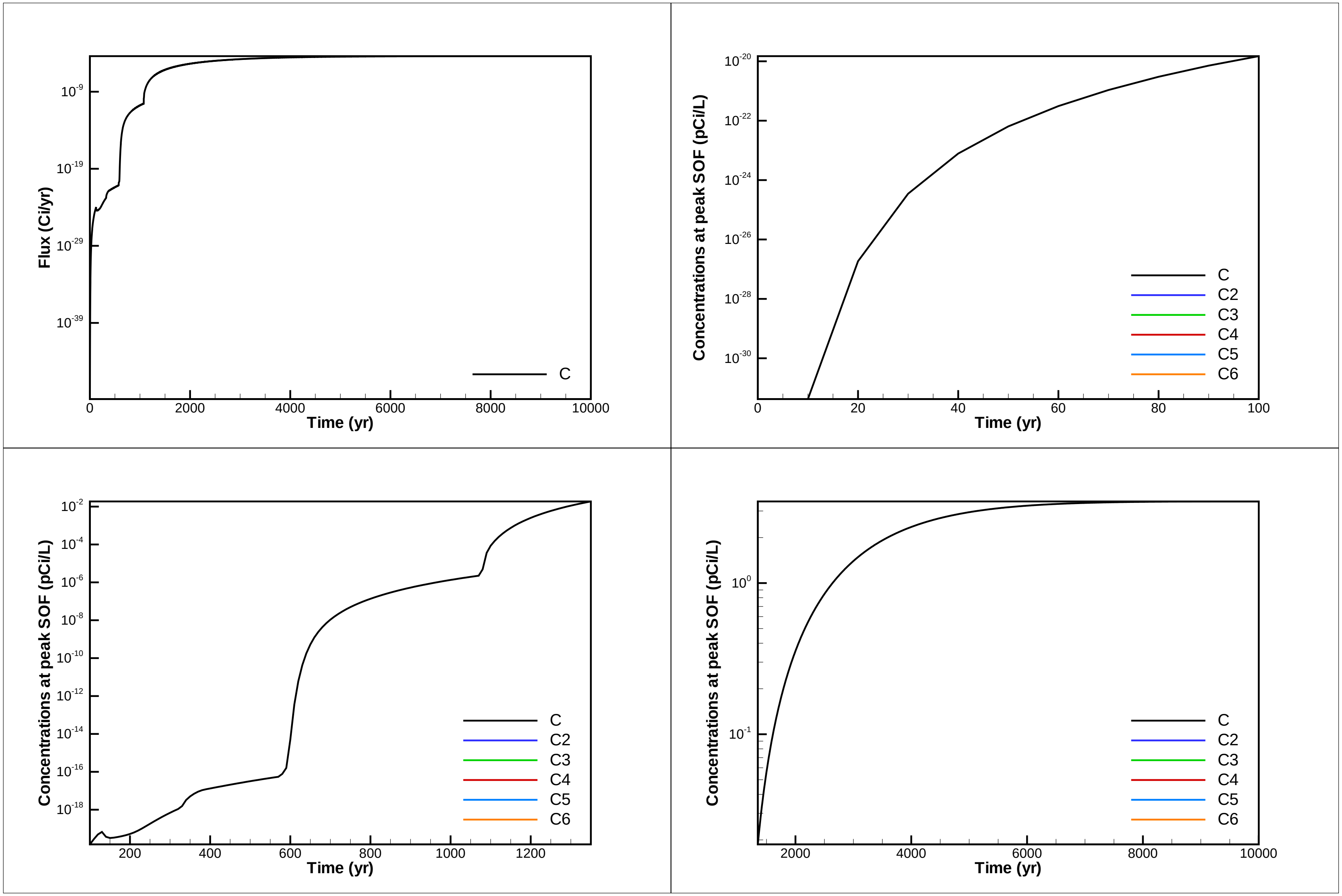


Figure A-66. Flux and concentration results for case Tc-99_KB_1: Tc-99_KB

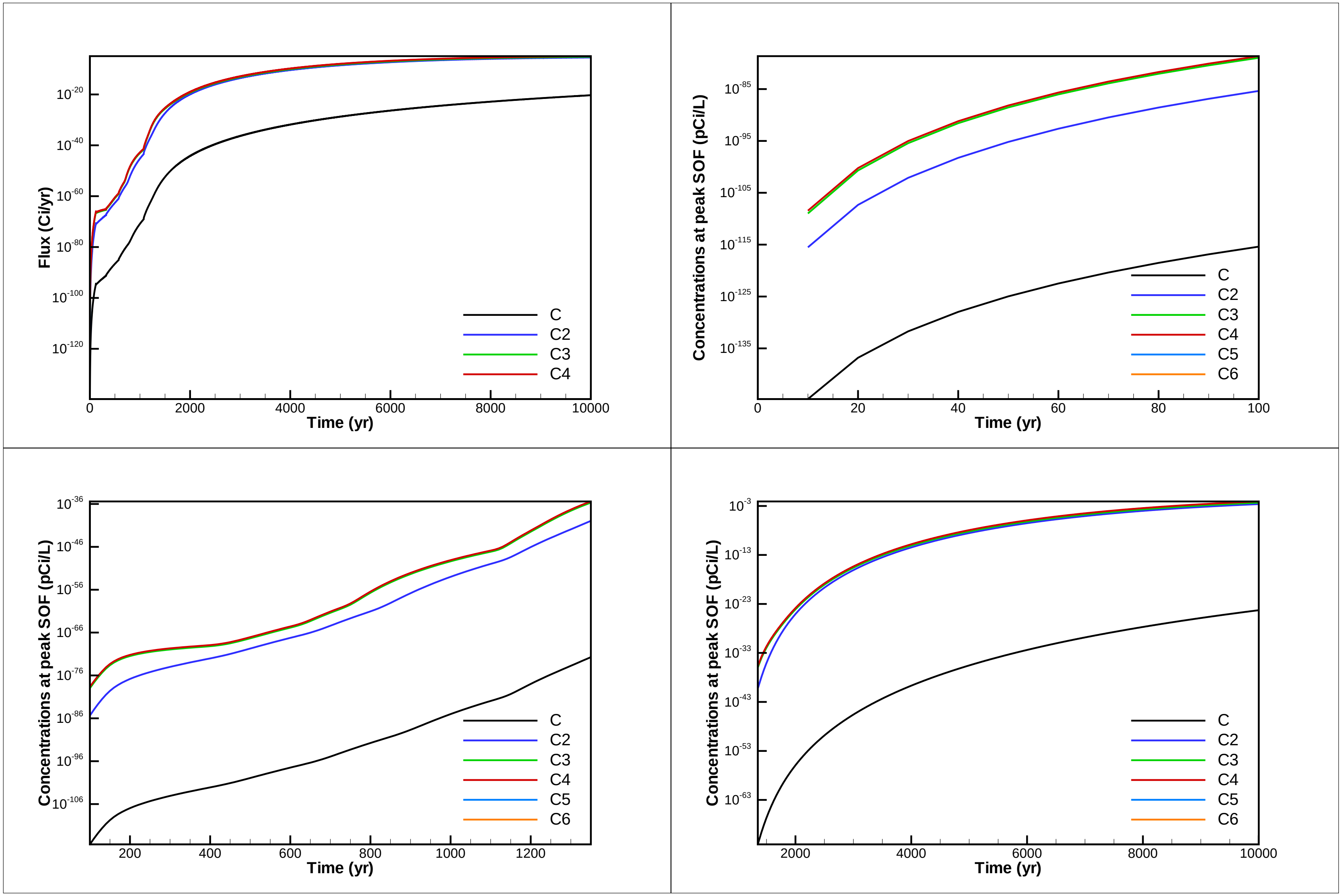


Figure A-67. Flux and concentration results for case Th-230_1: Th-230 Ra-226 Pb-210 Po-210

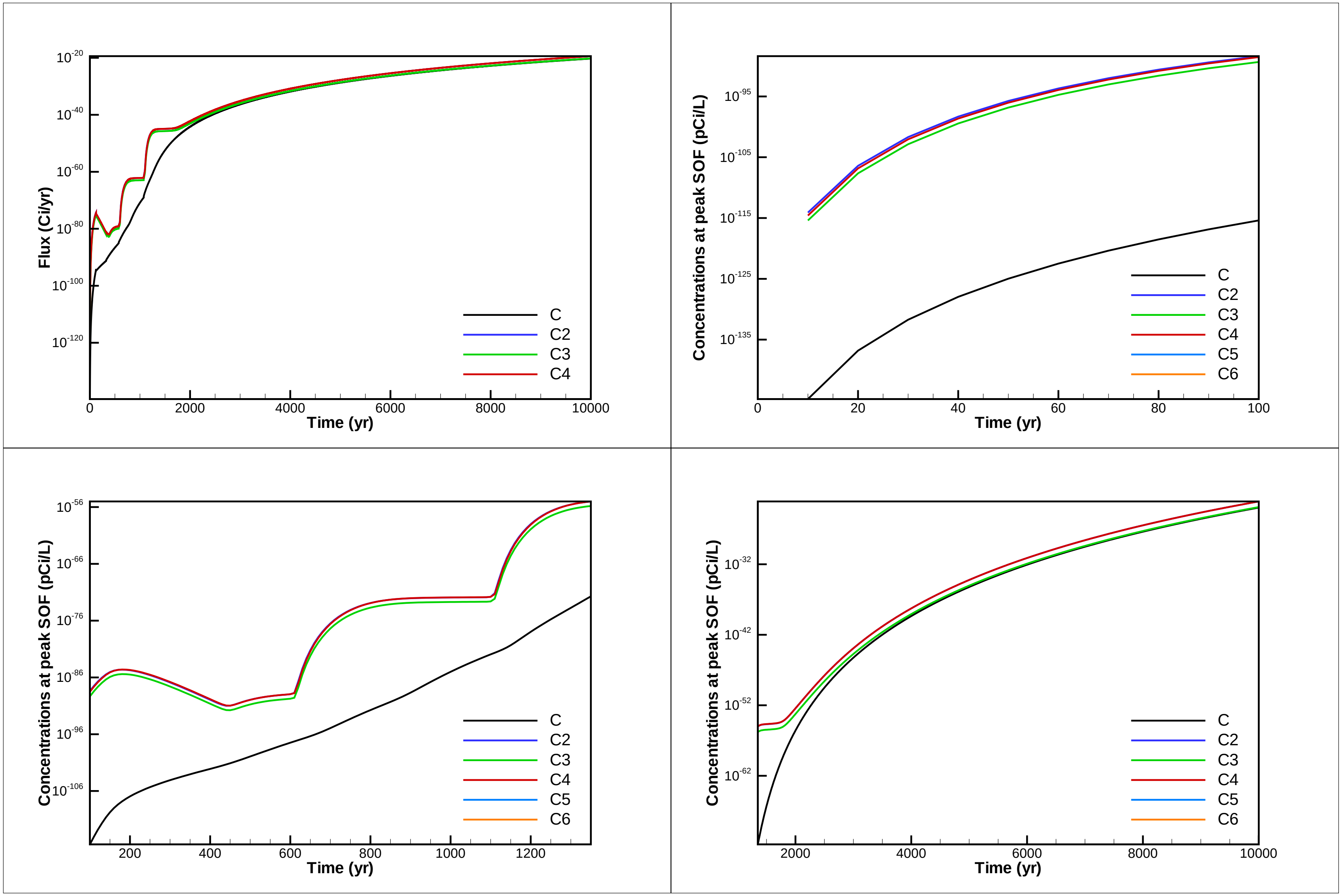


Figure A-68. Flux and concentration results for case Th-232_1: Th-232 Ra-228 Th-228 Ra-224

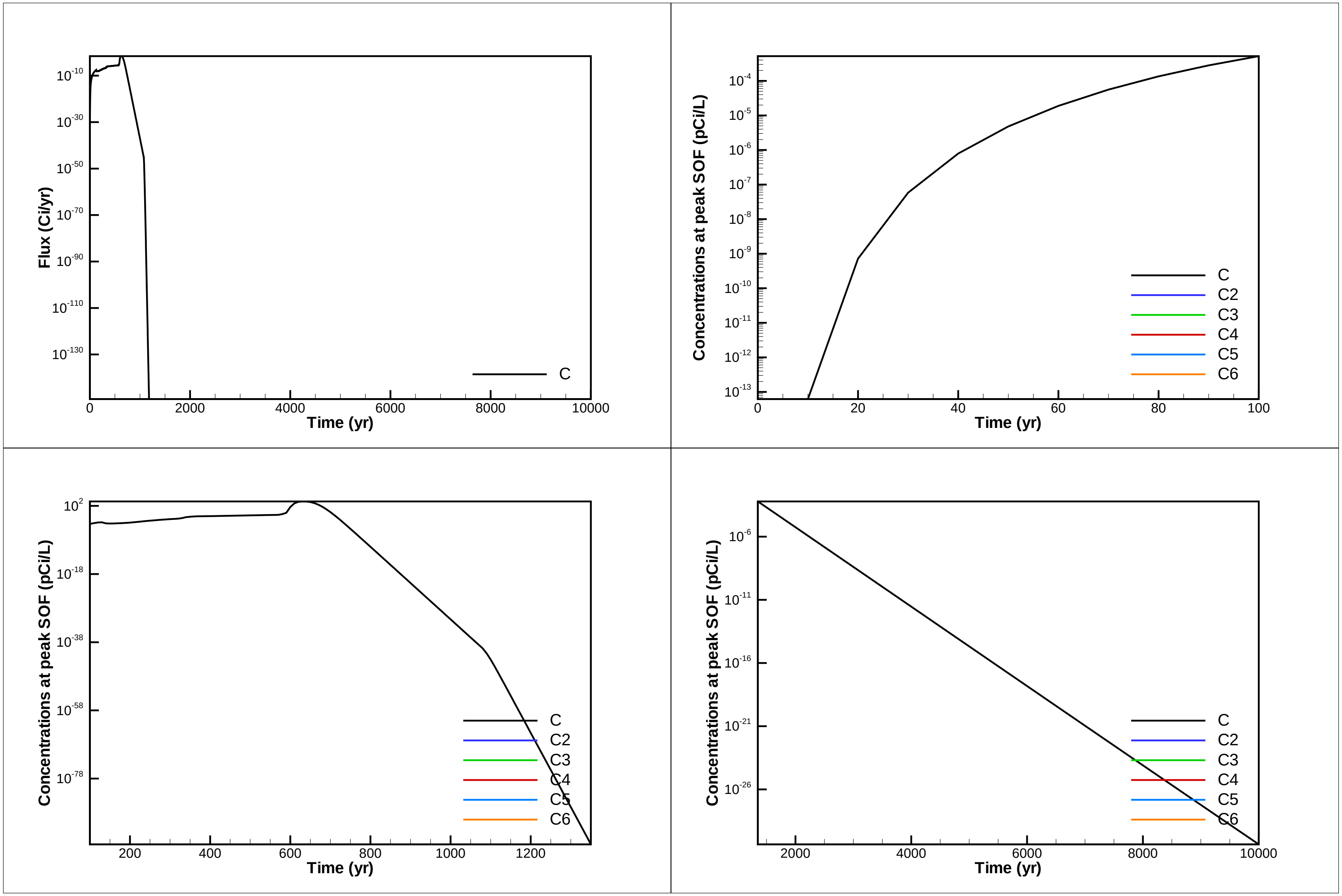


Figure A-69. Flux and concentration results for case Tracer_1: Tracer

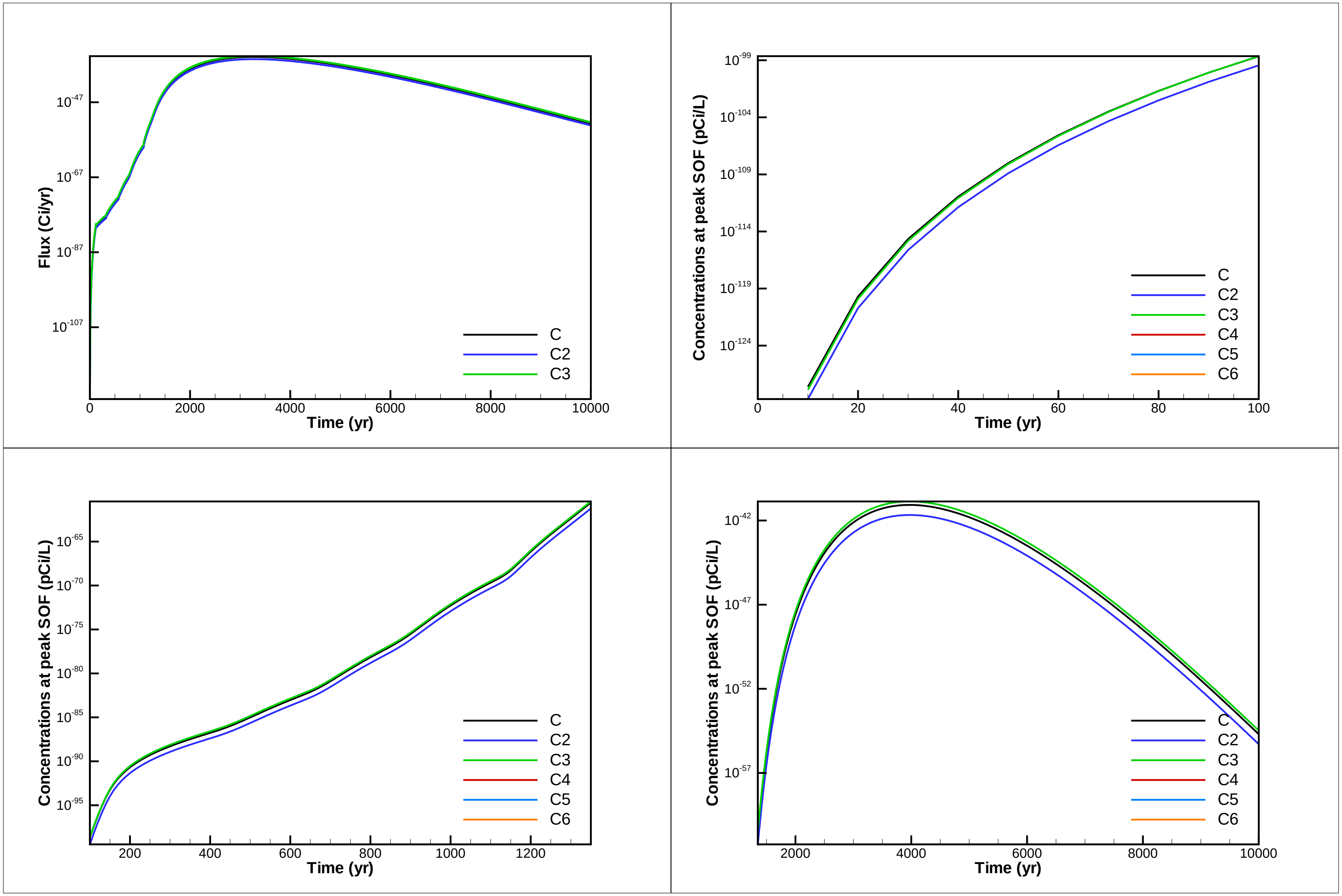


Figure A-70. Flux and concentration results for case U-232_0.001: U-232 Th-228 Ra-224

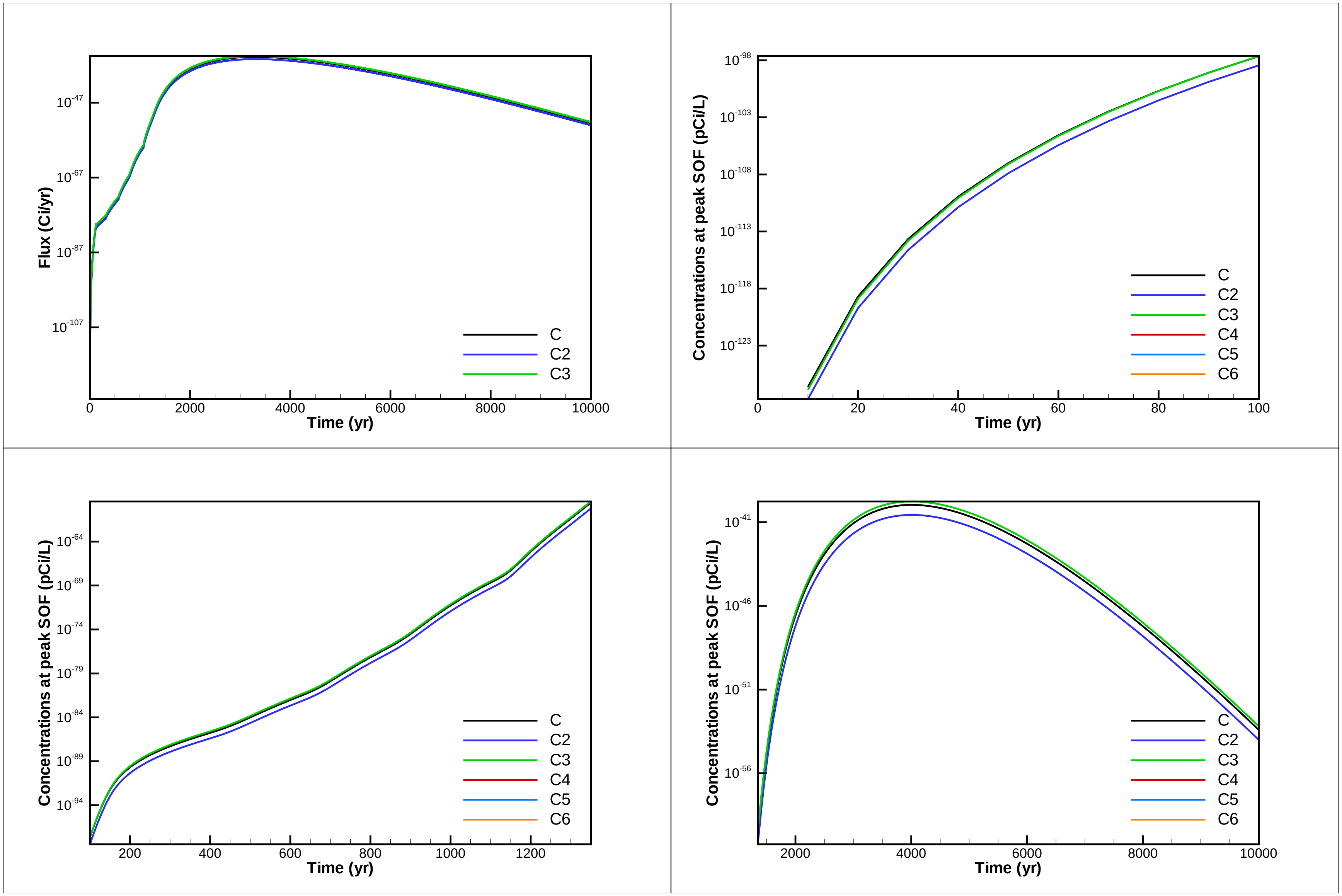


Figure A-71. Flux and concentration results for case U-232_0.01: U-232 Th-228 Ra-224

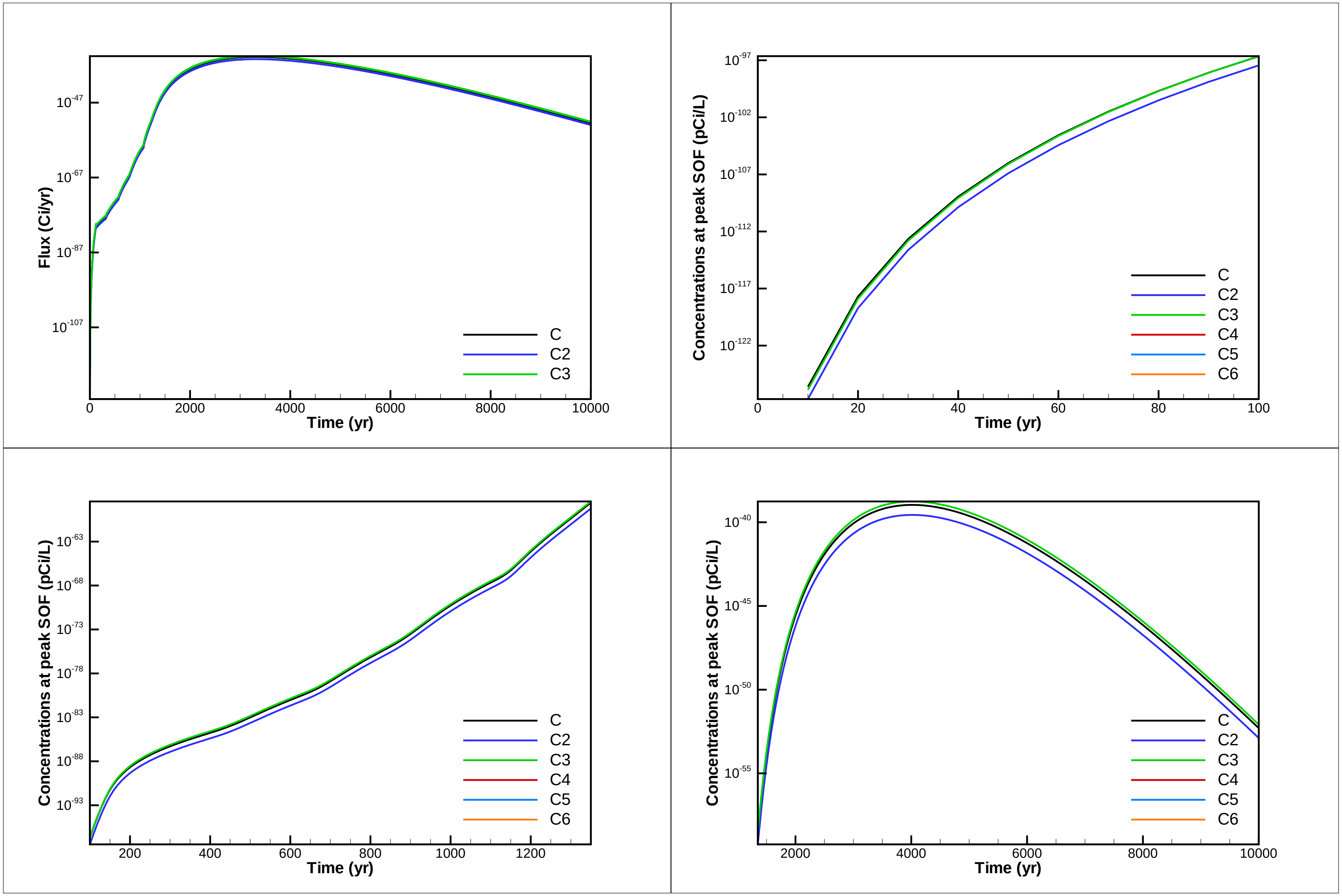


Figure A-72. Flux and concentration results for case U-232_0.1: U-232 Th-228 Ra-224

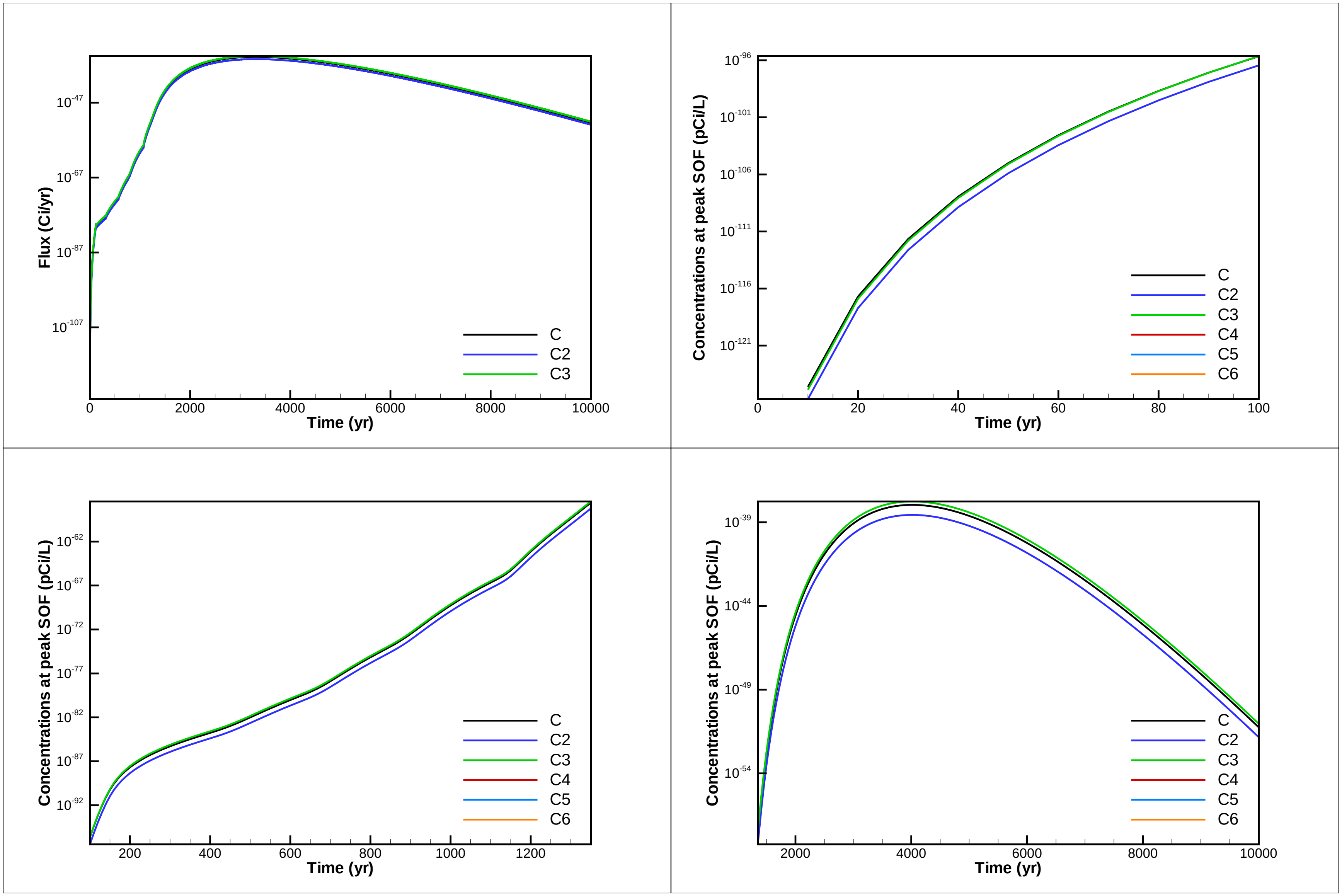


Figure A-73. Flux and concentration results for case U-232_1: U-232 Th-228 Ra-224

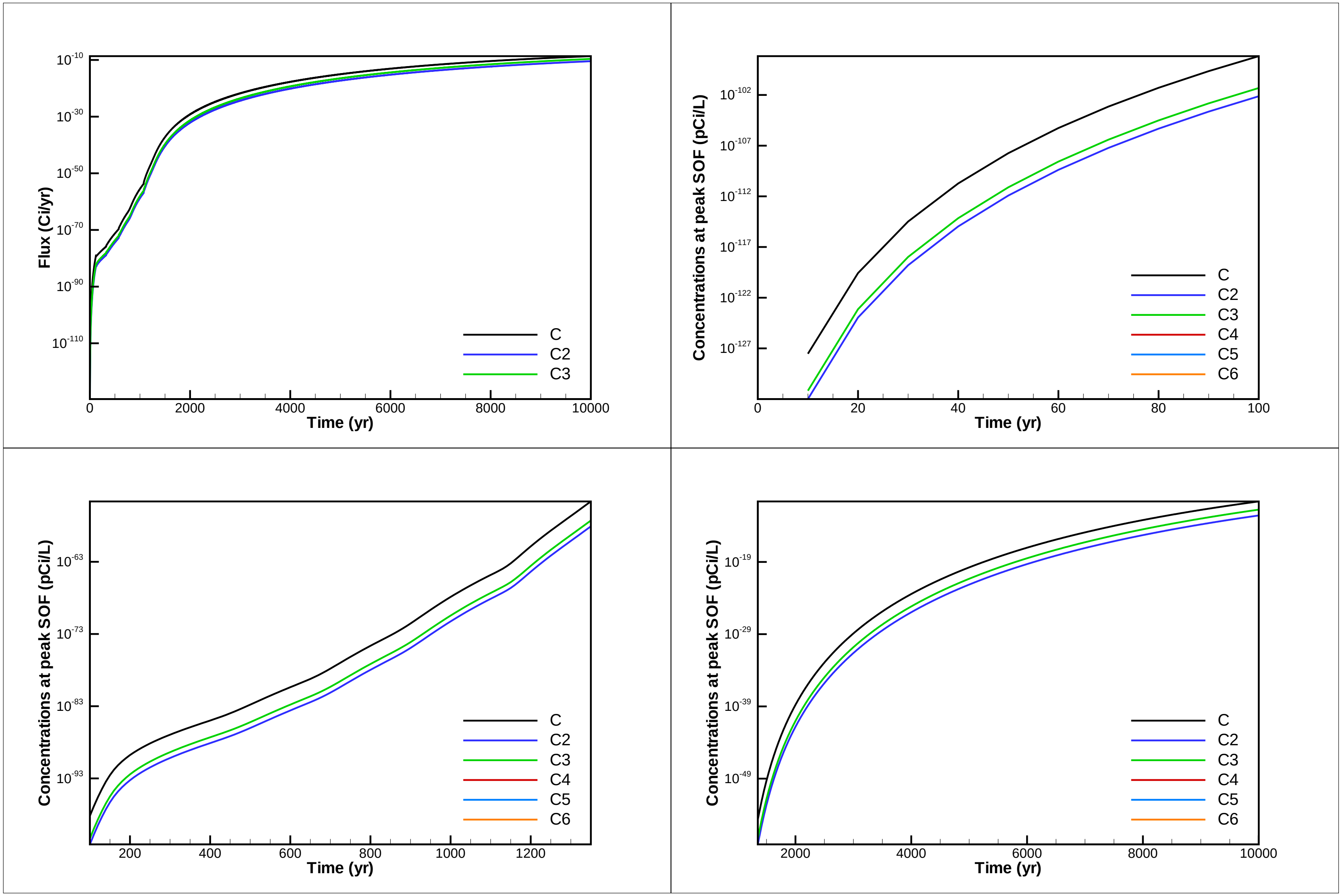


Figure A-74. Flux and concentration results for case U-233_0.001: U-233 Th-229 Ra-225

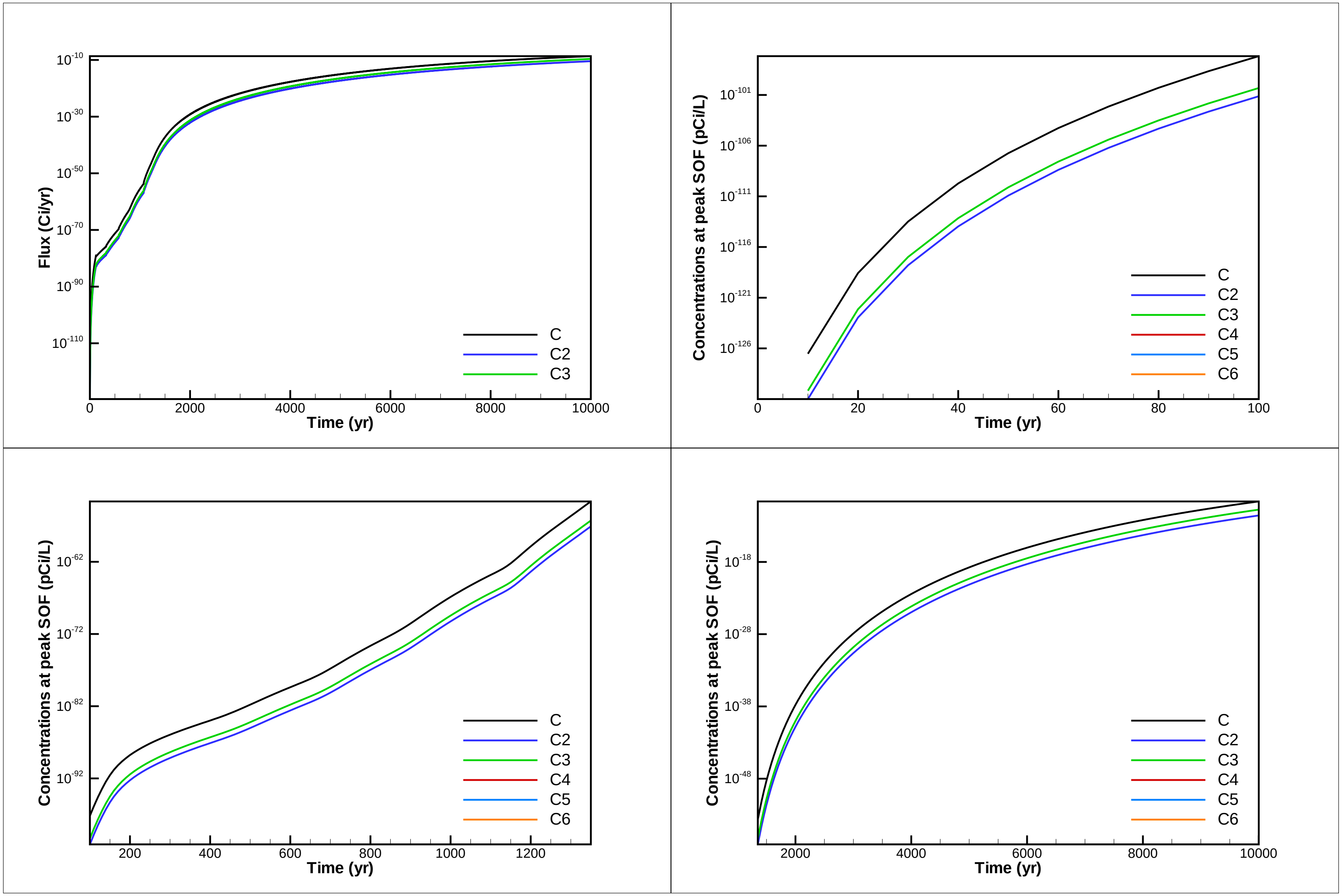


Figure A-75. Flux and concentration results for case U-233_0.01: U-233 Th-229 Ra-225

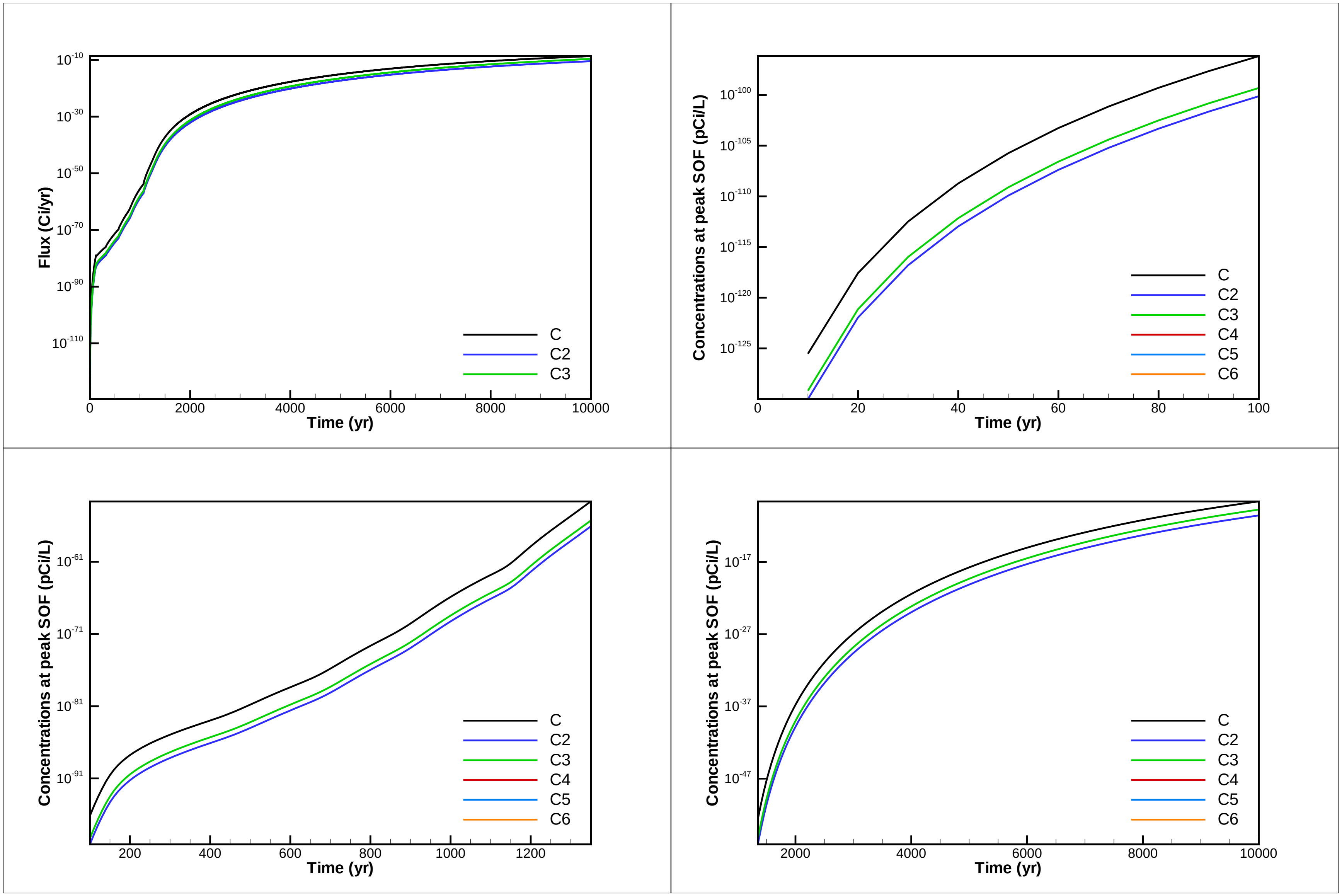


Figure A-76. Flux and concentration results for case U-233_0.1: U-233 Th-229 Ra-225

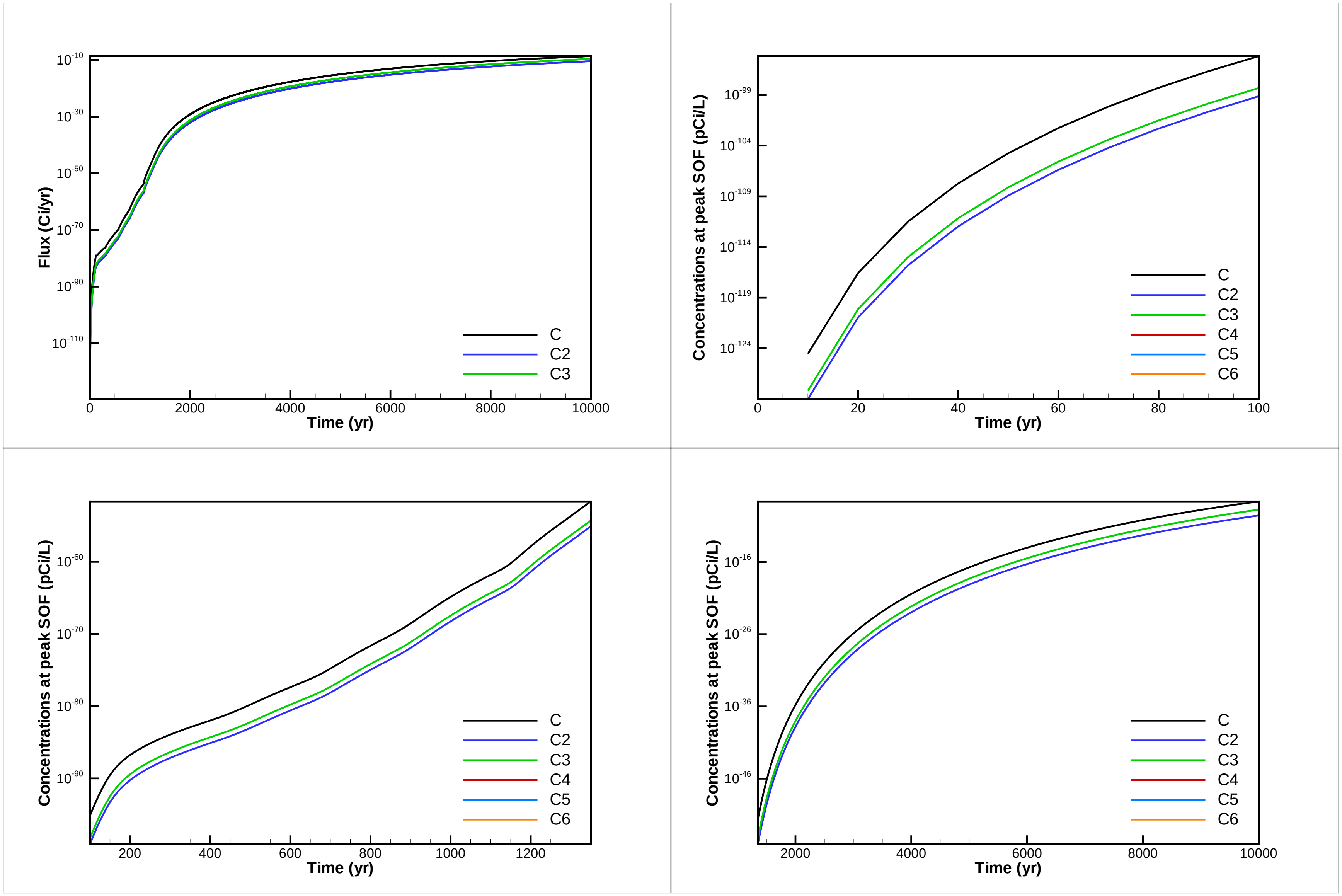


Figure A-77. Flux and concentration results for case U-233_1: U-233 Th-229 Ra-225

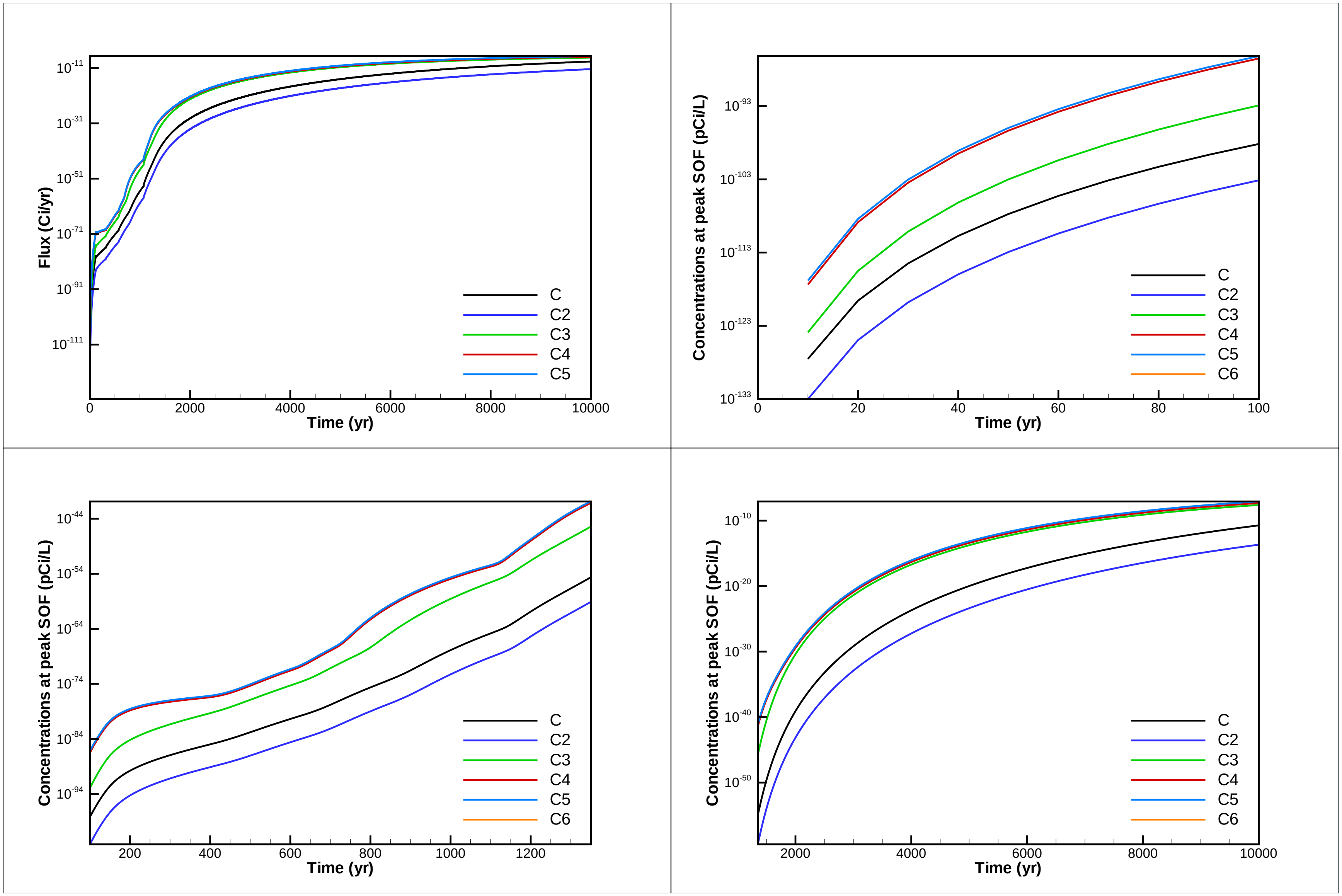


Figure A-78. Flux and concentration results for case U-234_0.001: U-234 Th-230 Ra-226 Pb-210 Po-210

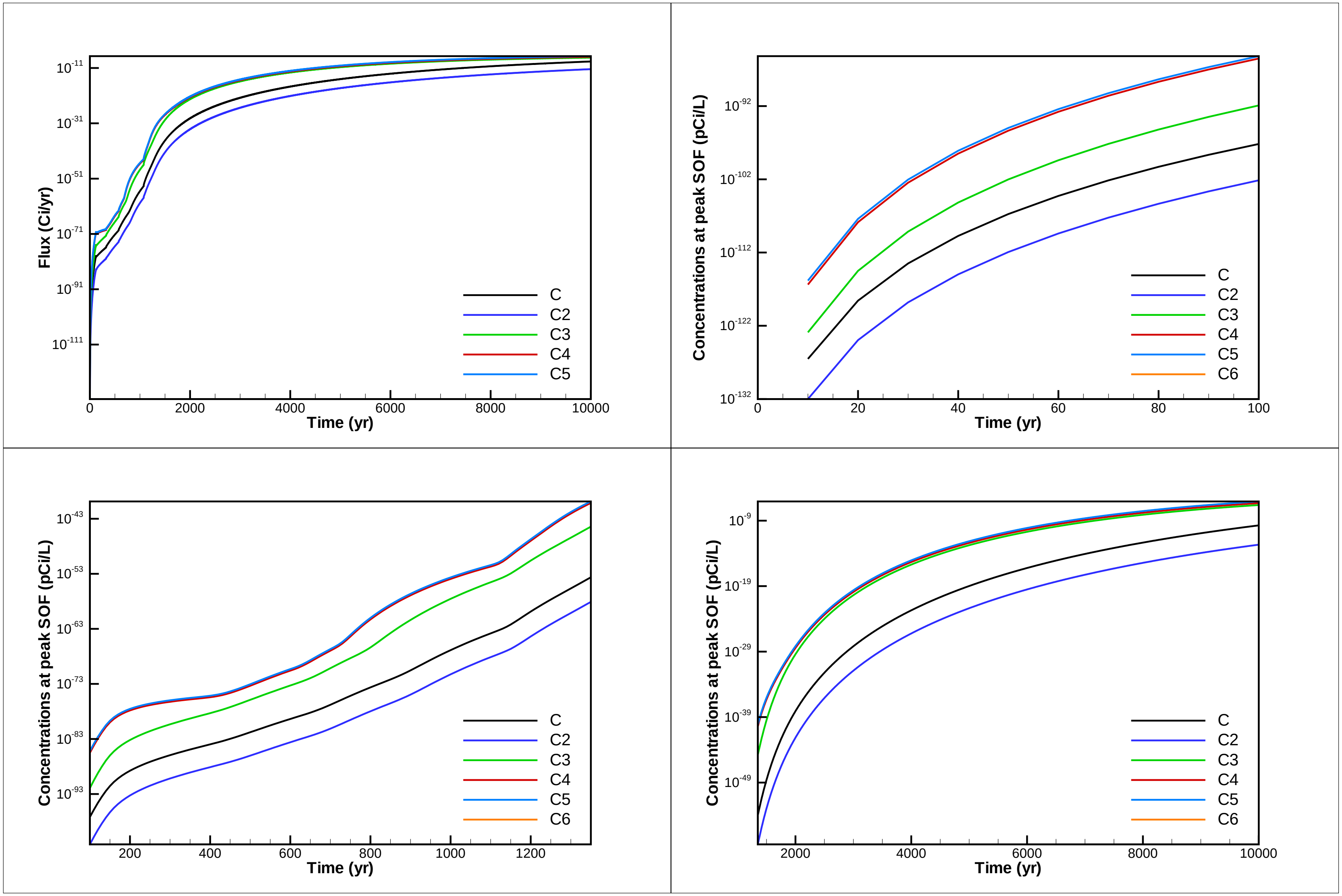


Figure A-79. Flux and concentration results for case U-234_0.01: U-234 Th-230 Ra-226 Pb-210 Po-210

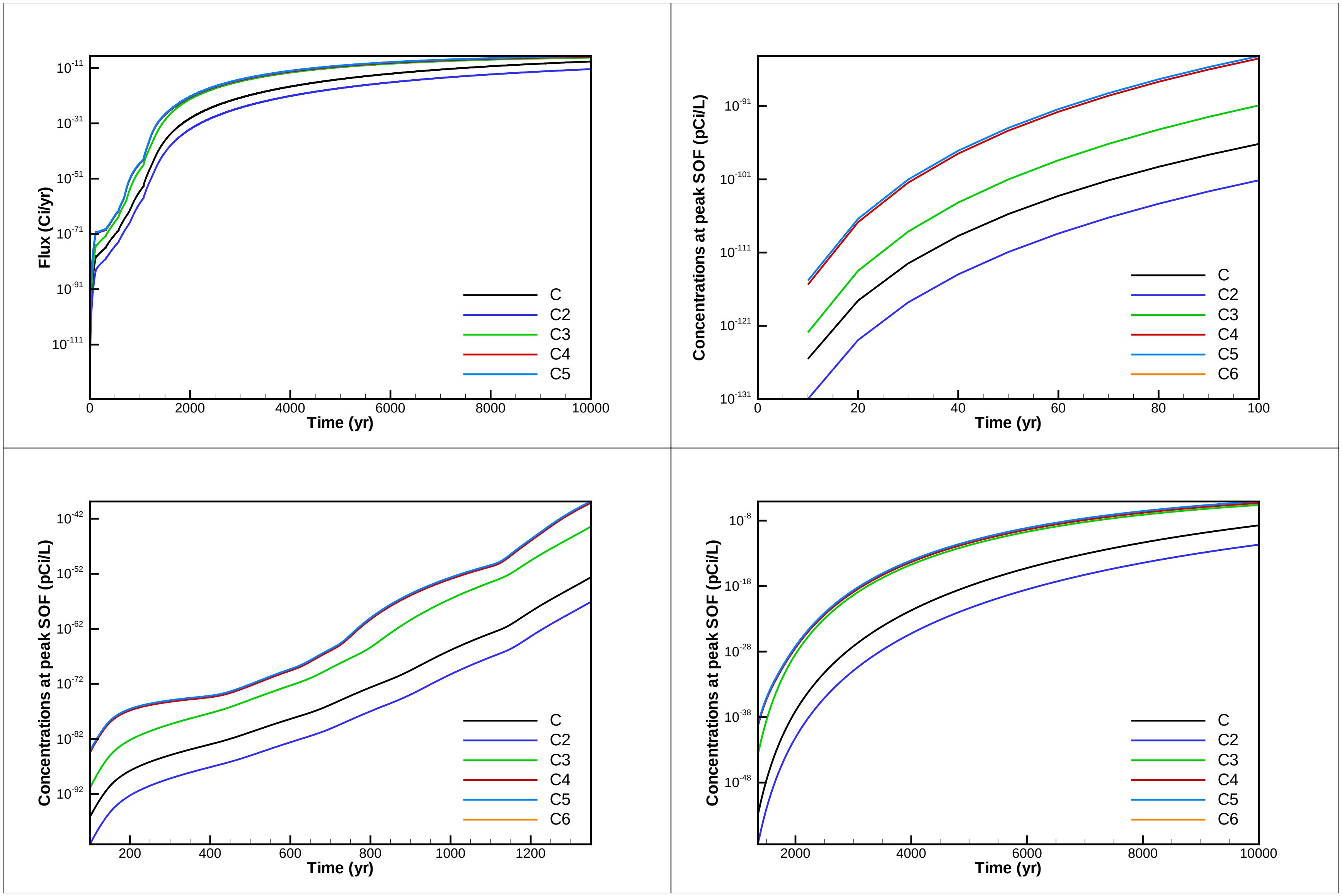


Figure A-80. Flux and concentration results for case U-234_0.1: U-234 Th-230 Ra-226 Pb-210 Po-210

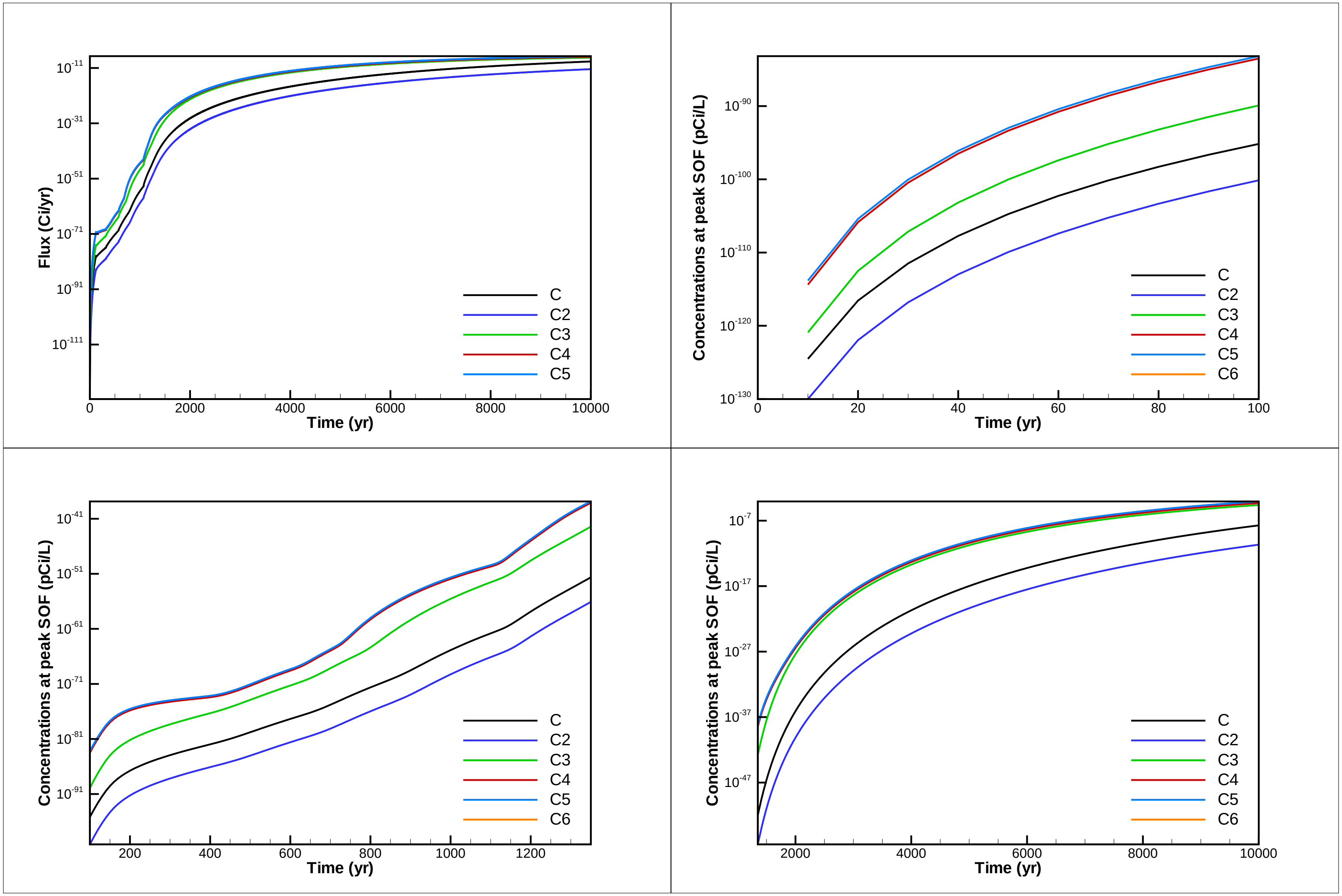


Figure A-81. Flux and concentration results for case U-234_1: U-234 Th-230 Ra-226 Pb-210 Po-210

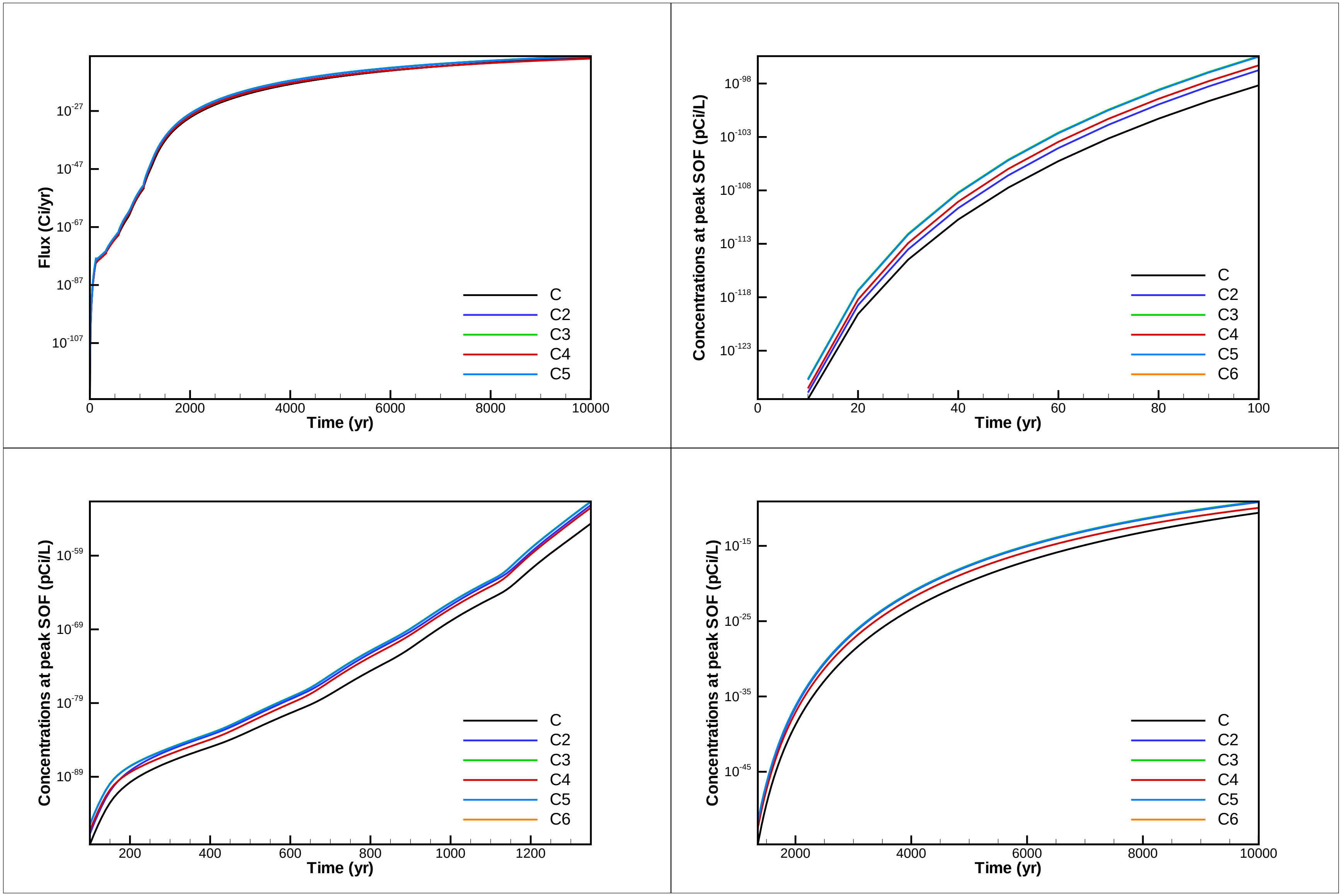


Figure A-82. Flux and concentration results for case U-235_0.001: U-235 Pa-231 Ac-227 Th-227 Ra-223

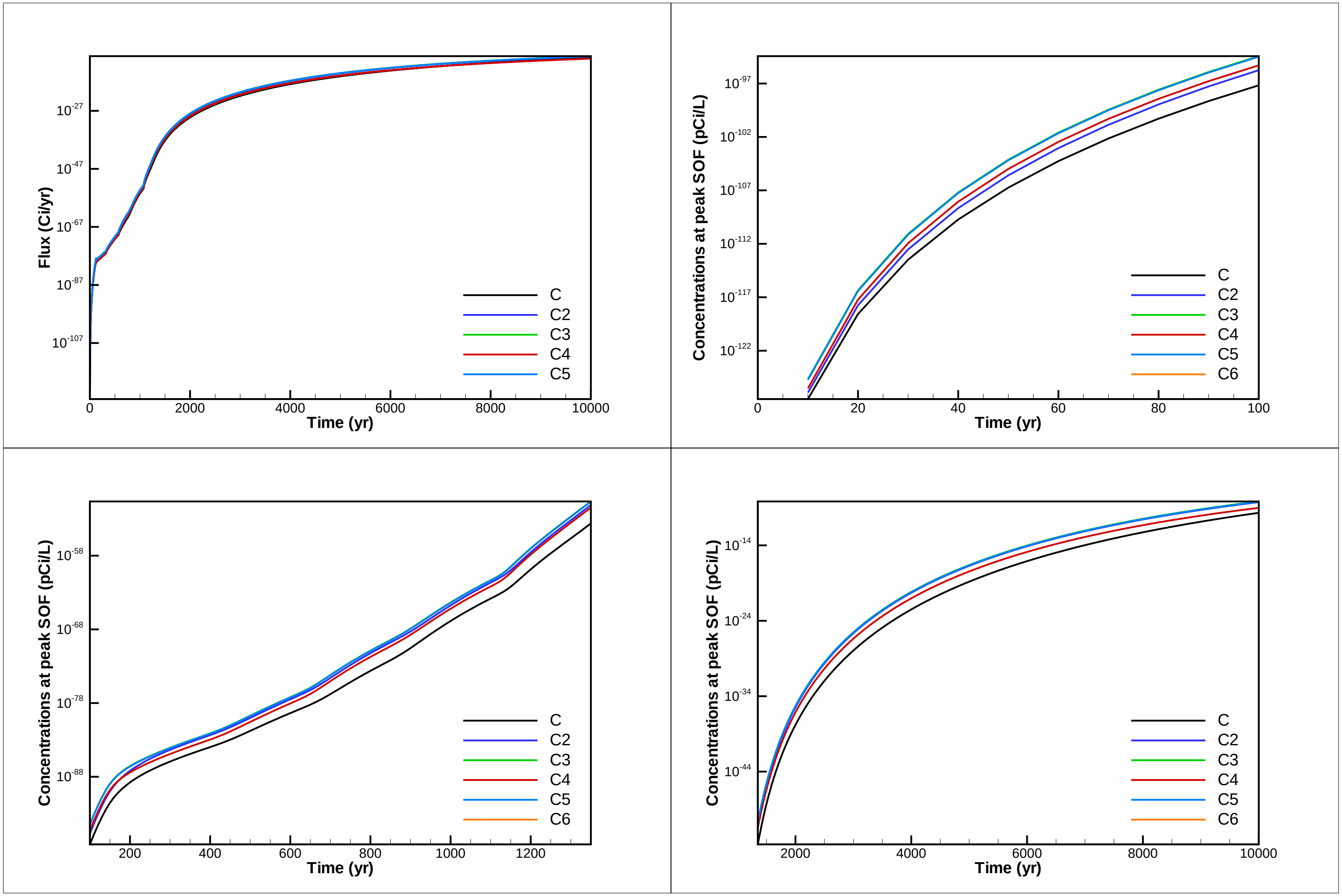


Figure A-83. Flux and concentration results for case U-235_0.01: U-235 Pa-231 Ac-227 Th-227 Ra-223

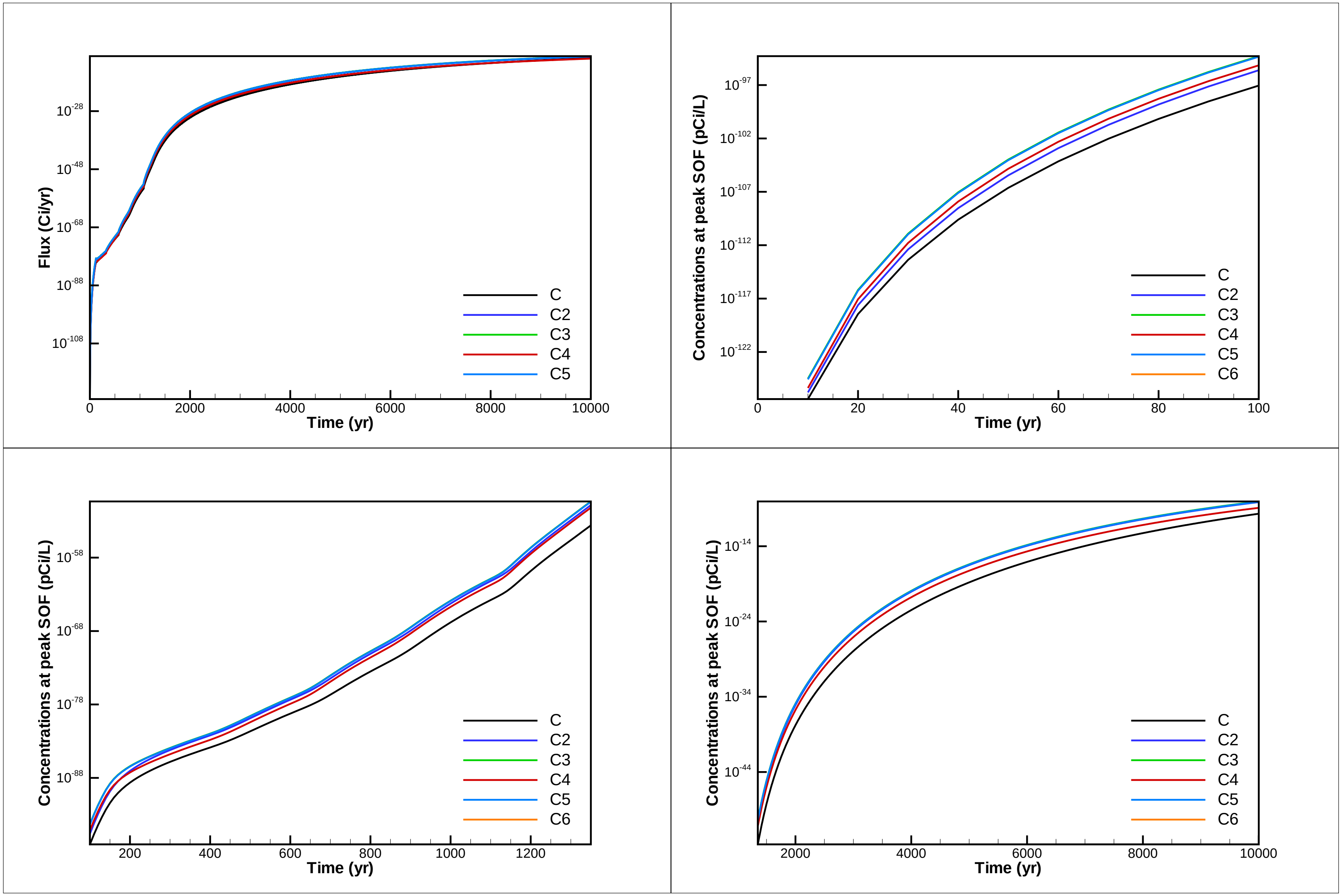


Figure A-84. Flux and concentration results for case U-235_0.1: U-235 Pa-231 Ac-227 Th-227 Ra-223

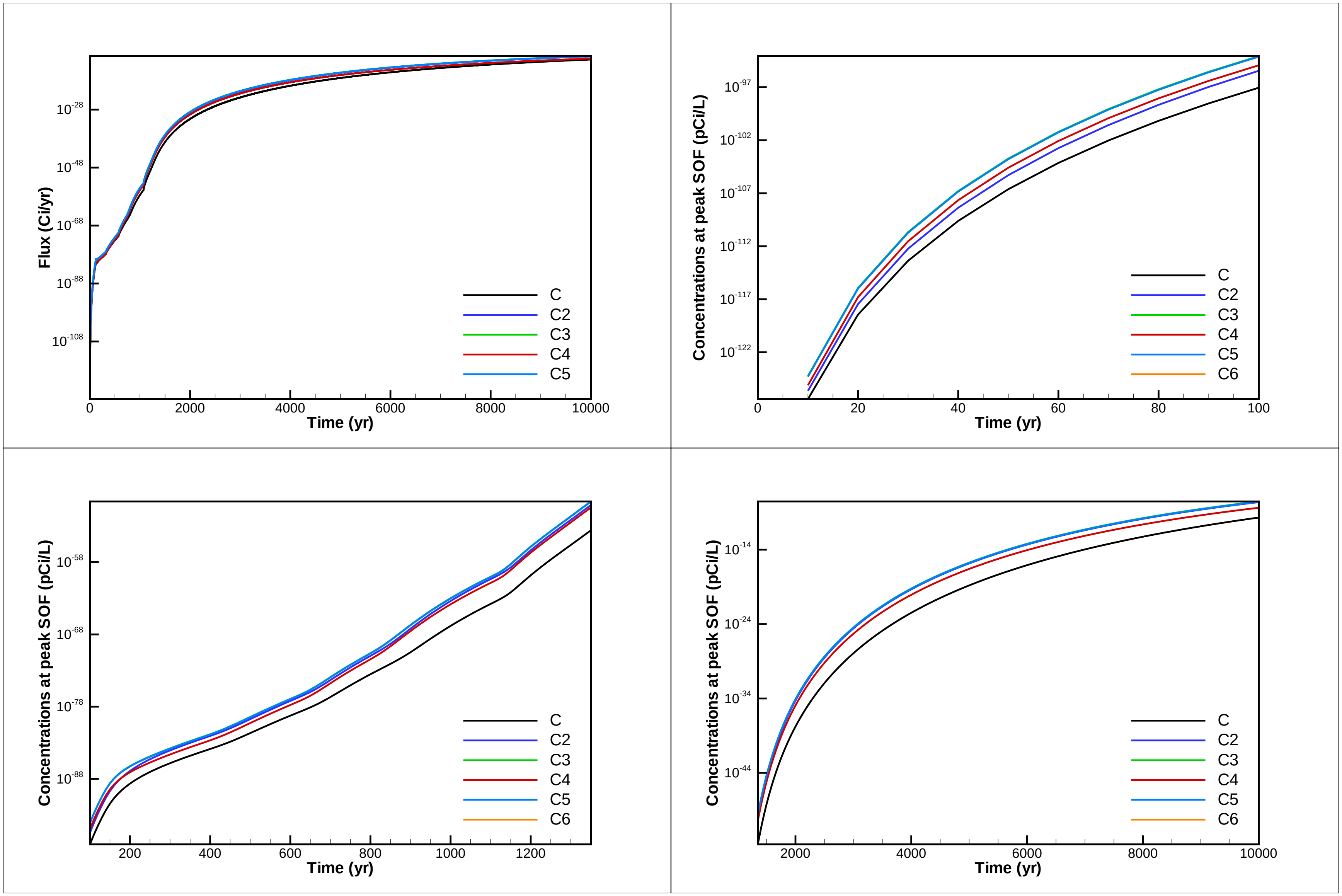


Figure A-85. Flux and concentration results for case U-235_1: U-235 Pa-231 Ac-227 Th-227 Ra-223

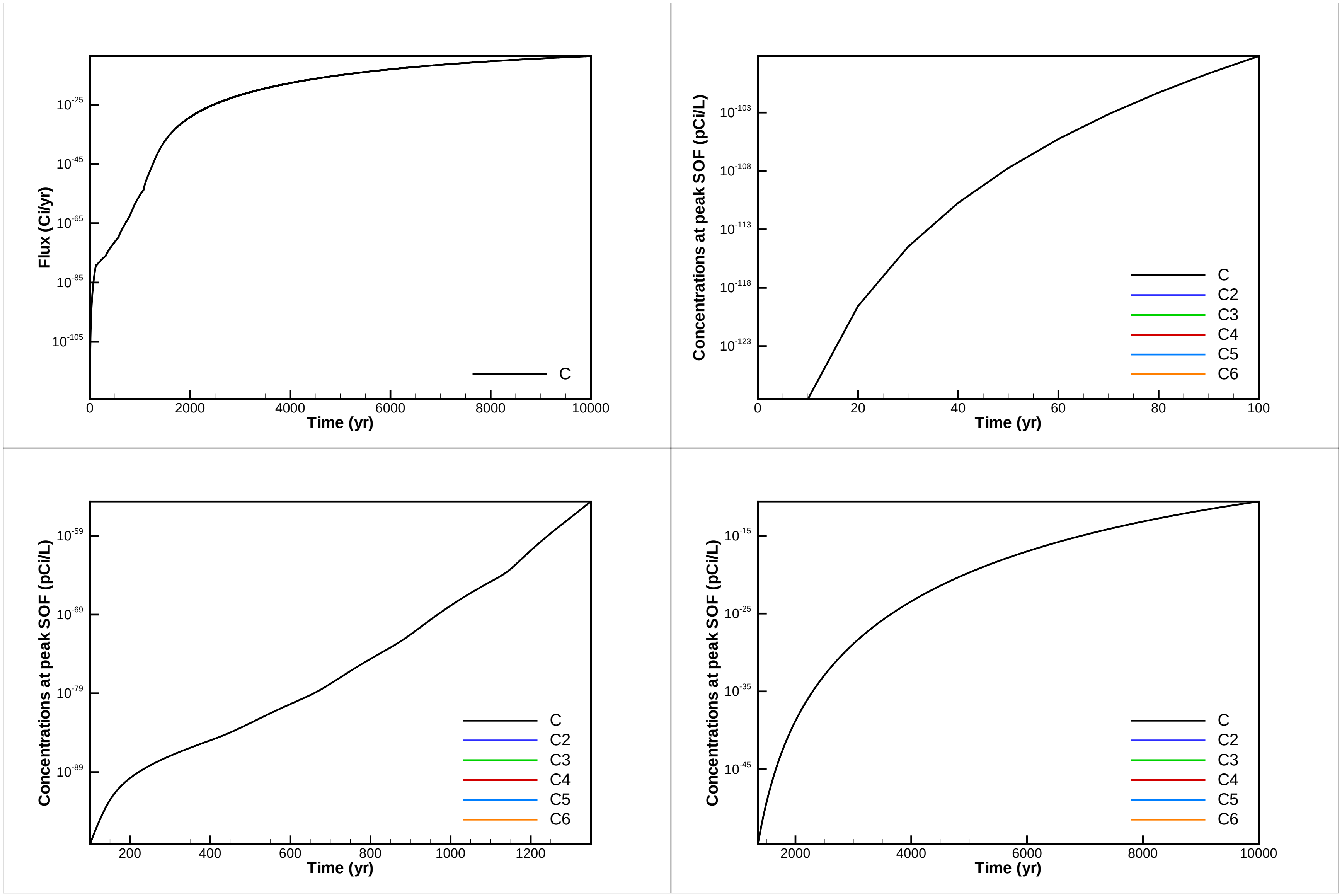


Figure A-86. Flux and concentration results for case U-236_0.001: U-236

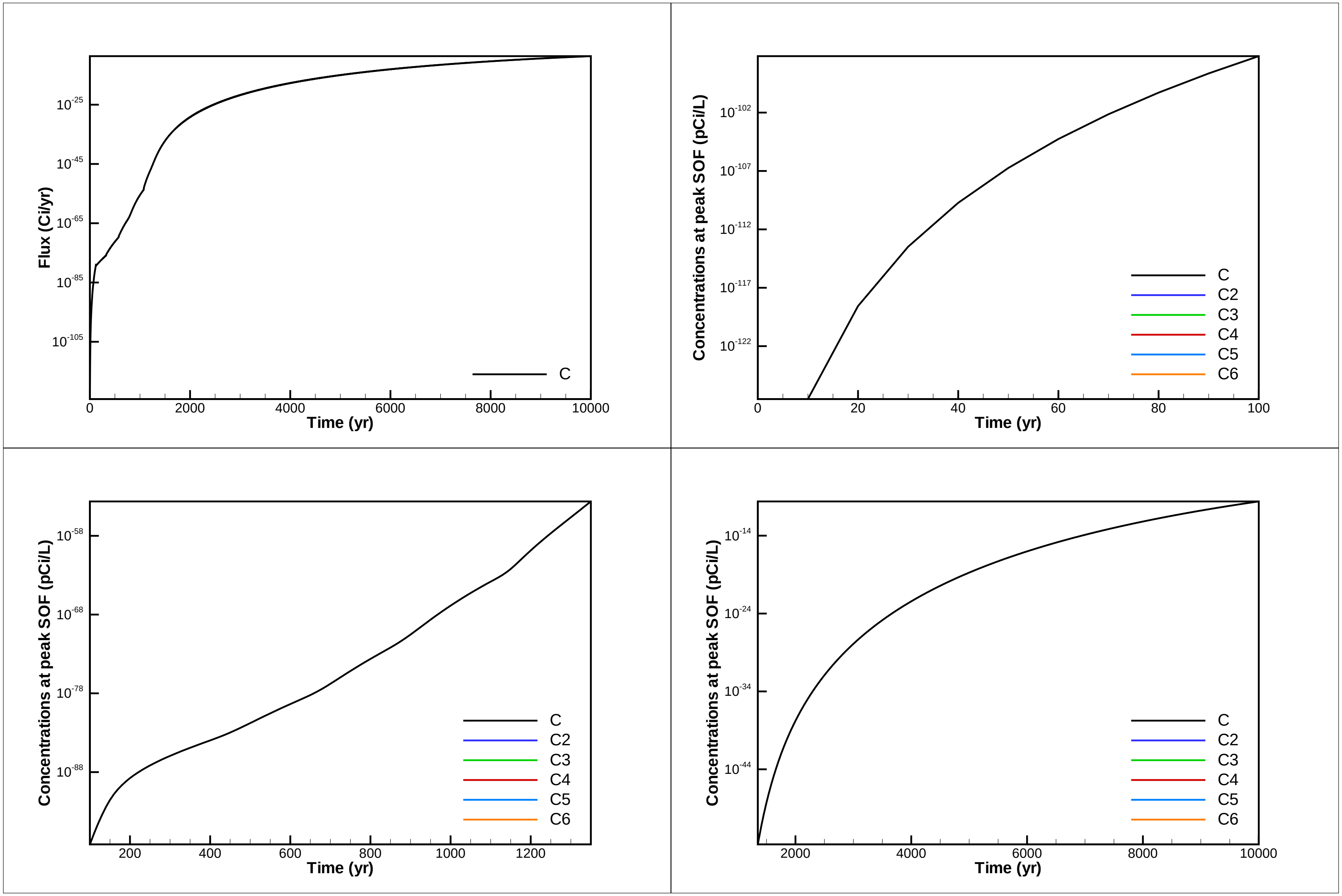


Figure A-87. Flux and concentration results for case U-236_0.01: U-236

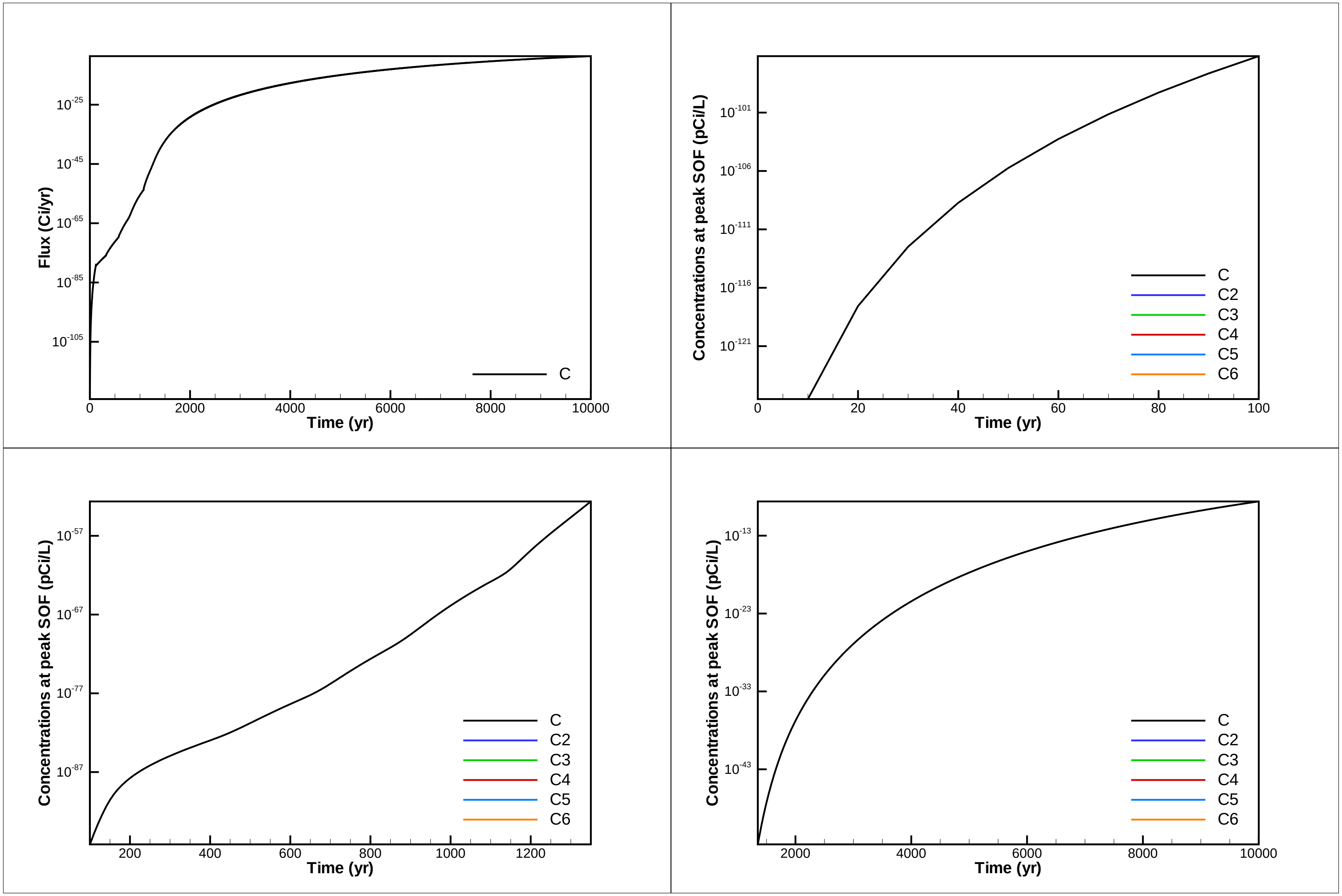


Figure A-88. Flux and concentration results for case U-236_0.1: U-236

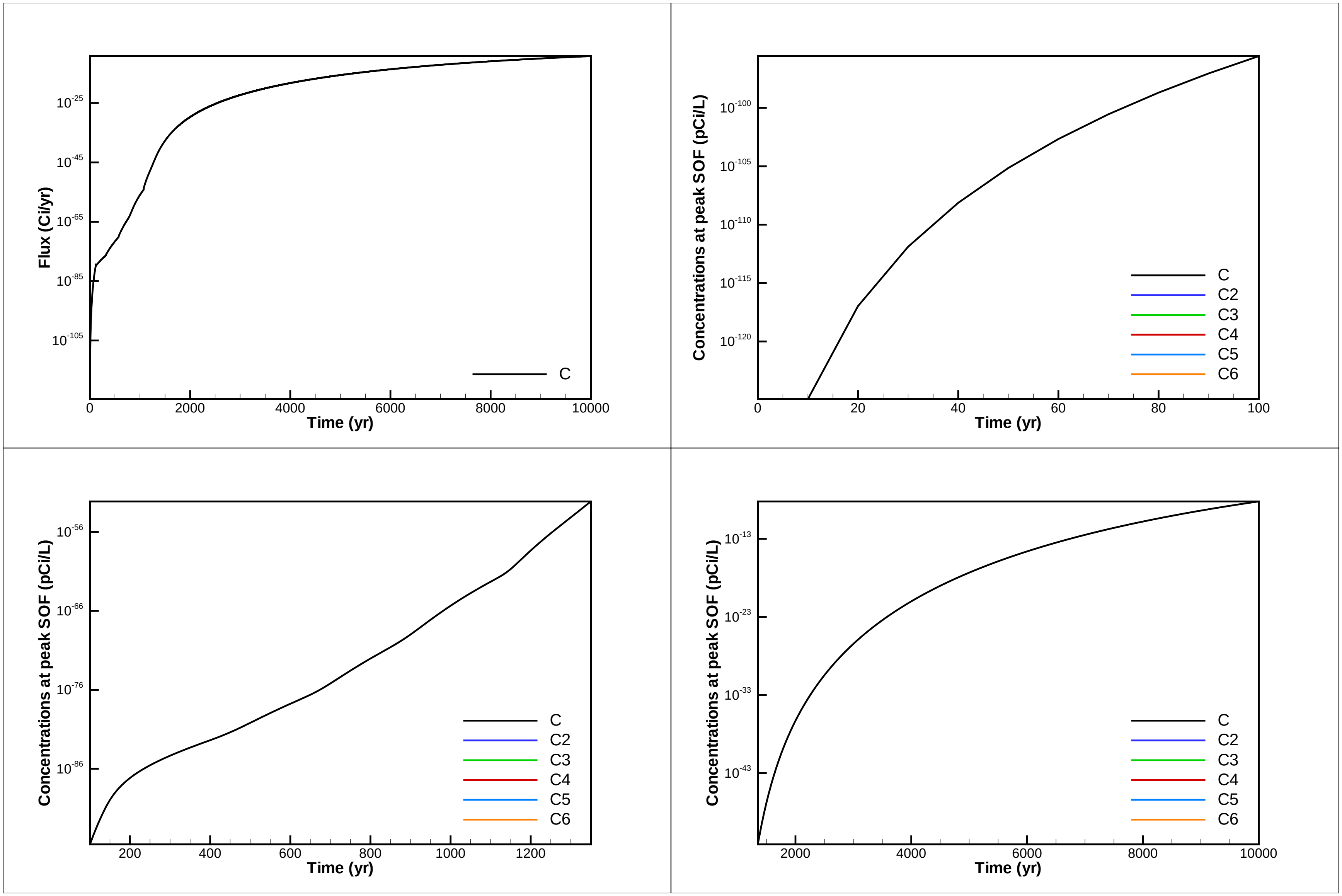


Figure A-89. Flux and concentration results for case U-236_1: U-236

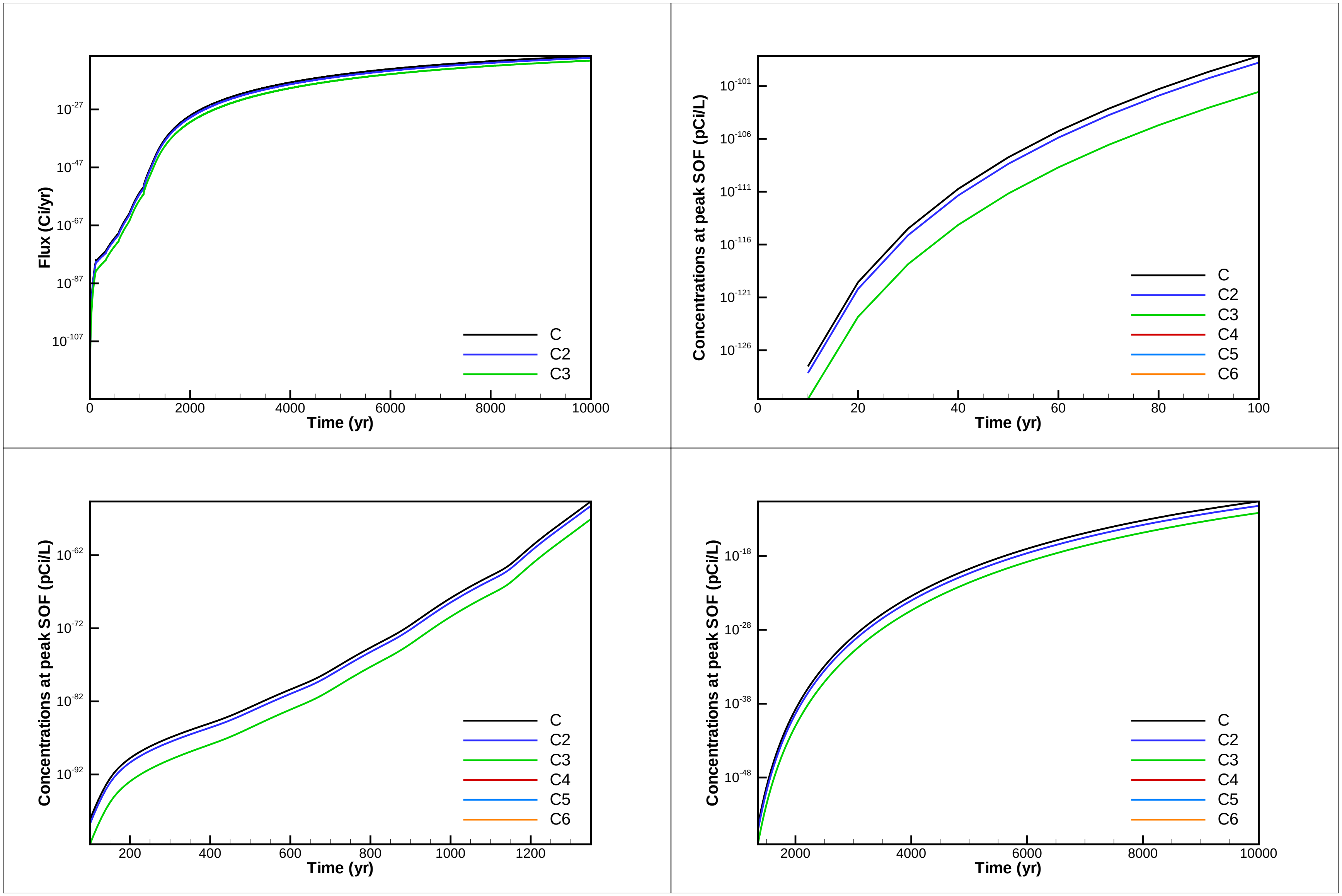


Figure A-90. Flux and concentration results for case U-238_0.001: U-238 Th-234 U-234

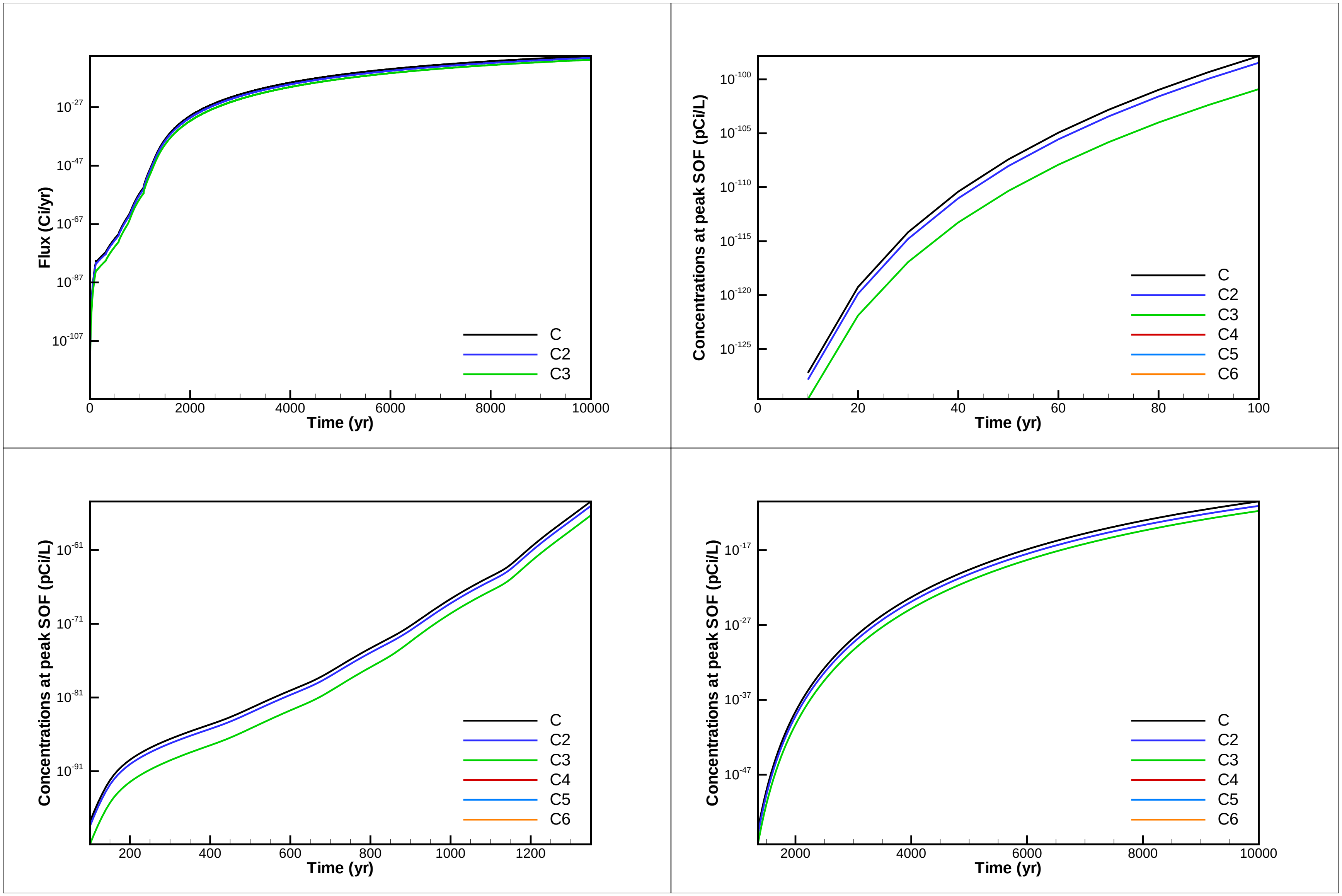


Figure A-91. Flux and concentration results for case U-238_0.01: U-238 Th-234 U-234

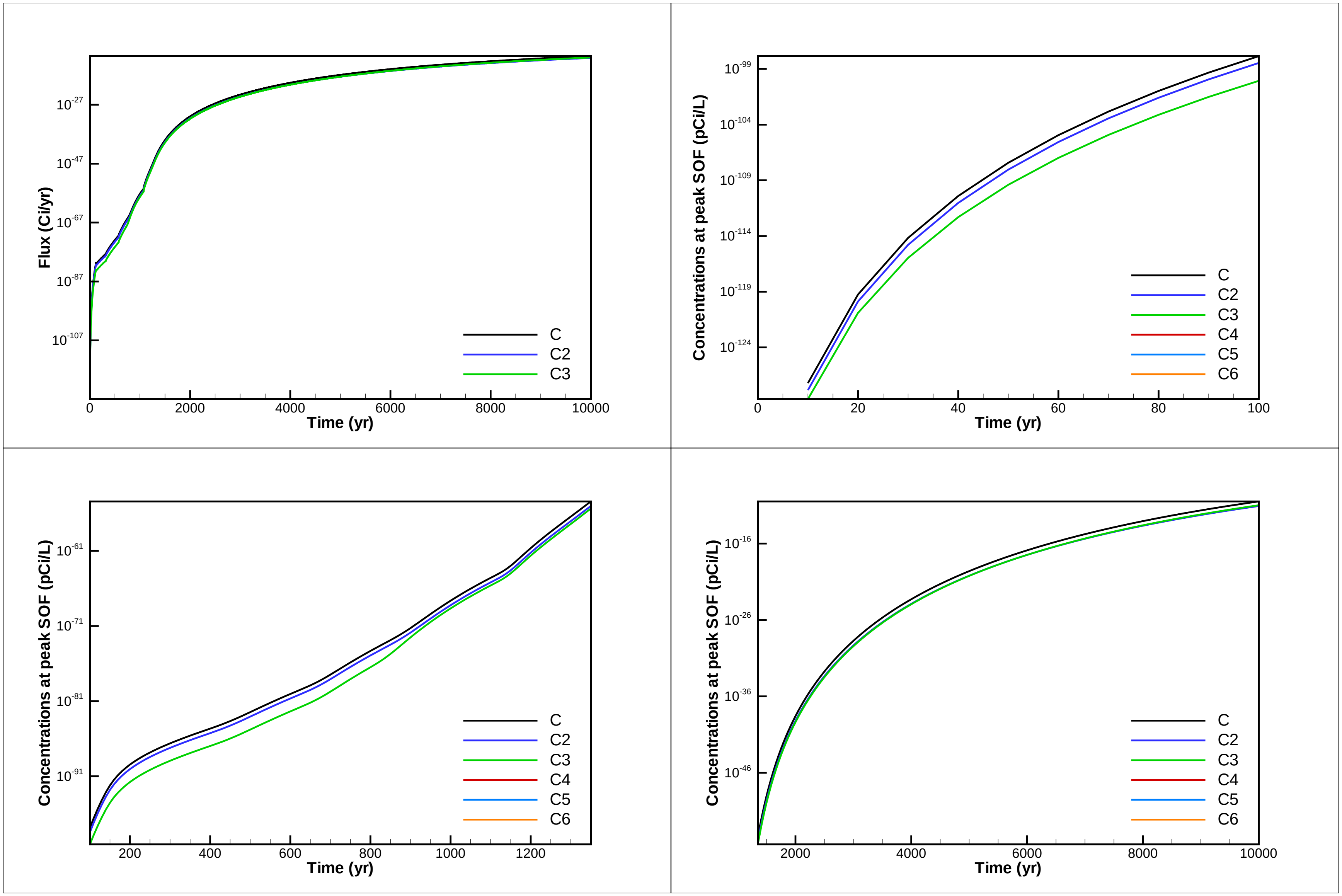


Figure A-92. Flux and concentration results for case U-238_0.1: U-238 Th-234 U-234

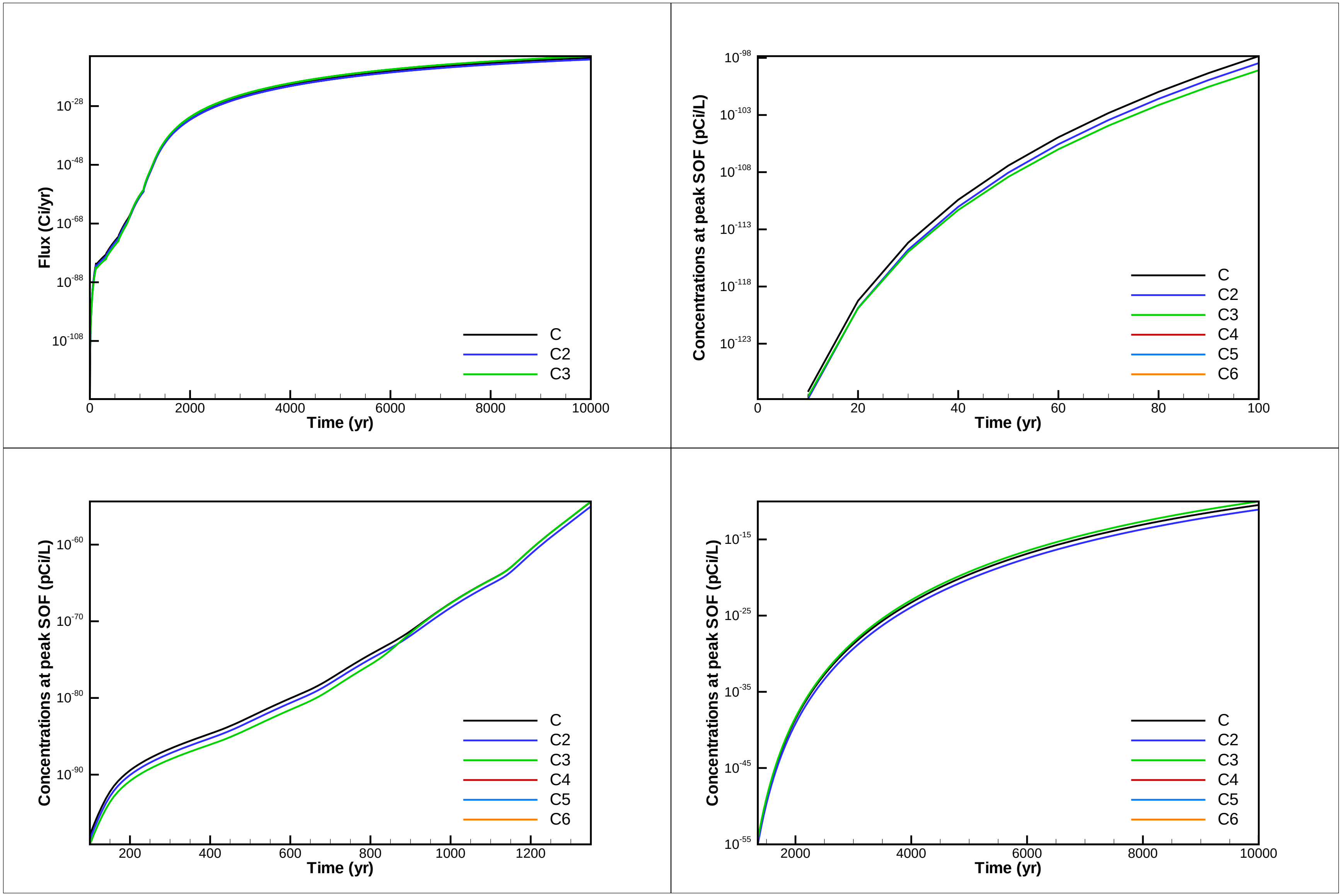


Figure A-93. Flux and concentration results for case U-238_1: U-238 Th-234 U-234

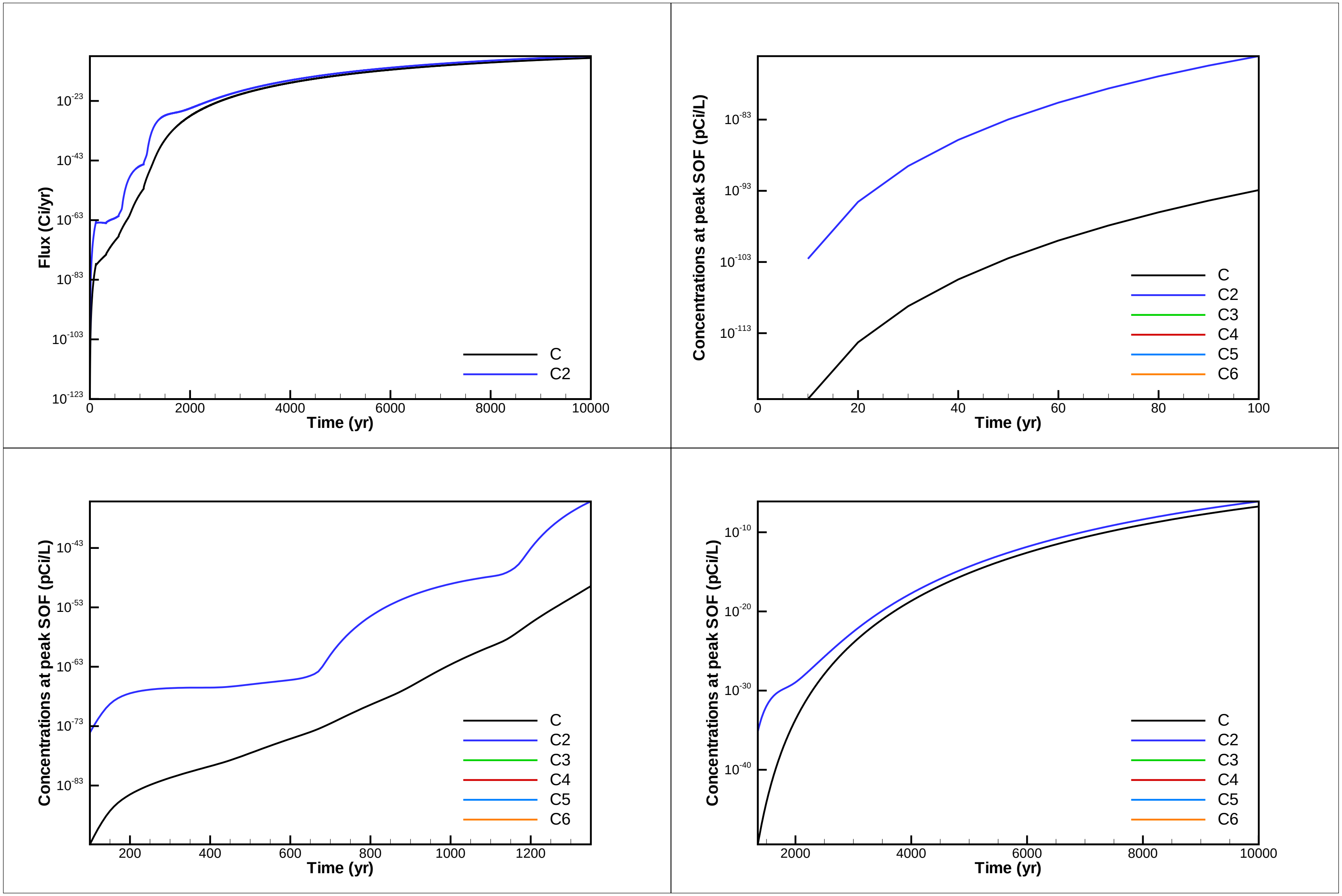


Figure A-94. Flux and concentration results for case Zr-93_1: Zr-93 Nb-93m

APPENDIX B – ADDITIONAL INFORMATION ON INTRUDER ANALYSIS

This appendix provides additional detail about the intruder analysis, primarily for design checking and diagnostic purposes. The topics addressed are

- Disposal unit inputs to the automated intruder analysis tool
- Detailed decay chain contributions to the maximum dose for the resident scenario

Disposal unit inputs

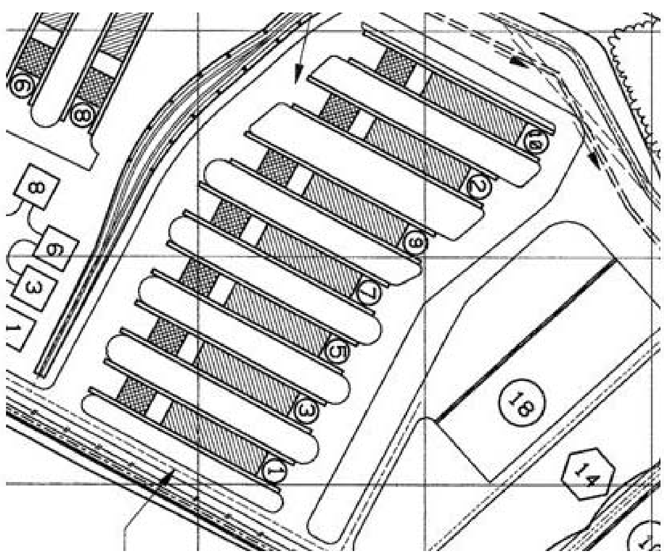
Inputs specific to the disposal unit in the automated intruder analysis are reproduced below

Facility	E-Area
Disposal Unit Name	Intermediate-Level Vaults
Abbreviated Name	ILVaults
Agriculture Geometry Factor	0.4
Resident Geometry Factor	0.4
Post-Drilling Geometry Factor	1
Waste Volume (m3)	7300
Agriculture Analysis Time (yr)	20000
Resident Analysis Time (yr)	100
Post-Drilling Analysis Time (yr)	20000
Resident Shielding Thickness (cm)	100

Transient Layer Model (Surface to Top of Waste)

Layer	Thickness (m)	Description	Erosion Rate (mm/yr)	Degradation Time (yr)
1	0.9144	Soil cover (36")	1.4	0
2	0.3048	Erosion barrier (12")	1.00E-10	0
3	1.6358	Soil backfill (64.4")	1.4	0
4	1.1176	Vault roof (27") + grout (17")	1.4	1000

The geometry factor is based on an IL vault width of 50 ft and a gap of 150 ft between vaults. The latter is consistent with current plans to footprints #1 and #5 indicated below (excerpt from drawing W2017860).



The total width of the combined facilities and gap is 50 + 150 + 50 = 250 ft. The width of both facilities excluding the gap is 100 ft, producing a geometry factor of 100 ft / 250 ft = 0.40.

According to the PA, the combined volume of the ILNT and ILT vaults is 5700 + 1600 m^3 (WSRC-RP-94-218, Revision 1, Section 2.2.2.1).

Cover layers are taken directly from Figure 3.3-2 of Phifer (2004b).

Detailed decay chain contributions

Table B-1 provides detailed decay chain contributions to the maximum resident scenario inventory limit given in Table 3-1.

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

In the following, the bold header line gives the parent radionuclide, the time in years of the maximum dose, and the dose (rem/yr) for 1 Ci of the parent in the waste volume.
Subsequent lines give the decay chain radionuclide, the activity (fraction remaining), and the dose contribution of the radionuclide towards the total.

Zero dose cases, where there is no maximum, are skipped and include the following parent radionuclides: H-3, C-14, S-35, Cl-36, Ar-39, Ca-41, Ni-59, Ni-63, Se-79, Rb-87, Sr-90, Zr-93, Nb-93m, Mo-93, Pd-107, Cd-113m, Sn-121m, Cs-135, Sm-151

Na-22	**100 yr**	**9.23E-17**
Na-22	2.69E-12	9.23E-17

Al-26	**100 yr**	**1.51E-04**
Al-26	1.00E+00	1.51E-04

K-40	**100 yr**	**6.53E-06**
K-40	1.00E+00	6.53E-06

Sc-46	**100 yr**	**1.84E-136**
Sc-46	7.37E-132	1.84E-136

Co-60	**100 yr**	**1.25E-10**
Co-60	1.96E-06	1.25E-10

Kr-85	**100 yr**	**2.64E-12**
Kr-85	1.61E-03	2.64E-12

Nb-94	**100 yr**	**7.57E-06**
Nb-94	9.97E-01	7.57E-06

Tc-99	**100 yr**	**1.31E-19**
Tc-99	1.00E+00	1.31E-19

Ag-108m	**100 yr**	**2.56E-06**
Ag-108m	8.47E-01	2.56E-06
Ag-108	7.54E-02	2.03E-09

Sn-126	**100 yr**	**4.69E-06**
Sn-126	9.99E-01	6.14E-15
Sb-126m	9.99E-01	3.55E-06
Sb-126	1.40E-01	1.14E-06

Sb-125	**100 yr**	**5.10E-18**
Sb-125	1.22E-11	5.10E-18
Te-125m	2.96E-12	1.03E-26

I-129	**100 yr**	**7.14E-42**
I-129	1.00E+00	7.14E-42

Cs-134	**100 yr**	**1.75E-20**
Cs-134	2.74E-15	1.75E-20

Cs-137	**100 yr**	**1.20E-07**
Cs-137	9.97E-02	0.00E+00
Ba-137m	9.44E-02	1.20E-07

Ba-133	**100 yr**	**5.97E-11**
Ba-133	1.40E-03	5.97E-11

Eu-152	**100 yr**	**1.12E-07**
Eu-152	5.93E-03	1.12E-07
Gd-152	3.46E-14	0.00E+00

Eu-154	**100 yr**	**6.25E-09**
Eu-154	3.14E-04	6.25E-09

Eu-155	**100 yr**	**6.44E-20**
Eu-155	4.76E-07	6.44E-20

W-181	**100 yr**	**1.69E-104**
W-181	2.20E-91	1.69E-104

W-185	**100 yr**	**1.02E-161**
W-185	4.94E-147	1.02E-161

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

W-188	**100 yr**	**1.08E-165**
W-188	4.76E-159	2.24E-169
Re-188	4.81E-159	1.08E-165

Pb-210	**100 yr**	**1.83E-12**
Pb-210	4.47E-02	1.72E-33
Bi-210	4.47E-02	0.00E+00
Po-210	4.55E-02	1.83E-12

Bi-207	**100 yr**	**2.33E-06**
Bi-207	1.11E-01	2.33E-06

Ra-226	**100 yr**	**7.05E-05**
Ra-226	9.58E-01	7.14E-12
Rn-222	9.58E-01	2.68E-10
Po-218	9.58E-01	0.00E+00
Pb-214	9.57E-01	8.89E-08
At-218	1.92E-04	0.00E+00
Bi-214	9.58E-01	7.04E-05
Po-214	9.57E-01	3.66E-10
Pb-210	9.26E-01	3.56E-32
Bi-210	9.26E-01	0.00E+00
Po-210	9.25E-01	3.72E-11

Ra-228	**100 yr**	**1.94E-09**
Ra-228	5.82E-06	0.00E+00
Ac-228	5.82E-06	8.02E-11
Th-228	8.71E-06	1.09E-17
Ra-224	8.73E-06	7.81E-16
Rn-220	8.73E-06	4.52E-15
Po-216	8.73E-06	6.04E-16
Pb-212	8.73E-06	9.34E-15
Bi-212	8.73E-06	3.48E-11
Tl-208	3.14E-06	1.82E-09
Po-212	5.59E-06	0.00E+00

Ac-227	**100 yr**	**8.20E-09**
Ac-227	4.14E-02	1.21E-16
Fr-223	5.72E-04	9.08E-12
Th-227	4.09E-02	1.24E-10
Ra-223	4.16E-02	2.35E-10
Rn-219	4.16E-02	2.82E-10
Po-215	4.16E-02	2.09E-12
Pb-211	4.16E-02	6.62E-09
Bi-211	4.16E-02	2.70E-10
Tl-207	4.15E-02	6.54E-10
Po-211	1.16E-04	4.39E-12

Th-228	**100 yr**	**3.82E-20**
Th-228	1.79E-16	2.24E-28
Ra-224	1.80E-16	1.61E-26
Rn-220	1.80E-16	9.31E-26
Po-216	1.80E-16	1.24E-26
Pb-212	1.80E-16	1.92E-25
Bi-212	1.80E-16	7.16E-22
Tl-208	6.46E-17	3.75E-20
Po-212	1.15E-16	0.00E+00

Th-229	**100 yr**	**1.90E-06**
Th-229	9.91E-01	2.73E-11
Ra-225	9.91E-01	1.75E-40
Ac-225	9.91E-01	1.99E-10
Fr-221	9.91E-01	1.65E-10
At-217	9.91E-01	3.23E-10
Bi-213	9.91E-01	1.43E-07
Tl-209	2.14E-02	1.76E-06
Po-213	9.69E-01	1.24E-10
Pb-209	9.91E-01	0.00E+00

Th-230	**1000 yr**	**2.58E-05**
Th-230	9.91E-01	8.10E-14
Ra-226	3.50E-01	2.61E-12
Rn-222	3.50E-01	9.80E-11
Po-218	3.50E-01	0.00E+00
Pb-214	3.50E-01	3.25E-08
At-218	7.00E-05	0.00E+00
Bi-214	3.50E-01	2.57E-05
Po-214	3.50E-01	1.34E-10
Pb-210	3.41E-01	1.31E-32
Bi-210	3.41E-01	0.00E+00
Po-210	3.41E-01	1.37E-11

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

Th-232	**180 yr**	**2.26E-04**
Th-232	1.00E+00	3.97E-15
Ra-228	1.00E+00	0.00E+00
Ac-228	1.00E+00	1.38E-05
Th-228	1.00E+00	1.25E-12
Ra-224	1.00E+00	8.95E-11
Rn-220	1.00E+00	5.18E-10
Po-216	1.00E+00	6.92E-11
Pb-212	1.00E+00	1.07E-09
Bi-212	1.00E+00	3.98E-06
Tl-208	3.59E-01	2.09E-04
Po-212	6.41E-01	0.00E+00

Pa-231	**230 yr**	**1.98E-07**
Pa-231	9.95E-01	1.52E-09
Ac-227	9.95E-01	2.91E-15
Fr-223	1.37E-02	2.18E-10
Th-227	9.81E-01	2.96E-09
Ra-223	9.95E-01	5.63E-09
Rn-219	9.95E-01	6.74E-09
Po-215	9.95E-01	5.00E-11
Pb-211	9.95E-01	1.58E-07
Bi-211	9.95E-01	6.45E-09
Tl-207	9.92E-01	1.56E-08
Po-211	2.78E-03	1.05E-10

U-232	**100 yr**	**8.00E-05**
U-232	3.66E-01	1.04E-14
Th-228	3.76E-01	4.71E-13
Ra-224	3.76E-01	3.37E-11
Rn-220	3.76E-01	1.95E-10
Po-216	3.76E-01	2.60E-11
Pb-212	3.76E-01	4.02E-10
Bi-212	3.76E-01	1.50E-06
Tl-208	1.35E-01	7.85E-05
Po-212	2.41E-01	0.00E+00

U-233	**1000 yr**	**1.73E-07**
U-233	9.96E-01	4.80E-15
Th-229	8.99E-02	2.48E-12
Ra-225	8.99E-02	1.59E-41
Ac-225	8.99E-02	1.81E-11
Fr-221	8.99E-02	1.50E-11
At-217	8.99E-02	2.93E-11
Bi-213	8.99E-02	1.30E-08
Tl-209	1.94E-03	1.60E-07
Po-213	8.80E-02	1.12E-11
Pb-209	8.99E-02	0.00E+00

U-234	**1000 yr**	**1.27E-07**
U-234	9.97E-01	2.55E-15
Th-230	9.14E-03	7.47E-16
Ra-226	1.73E-03	1.29E-14
Rn-222	1.73E-03	4.83E-13
Po-218	1.73E-03	0.00E+00
Pb-214	1.73E-03	1.60E-10
At-218	3.45E-07	0.00E+00
Bi-214	1.73E-03	1.27E-07
Po-214	1.73E-03	6.60E-13
Pb-210	1.62E-03	6.25E-35
Bi-210	1.62E-03	0.00E+00
Po-210	1.62E-03	6.52E-14

U-235	**1000 yr**	**4.15E-09**
U-235	1.00E+00	1.25E-10
Th-231	1.00E+00	1.78E-13
Pa-231	2.09E-02	3.20E-11
Ac-227	2.03E-02	5.93E-17
Fr-223	2.80E-04	4.44E-12
Th-227	2.00E-02	6.04E-11
Ra-223	2.03E-02	1.15E-10
Rn-219	2.03E-02	1.37E-10
Po-215	2.03E-02	1.02E-12
Pb-211	2.03E-02	3.23E-09
Bi-211	2.03E-02	1.31E-10
Tl-207	2.02E-02	3.19E-10
Po-211	5.68E-05	2.14E-12

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

U-236	**1000 yr**	**1.10E-11**
U-236	1.00E+00	4.37E-21
Th-232	4.93E-08	1.96E-22
Ra-228	4.89E-08	0.00E+00
Ac-228	4.89E-08	6.75E-13
Th-228	4.88E-08	6.11E-20
Ra-224	4.88E-08	4.37E-18
Rn-220	4.88E-08	2.53E-17
Po-216	4.88E-08	3.38E-18
Pb-212	4.88E-08	5.22E-17
Bi-212	4.88E-08	1.94E-13
Tl-208	1.75E-08	1.02E-11
Po-212	3.13E-08	0.00E+00

U-238	**1000 yr**	**1.29E-07**
U-238	1.00E+00	1.17E-21
Th-234	1.00E+00	7.79E-15
Pa-234m	1.00E+00	9.97E-08
Pa-234	1.30E-03	2.94E-08
U-234	2.82E-03	7.20E-18
Th-230	1.29E-05	1.06E-18
Ra-226	1.68E-06	1.25E-17
Rn-222	1.68E-06	4.71E-16
Po-218	1.68E-06	0.00E+00
Pb-214	1.68E-06	1.56E-13
At-218	3.36E-10	0.00E+00
Bi-214	1.68E-06	1.24E-10
Po-214	1.68E-06	6.44E-16
Pb-210	1.53E-06	5.90E-38
Bi-210	1.53E-06	0.00E+00
Po-210	1.53E-06	6.16E-17

Np-237	**1000 yr**	**1.55E-08**
Np-237	1.00E+00	2.56E-12
Pa-233	1.00E+00	1.51E-08
U-233	4.34E-03	2.09E-17
Th-229	1.99E-04	5.49E-15
Ra-225	1.99E-04	3.52E-44
Ac-225	1.99E-04	3.99E-14
Fr-221	1.99E-04	3.32E-14
At-217	1.99E-04	6.49E-14
Bi-213	1.99E-04	2.87E-11
Tl-209	4.30E-06	3.53E-10
Po-213	1.95E-04	2.49E-14
Pb-209	1.99E-04	0.00E+00

Pu-238	**1000 yr**	**3.58E-11**
Pu-238	3.69E-04	8.36E-30
U-234	3.56E-04	9.10E-19
Th-230	2.85E-06	2.33E-19
Ra-226	4.87E-07	3.63E-18
Rn-222	4.87E-07	1.36E-16
Po-218	4.87E-07	0.00E+00
Pb-214	4.87E-07	4.52E-14
At-218	9.73E-11	0.00E+00
Bi-214	4.87E-07	3.58E-11
Po-214	4.87E-07	1.86E-16
Pb-210	4.55E-07	1.75E-38
Bi-210	4.55E-07	0.00E+00
Po-210	4.54E-07	1.83E-17

Pu-239	**1000 yr**	**3.01E-15**
Pu-239	9.72E-01	9.78E-16
U-235	9.71E-07	1.21E-16
Th-231	9.71E-07	1.72E-19
Pa-231	1.02E-08	1.57E-17
Ac-227	9.63E-09	2.81E-23
Fr-223	1.33E-10	2.11E-18
Th-227	9.49E-09	2.86E-17
Ra-223	9.62E-09	5.45E-17
Rn-219	9.62E-09	6.52E-17
Po-215	9.62E-09	4.84E-19
Pb-211	9.62E-09	1.53E-15
Bi-211	9.62E-09	6.24E-17
Tl-207	9.59E-09	1.51E-16
Po-211	2.69E-11	1.02E-18

Pu-240	**1000 yr**	**1.56E-16**
Pu-240	9.00E-01	6.12E-27
U-236	2.81E-05	1.23E-25
Th-232	7.05E-13	2.80E-27
Ra-228	6.94E-13	0.00E+00
Ac-228	6.94E-13	9.56E-18
Th-228	6.90E-13	8.64E-25
Ra-224	6.90E-13	6.17E-23
Rn-220	6.90E-13	3.57E-22
Po-216	6.90E-13	4.77E-23
Pb-212	6.90E-13	7.38E-22
Bi-212	6.90E-13	2.75E-18
Tl-208	2.48E-13	1.44E-16
Po-212	4.42E-13	0.00E+00

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

Pu-241	**1000 yr**	**8.08E-14**
Pu-241	8.59E-22	0.00E+00
Am-241	6.88E-03	1.04E-22
Np-237	5.28E-06	1.35E-17
Pa-233	5.28E-06	7.99E-14
U-233	1.41E-08	6.78E-23
Th-229	4.73E-10	1.30E-20
Ra-225	4.73E-10	8.37E-50
Ac-225	4.73E-10	9.49E-20
Fr-221	4.73E-10	7.89E-20
At-217	4.73E-10	1.54E-19
Bi-213	4.73E-10	6.81E-17
Tl-209	1.02E-11	8.40E-16
Po-213	4.62E-10	5.91E-20
Pb-209	4.73E-10	0.00E+00

Pu-242	**1000 yr**	**2.00E-14**
Pu-242	9.98E-01	8.42E-26
U-238	1.55E-07	1.81E-28
Th-234	1.55E-07	1.21E-21
Pa-234m	1.55E-07	1.54E-14
Pa-234	2.01E-10	4.56E-15
U-234	2.19E-10	5.59E-25
Th-230	6.69E-13	5.47E-26
Ra-226	6.66E-14	4.96E-25
Rn-222	6.66E-14	1.87E-23
Po-218	6.66E-14	0.00E+00
Pb-214	6.66E-14	6.19E-21
At-218	1.33E-17	0.00E+00
Bi-214	6.66E-14	4.90E-18
Po-214	6.66E-14	2.55E-23
Pb-210	5.89E-14	2.27E-45
Bi-210	5.89E-14	0.00E+00
Po-210	5.88E-14	2.36E-24

Pu-244	**100 yr**	**2.74E-06**
Pu-244	1.00E+00	1.36E-37
U-240	9.99E-01	1.09E-35
Np-240m	9.99E-01	2.74E-06
Pu-240	1.05E-02	7.13E-29
U-236	1.56E-08	6.80E-29
Th-232	2.55E-17	1.01E-31
Ra-228	2.00E-17	0.00E+00
Ac-228	1.78E-17	2.45E-22
Th-228	1.95E-17	2.45E-29
Ra-224	1.89E-17	1.70E-27
Rn-220	1.79E-17	9.27E-27
Po-216	1.80E-17	1.25E-27
Pb-212	1.89E-17	2.02E-26
Bi-212	1.96E-17	7.82E-23
Tl-208	6.71E-18	3.90E-21
Po-212	1.15E-17	0.00E+00

Am-241	**1000 yr**	**2.47E-12**
Am-241	2.01E-01	3.05E-21
Np-237	1.61E-04	4.13E-16
Pa-233	1.61E-04	2.44E-12
U-233	4.40E-07	2.12E-21
Th-229	1.51E-08	4.16E-19
Ra-225	1.51E-08	2.67E-48
Ac-225	1.51E-08	3.03E-18
Fr-221	1.51E-08	2.52E-18
At-217	1.51E-08	4.92E-18
Bi-213	1.51E-08	2.18E-15
Tl-209	3.26E-10	2.68E-14
Po-213	1.48E-08	1.89E-18
Pb-209	1.51E-08	0.00E+00

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

Am-242m	**100 yr**	**1.75E-08**
Am-242m	6.12E-01	1.06E-15
Np-238	2.91E-03	1.75E-08
Am-242	6.09E-01	8.48E-14
Pu-238	3.45E-01	7.81E-27
U-234	6.04E-05	1.54E-19
Th-230	2.04E-08	1.67E-21
Ra-226	2.31E-10	1.72E-21
Rn-222	2.31E-10	6.48E-20
Po-218	2.31E-10	0.00E+00
Pb-214	2.31E-10	2.15E-17
At-218	4.63E-14	0.00E+00
Bi-214	2.31E-10	1.70E-14
Po-214	2.31E-10	8.85E-20
Pb-210	9.53E-11	3.67E-42
Bi-210	9.52E-11	0.00E+00
Po-210	9.30E-11	3.74E-21
Pu-242	2.52E-05	2.13E-30
Cm-242	5.05E-01	6.48E-25
U-238	2.12E-13	2.48E-34
Th-234	2.11E-13	1.65E-27
Pa-234m	2.11E-13	2.11E-20
Pa-234	2.75E-16	6.22E-21

Am-243	**100 yr**	**2.28E-09**
Am-243	9.91E-01	7.14E-14
Np-239	9.91E-01	2.28E-09
Pu-239	2.86E-03	2.88E-18
U-235	1.41E-10	1.76E-20
Th-231	1.41E-10	2.50E-23
Pa-231	9.94E-14	1.52E-22
Ac-227	4.69E-14	1.37E-28
Fr-223	6.47E-16	1.03E-23
Th-227	4.61E-14	1.39E-22
Ra-223	4.67E-14	2.64E-22
Rn-219	4.67E-14	3.16E-22
Po-215	4.67E-14	2.35E-24
Pb-211	4.67E-14	7.43E-21
Bi-211	4.67E-14	3.03E-22
Tl-207	4.65E-14	7.34E-22
Po-211	1.31E-16	4.93E-24

Cm-242	**1000 yr**	**1.82E-13**
Cm-242	0.00E+00	0.00E+00
Pu-238	1.89E-06	4.27E-32
U-234	1.81E-06	4.63E-21
Th-230	1.45E-08	1.19E-21
Ra-226	2.47E-09	1.84E-20
Rn-222	2.47E-09	6.92E-19
Po-218	2.47E-09	0.00E+00
Pb-214	2.47E-09	2.30E-16
At-218	4.94E-13	0.00E+00
Bi-214	2.47E-09	1.82E-13
Po-214	2.47E-09	9.46E-19
Pb-210	2.31E-09	8.88E-41
Bi-210	2.31E-09	0.00E+00
Po-210	2.31E-09	9.27E-20

Cm-243	**100 yr**	**1.03E-10**
Cm-243	9.24E-02	1.03E-10
Pu-239	1.09E-03	1.10E-18
Am-243	8.55E-06	6.16E-19
U-235	7.33E-11	9.15E-21
Th-231	7.33E-11	1.30E-23
Pa-231	6.02E-14	9.20E-23
Ac-227	3.02E-14	8.81E-29
Fr-223	4.16E-16	6.60E-24
Th-227	2.97E-14	8.95E-23
Ra-223	3.00E-14	1.70E-22
Rn-219	3.00E-14	2.03E-22
Po-215	3.00E-14	1.51E-24
Pb-211	3.00E-14	4.78E-21
Bi-211	3.00E-14	1.95E-22
Tl-207	2.99E-14	4.72E-22
Po-211	8.41E-17	3.17E-24
Np-239	8.55E-06	1.96E-14

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

Cm-244	**1000 yr**	**4.09E-19**
Cm-244	2.34E-17	2.00E-42
Pu-240	2.49E-03	1.69E-29
U-236	7.55E-08	3.30E-28
Th-232	1.85E-15	7.34E-30
Ra-228	1.82E-15	0.00E+00
Ac-228	1.82E-15	2.50E-20
Th-228	1.81E-15	2.26E-27
Ra-224	1.81E-15	1.62E-25
Rn-220	1.81E-15	9.35E-25
Po-216	1.81E-15	1.25E-25
Pb-212	1.81E-15	1.93E-24
Bi-212	1.81E-15	7.19E-21
Tl-208	6.49E-16	3.77E-19
Po-212	1.16E-15	0.00E+00

Cm-245	**1000 yr**	**1.21E-11**
Cm-245	9.22E-01	9.81E-12
Pu-241	9.23E-01	0.00E+00
Am-241	7.54E-01	1.14E-20
Np-237	1.52E-04	3.91E-16
Pa-233	1.52E-04	2.31E-12
U-233	2.44E-07	1.17E-21
Th-229	5.94E-09	1.64E-19
Ra-225	5.94E-09	1.05E-48
Ac-225	5.94E-09	1.19E-18
Fr-221	5.94E-09	9.91E-19
At-217	5.94E-09	1.94E-18
Bi-213	5.94E-09	8.56E-16
Tl-209	1.28E-10	1.05E-14
Po-213	5.81E-09	7.42E-19
Pb-209	5.94E-09	0.00E+00

Cm-246	**1000 yr**	**1.77E-17**
Cm-246	8.64E-01	6.45E-37
Pu-242	1.73E-03	1.46E-28
U-238	1.37E-10	1.61E-31
Th-234	1.37E-10	1.07E-24
Pa-234m	1.37E-10	1.37E-17
Pa-234	1.78E-13	4.04E-18
U-234	1.31E-13	3.33E-28
Th-230	3.02E-16	2.47E-29
Ra-226	2.45E-17	1.82E-28
Rn-222	2.45E-17	6.86E-27
Po-218	2.45E-17	0.00E+00
Pb-214	2.45E-17	2.27E-24
At-218	4.90E-21	0.00E+00
Bi-214	2.45E-17	1.80E-21
Po-214	2.45E-17	9.37E-27
Pb-210	2.11E-17	8.10E-49
Bi-210	2.11E-17	0.00E+00
Po-210	2.10E-17	8.44E-28

Cm-247	**1000 yr**	**6.99E-08**
Cm-247	1.00E+00	6.92E-08
Pu-243	1.00E+00	4.81E-10
Am-243	8.98E-02	6.47E-15
Np-239	8.98E-02	2.06E-10
Pu-239	1.30E-03	1.31E-18
U-235	4.30E-10	5.37E-20
Th-231	4.30E-10	7.64E-23
Pa-231	2.28E-12	3.49E-21
Ac-227	2.02E-12	5.91E-27
Fr-223	2.79E-14	4.43E-22
Th-227	1.99E-12	6.01E-21
Ra-223	2.02E-12	1.14E-20
Rn-219	2.02E-12	1.37E-20
Po-215	2.02E-12	1.02E-22
Pb-211	2.02E-12	3.21E-19
Bi-211	2.02E-12	1.31E-20
Tl-207	2.01E-12	3.18E-20
Po-211	5.65E-15	2.13E-22

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

Cm-248	**1000 yr**	**2.17E-11**
Cm-248	9.98E-01	3.93E-26
Pu-244	7.94E-06	1.08E-42
U-240	7.93E-06	8.64E-41
Np-240m	7.93E-06	2.17E-11
Pu-240	4.05E-07	2.75E-33
U-236	4.03E-12	1.76E-32
Th-232	5.10E-20	2.03E-34
Ra-228	4.70E-20	0.00E+00
Ac-228	5.34E-20	7.36E-25
Th-228	6.35E-20	7.96E-32
Ra-224	6.09E-20	5.45E-30
Rn-220	5.86E-20	3.03E-29
Po-216	5.14E-20	3.55E-30
Pb-212	5.66E-20	6.06E-29
Bi-212	6.13E-20	2.44E-25
Tl-208	2.07E-20	1.20E-23
Po-212	3.89E-20	0.00E+00

Bk-249	**100 yr**	**1.24E-10**
Bk-249	5.06E-34	0.00E+00
Cf-249	2.12E-03	1.24E-10
Cm-245	1.88E-05	2.00E-16
Pu-241	1.51E-05	0.00E+00
Am-241	9.89E-07	1.50E-26
Np-237	9.37E-12	2.40E-23
Pa-233	9.34E-12	1.41E-19
U-233	9.01E-16	4.34E-30
Th-229	1.52E-18	4.20E-29
Ra-225	1.52E-18	2.69E-58
Ac-225	1.51E-18	3.04E-28
Fr-221	1.51E-18	2.53E-28
At-217	1.51E-18	4.94E-28
Bi-213	1.51E-18	2.18E-25
Tl-209	3.27E-20	2.69E-24
Po-213	1.48E-18	1.89E-28
Pb-209	1.51E-18	0.00E+00

Cf-249	**100 yr**	**4.81E-08**
Cf-249	8.21E-01	4.81E-08
Cm-245	7.37E-03	7.84E-14
Pu-241	5.95E-03	0.00E+00
Am-241	3.96E-04	5.99E-24
Np-237	3.80E-09	9.74E-21
Pa-233	3.79E-09	5.73E-17
U-233	3.71E-13	1.79E-27
Th-229	6.34E-16	1.75E-26
Ra-225	6.32E-16	1.12E-55
Ac-225	6.31E-16	1.27E-25
Fr-221	6.31E-16	1.05E-25
At-217	6.31E-16	2.06E-25
Bi-213	6.31E-16	9.09E-23
Tl-209	1.36E-17	1.12E-21
Po-213	6.17E-16	7.88E-26
Pb-209	6.31E-16	0.00E+00

Cf-250	**1000 yr**	**4.69E-20**
Cf-250	9.67E-24	9.26E-43
Cm-246	2.38E-03	1.78E-39
Pu-242	4.66E-06	3.93E-31
U-238	3.63E-13	4.25E-34
Th-234	3.63E-13	2.83E-27
Pa-234m	3.63E-13	3.62E-20
Pa-234	4.72E-16	1.07E-20
U-234	3.39E-16	8.66E-31
Th-230	7.70E-19	6.29E-32
Ra-226	6.14E-20	4.58E-31
Rn-222	6.14E-20	1.72E-29
Po-218	6.14E-20	0.00E+00
Pb-214	6.14E-20	5.71E-27
At-218	1.23E-23	0.00E+00
Bi-214	6.14E-20	4.52E-24
Po-214	6.14E-20	2.35E-29
Pb-210	5.27E-20	2.03E-51
Bi-210	5.27E-20	0.00E+00
Po-210	5.25E-20	2.11E-30

Table B-1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Intermediate-Level Vaults – Resident Scenario with Transient Calculation for 1,000 years

Cf-251	**100 yr**	**2.69E-10**
Cf-251	9.26E-01	2.68E-10
Cm-247	4.28E-06	2.96E-13
Pu-243	4.28E-06	2.06E-15
Am-243	2.03E-08	1.46E-21
Np-239	2.03E-08	4.67E-17
Pu-239	1.96E-11	1.97E-26
U-235	4.84E-19	6.04E-29
Th-231	4.84E-19	8.59E-32
Pa-231	9.19E-24	1.41E-32
Ac-227	-6.39E-22	-1.87E-36
Fr-223	-7.66E-24	-1.22E-31
Th-227	-1.27E-22	-3.83E-31
Ra-223	-3.04E-22	-1.72E-30
Rn-219	-4.46E-22	-3.02E-30
Po-215	-1.26E-22	-6.33E-33
Pb-211	-2.44E-22	-3.88E-29
Bi-211	-3.85E-22	-2.49E-30
Tl-207	-6.49E-22	-1.02E-29
Po-211	-1.20E-24	-4.53E-32

Cf-252	**1000 yr**	**1.59E-16**
Cf-252	1.55E-114	1.60E-135
Cm-248	7.35E-06	2.90E-31
Pu-244	5.83E-11	7.90E-48
U-240	5.82E-11	6.34E-46
Np-240m	5.82E-11	1.59E-16
Pu-240	2.96E-12	2.01E-38
U-236	2.93E-17	1.28E-37
Th-232	4.24E-25	1.69E-39
Ra-228	4.07E-25	0.00E+00
Ac-228	4.32E-25	5.96E-30
Th-228	4.07E-25	5.10E-37
Ra-224	3.63E-25	3.25E-35
Rn-220	4.35E-25	2.25E-34
Po-216	3.92E-25	2.71E-35
Pb-212	3.81E-25	4.07E-34
Bi-212	4.24E-25	1.69E-30
Tl-208	1.71E-25	9.91E-29
Po-212	2.81E-25	0.00E+00

APPENDIX C – ADDITIONAL INFORMATION ON AIR ANALYSIS

This appendix provides additional detail information on the air limit calculation summarized in Table 4-1.

The dose limit of 10 mrem/yr is defined in Table 2.5-1 of the PA (McDowell-Boyer et al. 2000). Dose factors are from Simpkins (2004). The release fractions are taken from Table 4.1-1 in the PA (McDowell-Boyer et al. 2000). A 100 year lag time at the 100 meter distance accounts for radioactive decay during the period of institutional control.

APPENDIX D – ADDITIONAL INFORMATION ON RADON ANALYSIS:

Evaluation of long-term Radon-222 release from the E-Area Intermediate Level Vault (ILV) Disposal Units

INTRODUCTION

This section describes the investigation conducted to evaluate the potential for radon release from the E-Area Intermediate Level Vault (ILV) disposal unit over the 1000-year performance assessment period of interest. The permissible radon flux for DOE facilities is addressed in USDOE 1999a (DOE Order 435.1). This order states that radon, either as a constituent of waste at the time of disposal or produced by radioactive decay following disposal, should not be released from the disposal facility at a rate that would exceed the limit established in 40 CFR Part 61. From this statute, the standard identified for radon release is stated as "No source at a Department of Energy facility shall emit more than 20 pCi/m^2-s of Rn-222 as an average for the entire source, into the air". No other radon isotopes are identified in this guidance. Therefore, USDOE Order 435.1 indicates that the radon release projected for a specific facility at the land surface should be compared to the 20 pCi/m^2-s standard.

This guidance forms the basis for the investigation to evaluate radon flux above an E-Area ILV disposal unit. The scope of the investigation involved defining a decay chain of parent radioisotopes to evaluate with a 1D vertical numerical model. The model was customized to represent the thickness of the vault waste zones and cover material over the facility. The instantaneous Rn-222 flux at the land surface was evaluated for the Performance Assessment (PA) compliance period of 1000 years. This flux was then compared to the standard identified in 40 CFR Part 61.

The potential parent radioisotopes that can contribute to the creation of Rn-222 are illustrated in Figure D-1. The diagram indicates the specific decay chains that lead to the formation of Rn-222, as well as the half-lives for each radioisotope. The extremely long half-lives of Pu-242 and U-238 (375,500 and 4,500,000 years respectively) cause the other radioisotopes higher up on the chain of parents to be of little concern with regard to their potential to contribute significantly to the Rn-222 flux at the land surface over the period of interest. The only other radon isotope that is mentioned in DOE Order 435.1 is "Rn-220 from Thorium". This decay chain was screened out as a part of this investigation due to its extremely short half-life of 55.6 seconds.

ILV CLOSURE CONSIDERATIONS

The concepts for closure of the ILV are relevant to the determination of the radon flux at the land surface during the PA evaluation period (1,000 years). ILV construction specifics and closure concept are described in Phifer, 2004, *Preliminary E-Area Intermediate Level Vault Closure Cap Infiltration (U)* and are summarized below. The current IL Vault is a below grade, reinforced concrete vault. The bottom of the base slab is approximately 26 feet below existing grade and the top of exterior walls are approximately 5.5 feet above existing grade. The exterior vault wall footprint is approximately 279 feet long by 48 feet wide. It contains seven 25-foot by 44.5-foot by 28.5-foot deep bulk waste cells and two 25-foot by 44.5-foot by 26-foot deep cells (interior dimensions). One of the 26-foot deep cells contains 140 vertical silos. The silos are approximately 30 inches in diameter at the top, 20 inches in diameter at the bottom, and 24.83 feet deep (interior dimensions). The other 26-foot deep cell is a bulk waste cell. There is currently one IL Vault in the E-Area LLWF and it is anticipated that two will be required (McDowell-Boyer et al. 2000).

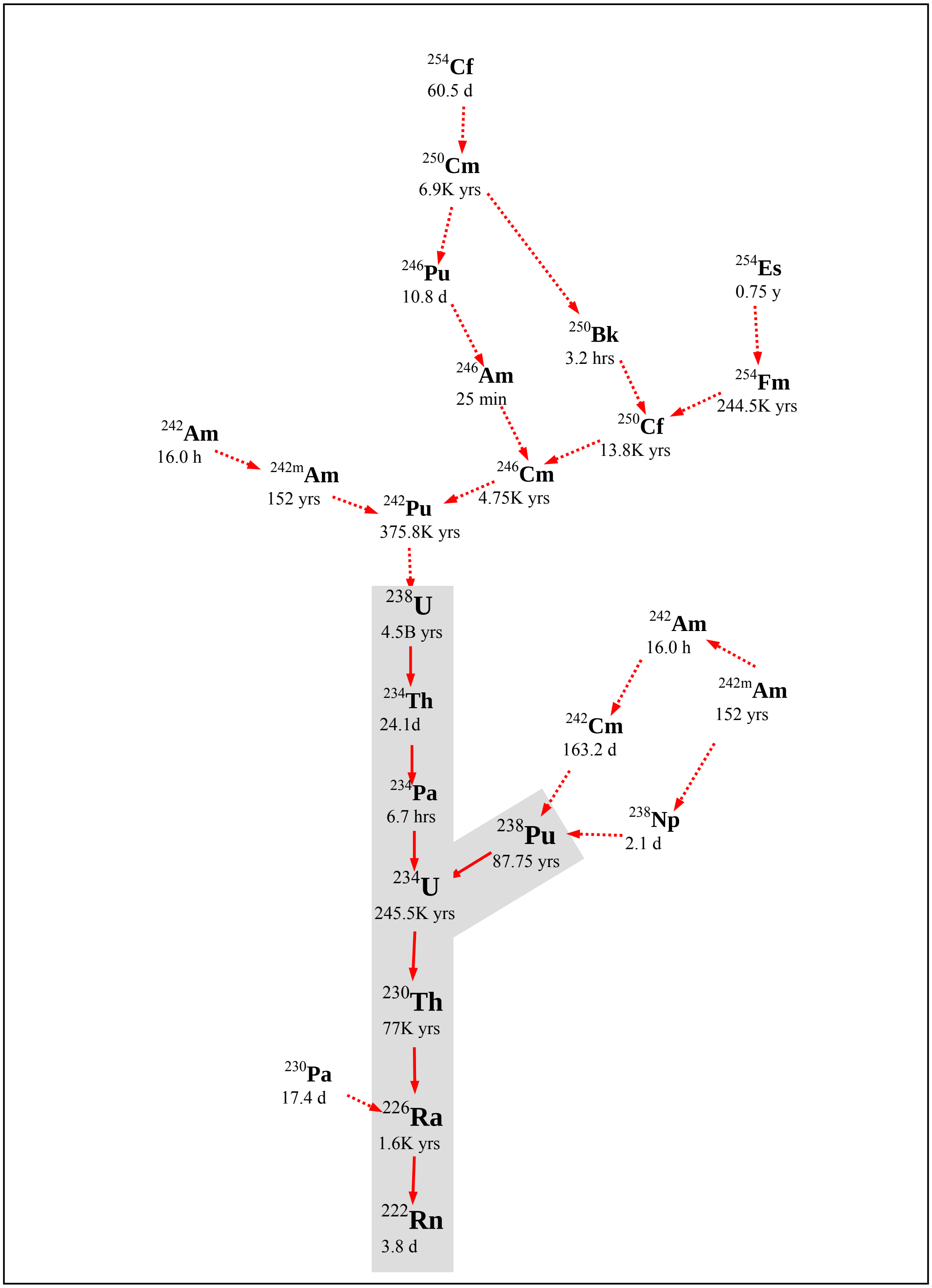


Figure D-1. Decay chain of parent radioisotopes leading to Rn-222 formation.

For the purposes of this investigation, it is assumed that there will be a 25-year operations period during which the unit is loaded with waste. This is followed by a 100-year period of institutional control during which a temporary surface runoff cover will be placed over the ILV and maintained. Following the institutional control period the ILV will be prepared for final closure, as described in Phifer, 2004. Specific information with regard to the construction of the final closure cap is presented below. The final closure cap will exist far into the future and is the configuration that must be considered in evaluating the long-term radon release at the land surface.

Closure configuration

During the operational period, the ILV will be filled with equipment and containerized waste (predominately in drums, B-12 boxes, B-25 boxes, and concrete containers) each placed in the cell in layers. Each layer of waste will be encapsulated in grout, which forms the surface for the placement of the next layer of waste. In this fashion, the full 28.5-foot (8.7 m) depth of an ILV cell will be filled in, with the upper 17 inches (0.43 m) being filled in with grout (Phifer, 2004).

As the individual cells are filled they will be grouted shut with the upper 17-inch grout layer. A temporary roof will be maintained over each completed cell until the end of the 25-year operations period. At that point the concrete roof will be constructed and maintained over the 100-year institutional control period. At the end of institutional control, a permanent closure cap will be constructed to cover the entire ILV (Phifer, 2004).

Table D-1, below, describes the individual components of the closure cap. Materials are indicated with the associated thickness of each component, in inches, cm and m.

Table D-1. Vertical layer sequence and associated thickness for ILV cover material. (Adapted from Phifer, 2004)

Layer	Thickness (inches)	Thickness (cm)	Thickness (m)
Topsoil	6	15.2	0.15
Upper Compacted Backfill	30	76.2	0.76
Erosion Barrier	12	30.5	0.30
Geotextile Filter Fabric	0.1	0.25	0.003
Middle Compacted Backfill	12	30.5	0.30
Geotextile Filter Fabric	0.1	0.25	0.003
Drainage Layer	12	30.5	0.30
GCL	0.2	0.5	0.01
Lower Compacted Backfill	40	102	1.02
ILV Roof Slab	33 (avg.)	83.8	0.84
ILV upper grout layer	17	43.2	0.43
Vault Waste Zone	~345	~877	~8.7

The components of concern for the long-term radon performance calculation are those that will persist over the 1000-year evaluation period and probably for > 10,000 years. These components are situated below the top of the Erosion Barrier. For the purpose of this investigation, the concrete roof slab is considered to be part of the Soil Cover Zone in the 1D model while the upper grout seal on top of the ILV waste is considered to be part of the ILV Waste Zone. Therefore, the composite thickness of the non-waste material below the top of the Erosion Barrier is 109.4 inches (2.77 m).

MODEL DEVELOPMENT

Conceptual Model

The Rn-222 flux at the land surface above an ILV was evaluated for its specific closure configuration. Rn-222 is generated within the ILV waste zones by radioactive decay of different parent isotopes following along the decay chains that lead to the formation of Rn-222. The decay chains for all possible parent isotopes of Rn-222 are shown in Figure D-1. In this figure the part of the decay chain that was simulated is indicated with the gray shaded area (i.e. beginning with Pu-238 and U-238). Rn-222 generated within the ILV waste zone is in the gaseous phase and diffuses outward from this zone into the air-filled soil pores surrounding the ILV, eventually resulting in some of the radon emanating at the land surface. As such, air is the fluid through which Rn-222 diffuses, although some Rn-222 may dissolve in residual pore water. Advective transport of Rn-222 in air-filled soil pores is not considered to be a significant process when compared to air diffusion. The parent isotopes exist in the solid phase and therefore do not migrate upward through the air-filled pore space, although they could be leached and transported downward from the waste zone by pore water movement. Within the Waste Zone, the assorted waste materials are generally placed in B-12 and B-25 boxes for placement within individual layers. There is a considerable amount of air space that remains inside the boxes when they are surrounded, and covered, with cement.

The time period of interest for which the flux of Rn-222 at the land surface was evaluated is 1000 years, as specified in DOE Order 435.1. An additional 125 years were added to this to account for any possible Rn-222 buildup during the 25-year operational period and 100-year institutional control period.

Numerical Model

The mathematical model utilized in this report is provided by the PORFLOW™ simulation package. PC-based PORFLOW™ Version 5.97.0 was used to conduct a series of simulations. PORFLOW™ is developed and marketed by Analytic & Computational Research, Inc. to solve problems involving transient and steady-state fluid flow, heat and mass transport in multi-phase, variably saturated, porous or fractured media with dynamic phase change. PORFLOW™ has been widely used at the SRS and in the DOE complex to address major issues related to the ground water and nuclear waste management.

The governing equation for mass transport of species *k* in the fluid phase is given by

$$\frac{\partial C_k}{\partial t} + \frac{\partial}{\partial x_i}(V_i C_k) = \frac{\partial}{\partial x_i}(D_{ij}\frac{\partial C_k}{\partial x_j}) + \gamma_k$$

where

C_k concentration of species *k*
V_i fluid velocity in the i^{th} direction

D_{ij}	effective diffusion coefficient for the species
γ_k	net decay of species *k*
i, j	direction index
t	time
x	distance coordinate

This equation is solved using PORFLOW to evaluate transient Rn-222 transport through the soil cover above the ILV to evaluate Rn-222 flux at the land surface over time.

Model Development and Assumptions

The numerical representation of the conceptual model is as a 1-dimensional vertical stack of elements configured to represent the thickness of the ILV waste zone and overlying cover material associated with final closure of an ILV. The conditions and assumptions of this model are:

Decay chains evaluated were U-238→Th-234→Pa-234→U-234→Th-230→Ra-226→Rn-222 and Pu-238 →U-234→Th-230→Ra-226→Rn-222. These chains are shaded solid gray in Figure D-1. Each parent in these chains, except Th-234 and Pa-234, were simulated separately as the starting point of the decay chain. Th-234 and Pa-234 have extremely short half-lives compared to the other parent isotopes in these chains. Only a fraction of the Rn-222 generated by the decay of each parent is available for migration away from its source and into open pore space. Since the Rn-222 parent isotopes exist as oxides or in other crystalline forms, only a fraction of Rn-222 generated by decay of Ra-226 has sufficient energy to migrate away from its original location into adjacent pore space before further decay occurs (3.2 day half-life for Rn-222). The fraction of radon escaping its source and migrating into adjacent pore space is approximated by the use of a radon emanation coefficient. This coefficient has been shown to vary between 0.02 and 0.7 in soils but is typically 0.25 (Yu, et. al, 2001). This value is taken as the default factor value for the RESRAD program, developed for the DOE. To account for this effect in this model, an effective source term of 0.25 Ci of parent isotope was utilized as the source term for each Ci disposed within the facility.

Since Rn-222 exists primarily in the gaseous state, air was taken to be the fluid within which radon transport occurs. Air-diffusion was the only transport mechanism simulated in the model and advective air-transport is assumed to be negligible. Some radon dissolves in pore water but since diffusion proceeds more slowly in that fluid, air-diffusion is the only transport process by which Rn-222 can reach the land surface when it is placed in the ILV. Transport was allowed to proceed only through air-filled pore space and, therefore, residual pore water was treated as if it was part of the solid matrix material within the flow field. No credit was taken for airborne radon dissolving in pore water as it proceeds from the ILV to the land surface although it has been observed to partition between air and water in the ratio of 4 to 1, respectively, at 20 C (Nazaroff and Nero, 1988).

The boundary conditions imposed on the domain included:

- No-flux specified for all parent isotopes at perimeter of the domain
- No-flux specified for Rn-222 along sides and bottom
- Rn-222 concentration set to 0 at land surface.

Waste is disposed in various forms in the ILV, commonly within B-12 and B-25 boxes. Waste is disposed in individual layers, which are then surrounded and covered by grout. This forms the floor of the next waste layer. Since each waste disposal box may have a considerable percentage of air-filled void space, accurate simulation of air-diffusion of Rn-222 must incorporate these "pockets" in which waste is disposed. The equivalent porosity and residual moisture content of these pockets are much different than the surrounding cement. Within the model, these pockets are assigned a representative air-filled porosity value of 0.5 to reflect the degree of waste compaction. A series of 5 layers, each 0.9 m tall were configured and separated by 0.9 feet of cement material to approximate the placement of Rn-222 parent isotopes within the waste disposal zone. The source term was assigned in 5 equal components within each of these layers.

Simulations were conducted in transient mode for diffusive transport in air, with results being obtained at 1,125 years and 10,125 years. The rationale for these precise simulation lengths was explained in the conceptual model.

Measures implemented to assure conservative results

In this analysis, several conditions introduce a significant measure of conservatism into the calculations, these include:

- The use of boundary conditions that force all of the Rn-222 to move upward from the waste disposal zone to the land surface. In reality, some of the Rn-222 diffuses sideways and downward in the air-filled pores surrounding the waste zone, hence ignoring this has the effect of increasing the radon flux at the land surface.

- Not taking credit for the removal of either Rn-222 or of the parent isotopes by pore water moving vertically downward through the model domain. This mechanism would likely carry off some dissolved Rn-222 in addition to the parent isotopes, and therefore its omission has the effect of increasing the estimate of instantaneous Rn-222 flux at the land surface in simulations conducted as a part of this investigation.

- The addition of an extra 125 years to the required 1000-year evaluation period to account for any Rn-222 generated during the operations and institutional control period, thus incrementally increasing the instantaneous Rn-222 flux. The extra time means slightly higher instantaneous fluxes for all parent isotopes except Ra-226.

- Use of the top of the erosion layer in the soil cover as the land surface for the purpose of calculating Rn-222 flux. No credit is taken for the additional distance Rn-222 must migrate above the erosion layer prior to that portion of the Soil Cover Zone eroding away.

- Placement of the source term in fewer layers than will actually be the case as the ILV is filled. With respect to Rn-222 generation, less void space means that Rn-222 concentration gradients can build up sooner to drive Rn-222 diffusion to the land surface through the overlying material.

- Assignment of soil properties to the cement material surrounding the waste packages. This facilitates more rapid diffusion of Rn-222 toward the land surface during the period when intact cement retains properties that would impede air-diffusion.

Grid Construction

The model grid was constructed as a node mesh 3 nodes wide by 33 nodes high. This mesh creates the vertical stack of 31 model elements. This node and element configuration is illustrated below in Figure D-2, which also indicates the correspondence of model zones with the revised closure configuration for an ILV structure, as presented in Phifer, 2004. The grid extends upward only as far as the erosion barrier, anticipating that this is the cover thickness that will prevail over the majority of the 1000-year PA evaluation period. A set of consistent units were employed in the simulations for length, mass and time, these being meters, grams and years, respectively.

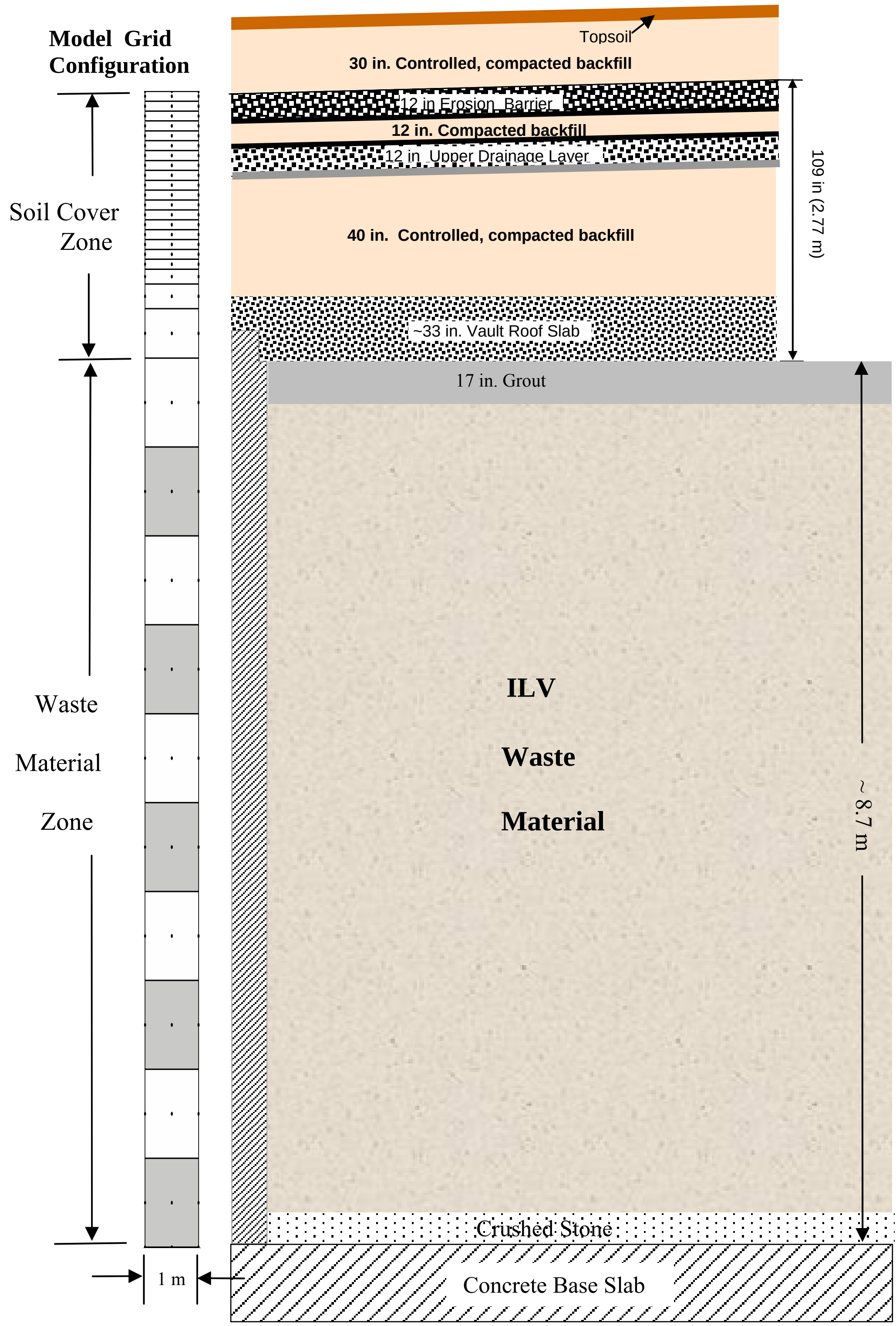


Figure D-2. Model grid and the ILV closure configuration.

Material zones

The model domain was divided into two primary zones, the ILV Waste Material Zone occupying the lower 345 inches (8.7 m) of the domain and the Soil Cover Zone, extending ~109.4 inches (~2.78 m) above the Waste Material Zone to the top of the domain. The Soil Cover Zone includes the concrete Vault roof as well as the different closure cap layers. The upper model elements were scaled to correspond to the geometry of the ILV closure cap thickness while the lower model elements were scaled to correspond to the ILV waste zone. The land surface over the PA period of interest is assumed to be the top of the erosion resistant layer, within the closure cap, and no credit is taken for the compacted soil and topsoil above that layer. The darker elements shown in the Waste Material Zone of Figure D-2 represent the individual waste disposal layers. In actuality, the concrete layers separating each waste layer will be thinner, therefore allowing the inclusion of several more waste layers.

Material zone properties and other input parameters

Material properties utilized within the 1-D numerical model were varied amongst 7 material zones defined within the model domain. Each material zone was assigned values for tortuosity, total porosity, residual saturation, air-filled porosity, matrix density, air density, and diffusivity.

The rock (matrix) density was selected based on the density of quartz, and is regarded to be representative of most soils. Tortuosity was assigned based on the commonly used value associated with a spherical particle tortuosity equation developed by Nielson and Rogers, 1982. Total porosities for soil materials were selected based on the typical values for soil materials found at the SRS. Values utilized for residual moisture in soil material were obtained from the 2-D cross-sectional model of the ILV developed for evaluating the groundwater pathway as a part of this investigation. Values utilized were the steady-state values that persist after the degradation of the closure cap. The density of air was obtained from the Bolz, et. al., CRC Handbook of tables for Applied Engineering Science. The Rn-222 diffusivity value was selected based on the value for coefficient of diffusion of Rn-222 in open air, as reported in Rogers, et. al., 1984.

While the Soil Cover and Waste Material zones form a basic distinction in terms of material properties, the Waste Material zone was further differentiated based on the distinction between waste layers and the concrete layers between them. The concrete layers were treated as "degraded" concrete, thus assuming properties similar to soil and were assigned different air-filled porosity values based on the steady-state residual moisture vertical distribution obtained in the groundwater pathway model. Air-filled porosity was calculated by subtracting the residual moisture content from the total porosity. The specific material property zones are listed in Table D-2 along with specific values used to represent matrix and fluid properties. The 7 zones are best described using the model structure illustrated in Figure D-2.

The Soil Cover Zone is treated as a single homogenous zone within this simulation, despite the layering within the closure cap. This simplification is justified for this type conceptual model where radon is simulated as diffusing only through the air filled pores. While the porosities of the separate materials undoubtedly range from a high in the gravel drain layers (up to 0.4) to a low in the compacted soil layers (<0.1) a single value of 0.2 for porosity is regarded to be a representative value for a composite of all the materials.

A typical model input file is presented in the Appendix showing the specific PORFLOW commands used to implement the numerical model.

Table D-2 Summary of matrix and fluid properties utilized within the numerical model.

	Material Type Zones						
	1	2	3	4	5	6	7
Property	Waste Zone Cavities	Concrete Layer	Concrete Layer	Concrete Layer	Concrete Layer	Concrete Layer	Soil Cover Layer
Tortuosity	1.0	0.66	0.66	0.66	0.66	0.66	0.66
Total Porosity	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Residual Saturation	0.0	0.6	0.6	0.7	0.7	0.8	0.7
Air-Filled Porosity	0.5	0.12	0.12	0.09	0.09	0.06	0.09
Matrix Density (g/m^3)	2.65E+06[a]	2.65E+06[a]	2.65E+06[a]	2.65E+06[a]	2.65E+06[a]	2.65E+06[a]	2.65E+06[a]
Air Density (g/m^3)	1.24E+03[b]	1.24E+03[b]	1.24E+03[b]	1.24E+03[b]	1.24E+03[b]	1.24E+03[b]	1.24E+03[b]
Molecular Diffusivity (m^2/yr)	3.47E+02[c]	3.47E+02[c]	3.47E+02[c]	3.47E+02[c]	3.47E+02[c]	3.47E+02[c]	3.47E+02[c]

a. CRC Handbook of Applied Engineering Science, 2'nd Ed. Table 1-2, pg. 11
b. CRC Handbook of Applied Engineering Science, 2'nd Ed. Table 1-121, pg.192
c. Rogers, et. al., 1984.

MODEL RESULTS

Model simulations were conducted to evaluate the peak instantaneous Rn-222 flux at the land surface over the 1125 year period. This time period includes the 25-year operations cycle, 100-years of institutional control and 1000-year PA compliance period identified in DOE Order 435.1. Model results were output in Ci/m^2-yr, consistent with the set of units employed in the model. The results were then converted into pCi/m^2-sec, which are the units used to define the regulatory flux limit in 40 CFR Part 61, Rev. 4. The results represent the peak Rn-222 flux per square meter at the top of the closure cap erosion barrier and are listed below in Table D-3. The top of the erosion barrier is expected to represent the land surface 1000 years in the future. Also shown in Table D-3 are disposal limits associated with each parent isotope, expressed in Ci of parent isotope permitted per square meter of surface area of the disposal facility.

Table D-3. Simulated peak instantaneous Rn-222 flux over 1000-years at the land surface and associated disposal limits for parent isotopes.

Parent Source (1 Ci)	Peak Instantaneous Rn-222 Flux at land surface	Unit Disposal Limit of parent isotope	Disposal Limit of parent per ILV (75 m x 15 m = 1125 m^2)
	(pCi/m^2-s)	(Ci/m^2)	(Ci/ILV)
Pu-238	5.38E-03	3.72E+03	4.18E+06
U-238	2.05E-02	9.74E+02	1.1E+06
U-234	1.86E+01	1.08E+00	1.21E+03
Th-230	3.31E+03	6.04E-03	6.79E+00
Ra-226	8.72E+03	2.29E-03	2.58E+00

The equation used to convert the simulated Rn-222 activity flux associated with each source isotope to determine the associated disposal limit is:

Disposal Limit (in Ci/m^2 of disposal facility footprint) = (20 pCi/m^2-sec) / (Rn-222 instantaneous flux, in pCi/m^2-sec).

In this equation the 20 pCi/m^2-sec is the Rn-222 flux limit applicable to the disposal facility at the land surface 1000 years after facility closure (40 CFR Part 61, Rev4). The Rn-222 instantaneous flux is the simulated flux determined for 1 Ci of each parent isotope evaluated in this investigation.

The instantaneous flux rates at the land surface versus time are shown in Figure D-3 for all 5 parent radioisotopes. The peak instantaneous Rn-222 flux simulated for 4 of the 5 parent isotopes occurs at t = 1125 years, or at the end of the PA period of interest. These parent isotopes are Th-230, U-234, U-238 and Pu-238. The other parent isotope, Ra-226 has its peak at approximately 64.2 days after disposal and slowly declines after that.

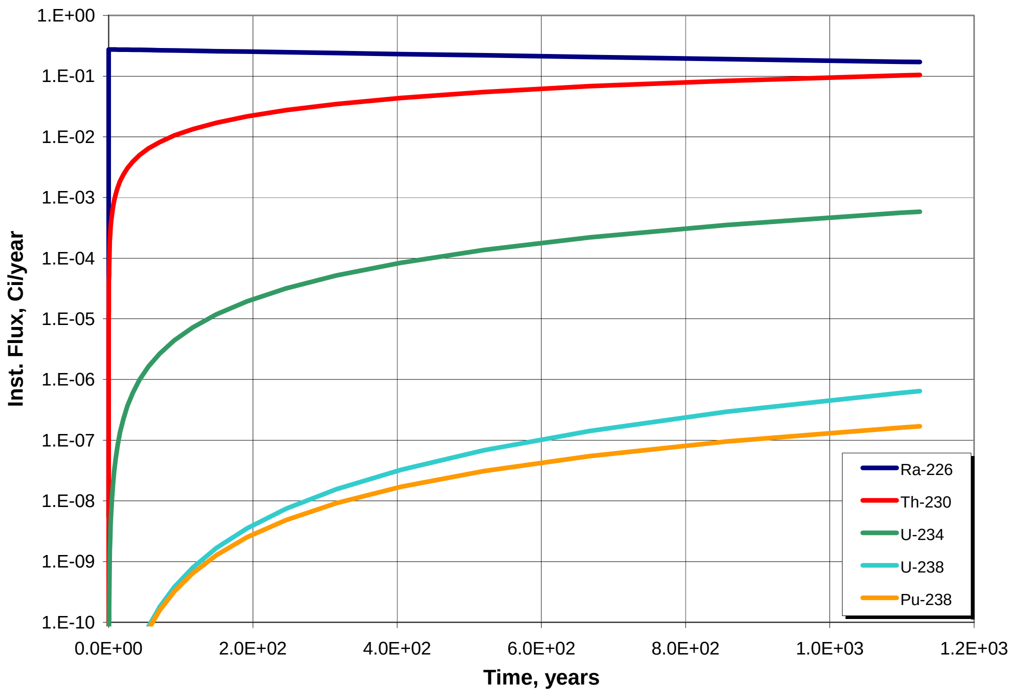


Figure D-3 Simulated instantaneous Rn-222 flux versus time.

DISPOSAL IMPLICATIONS

To simulate the instantaneous Rn-222 fluxes reported in Table D-3 the parent source isotope was distributed evenly in layers throughout the model waste zone (vault). However, the calculated Rn-222 instantaneous flux at the land surface after 1000 years is quite sensitive to the position of the unit source within the ILV. The instantaneous flux is lower when the parent isotopes are embedded near the base of the Vault and, conversely, is higher if the parent isotopes are embedded near the upper part of the Vault. This relationship is true because Rn-222 has a relatively short half-life of 3.82 days and therefore the flux has a strong negative correlation with the distance over which it must diffuse.

Since the limits calculated in this investigation assume uniform distribution of source isotope in 5 distinct layers throughout the vertical extent of the ILV, a sensitivity analysis was conducted to evaluate the impact of placing the source material within different, vertically differentiated, sub-zones of the ILV. In this evaluation, the absolute values calculated for disposal limits have no meaning other than to indicate in a relative fashion, how different disposal-modes compare to one another in terms of the resulting disposal limits.

In all sensitivity simulations the source was 1 Ci of U-234 and the time of simulation was 1,125 years. The sub-zones were selected to correspond to the vertical placement of the source as described below in Table D-4. Case 1 is the reference case, being the uniform distribution of the source throughout the full vertical extent of the ILV. In Cases 2-8, the extent of the source zone is expressed in terms of model grid coordinates, in meters from the bottom of the ILV.

The calculated disposal limit associated with each sensitivity case is graphically illustrated below in Figure D-4, which is a plot of the calculated disposal limit associated with each sensitivity case. Case 4, the situation where the source material is placed exclusively in the lower 1.8 m of the ILV produces the highest disposal limit, 2.77E-01 Ci/m^2. The lowest disposal limit, 1.78E-02 Ci/m^2 was realized if the source material was placed in the uppermost 1.8 m of the ILV. The results of this indicate that with the use of more fine-tuned waste placement practices, higher disposal limits might be achievable.

Table D-4. Description of sensitivity cases and associated disposal limits.

Sensitivity Case #	Description of Source Placement	Disposal Limit (Ci/m^2)
Case 1	Uniformly distributed throughout ILV (base case)	4.82 E-02
Case 2	Upper half of ILV Waste Zone (4.5 m to 9.0 m)	2.80E-02
Case 3	Lower half of ILV Waste Zone (0.0 m to 4.5 m)	1.73E-01
Case 4	Lowermost 2 elements (0.0 m to 1.8 m)	2.77E-01
Case 5	Next lowermost 2 elements (1.8 m to 3.6 m)	1.69E-01
Case 6	Next lowermost 2 elements (3.6 m to 5.4 m)	8.31E-02
Case 7	Next lowermost 2 elements (5.4 m to 7.2 m)	3.86E-02
Case 8	Uppermost 2 elements (7.2 m to 9.0 m)	1.78E-02

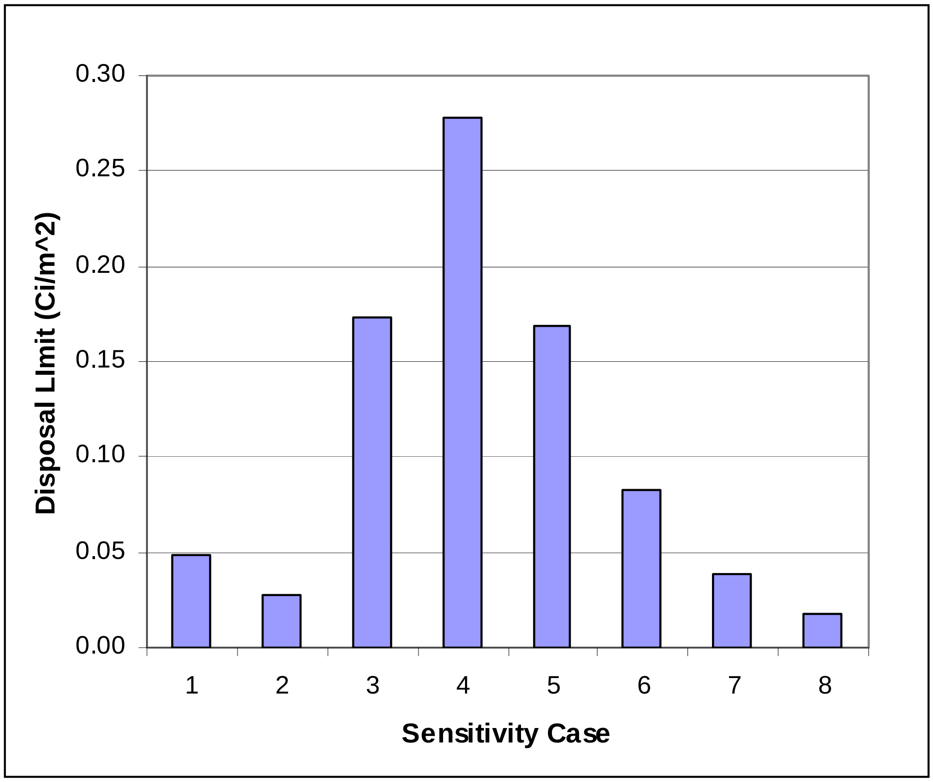


Figure D-4 Source zone sensitivity cases

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ADDENDUM

Example input code for ILV simulation

```
*******************************************************************
/Title ILV Diffusion for Rn-222
/1-D Vertical Column for disposal of 1 Ci U-234
/2.7 m of soil on top of 9 m of waste
/Pockets Created in Waste Zone to place Source Term (5 layers)
/SOURCE TERM: Emanation Factor of 0.25, apportioned to 5 cavities
/R. A. Hiergesell
/7/1/2004
/
/DECAY CHAIN is U-234-->Th-230-->Ra226-->Rn222
/SIMULATION UNITS: length = m, mass = g, time = years
/*******************************************************************
GRID 3 by 33
ALLOcate C3
ALLOcate C4
SCALE  1.0000
COORDINATE X:
            0.0         1.0
SCALE 1.0000
COORDINATE Y:
    0.0 0.9 1.8 2.7 3.6 4.5 5.4 6.3 7.2 8.1
    9.0 9.5 9.75 9.9
    10.0 10.1 10.2 10.3 10.4 10.5 10.6 10.7 10.8 10.9
    11.0 11.1 11.2 11.3 11.4 11.5 11.6 11.7  !!! element interfaces
DATUM = 0. 0.
/
MATErial type 1 from  1  1  to  3  2        $ Waste Package
MATErial type 1 from  1  4  to  3  4        $ Waste Package
MATErial type 1 from  1  6  to  3  6        $ Waste Package
MATErial type 1 from  1  8  to  3  8        $ Waste Package
MATErial type 1 from  1 10  to  3 10        $ Waste Package
MATErial type 2 from  1  3  to  3  3        $ Concrete, Rs = 0.6
MATErial type 3 from  1  5  to  3  5        $ Concrete, Rs = 0.6
MATErial type 4 from  1  7  to  3  7        $ Concrete, Rs = 0.7
MATErial type 5 from  1  9  to  3  9        $ Concrete, Rs = 0.7
MATErial type 6 from  1 11  to  3 11        $ Concrete, Rs = 0.8
MATErial type 7 from  1 12  to  3 33        $ Soil Cover
FOR 1
DENSity = 1.24e+3                           $ fluid density (air) in g/m^3
MATErial DENSity = 2.65e+6                  $ Particle density in g/m^3
MATErial POROsity = 0.5  0.5  0.5           $ Air-filled porosity (1 - 0.5)
FOR 2
DENSity = 1.24e+3                           $ fluid density (air) in g/m^3
MATErial DENSity = 2.65e+6                  $ Particle density in g/m^3
MATErial POROsity = 0.12  0.12  0.12        $ Air-filled porosity (.3 x (1 - 0.6))
FOR 3
DENSity = 1.24e+3                           $ fluid density (air) in g/m^3
MATErial DENSity = 2.65e+6                  $ Particle density in g/m^3
MATErial POROsity = 0.12  0.12  0.12        $ Air-filled porosity (.3 x (1 - 0.6))
FOR 4
DENSity = 1.24e+3                           $ fluid density (air) in g/m^3
```

```
MATErial DENSity = 2.65e+6              $ Particle density in g/m^3
MATErial POROsity = 0.09  0.09  0.09    $ Air-filled porosity (.3 x (1 - 0.7))
FOR 5
DENSity = 1.24e+3                       $ fluid density (air) in g/m^3
MATErial DENSity = 2.65e+6              $ Particle density in g/m^3
MATErial POROsity = 0.09  0.09  0.09    $ Air-filled porosity (.3 x (1 - 0.7))
FOR 6
DENSity = 1.24e+3                       $ fluid density (air) in g/m^3
MATErial DENSity = 2.65e+6              $ Particle density in g/m^3
MATErial POROsity = 0.06  0.06  0.06    $ Air-filled porosity (.3 x (1 - 0.8))
FOR 7
DENSity = 1.24e+3                       $ fluid density (air) in g/m^3
MATErial DENSity = 2.65e+6              $ Particle density in g/m^3
MATErial POROsity = 0.09  0.09  0.09    $ Air-filled porosity (.3 x (1 - 0.7))
FOR 2 to 7
MATErial TORTuosity = 0.66 0.66
/
LOCAte subregion ( 1,   1) to ( 3,  2) with ID = WASTE1
LOCAte subregion ( 1,   4) to ( 3,  4) with ID = WASTE2
LOCAte subregion ( 1,   6) to ( 3,  6) with ID = WASTE3
LOCAte subregion ( 1,   8) to ( 3,  8) with ID = WASTE4
LOCAte subregion ( 1,  10) to ( 3, 10) with ID = WASTE5
LOCAte subregion ( 1,  12) to ( 3, 33) with ID = SOIL
/
SET INVentory for C to 0.05 in ID=WASTE1   $ 0.25 Ci x 1/5 of Ra-226 ACTIVITY
SET INVentory for C to 0.05 in ID=WASTE2   $ 0.25 Ci x 1/5 of Ra-226 ACTIVITY
SET INVentory for C to 0.05 in ID=WASTE3   $ 0.25 Ci x 1/5 of Ra-226 ACTIVITY
SET INVentory for C to 0.05 in ID=WASTE4   $ 0.25 Ci x 1/5 of Ra-226 ACTIVITY
SET INVentory for C to 0.05 in ID=WASTE5   $ 0.25 Ci x 1/5 of Ra-226 ACTIVITY
/
FOR 1 to 7
TRANsport for C4  kd =  0.00, dm = 3.47e+2    $ C4 is Rn222
/
BOUN C  X-   FLUX = 0.          $ U234
BOUN C  X+   FLUX = 0.
BOUN C  Y-   FLUX = 0.
BOUN C  Y+   FLUX = 0.
/
BOUN C2 X-   FLUX = 0.          $ Th230
BOUN C2 X+   FLUX = 0.
BOUN C2 Y-   FLUX = 0.
BOUN C2 Y+   FLUX = 0.
/
BOUN C3 X-   FLUX = 0.          $ Ra226
BOUN C3 X+   FLUX = 0.
BOUN C3 Y-   FLUX = 0.
BOUN C3 Y+   FLUX = 0.
/
BOUN C4 X-   FLUX = 0.          $ Rn222
BOUN C4 X+   FLUX = 0.
BOUN C4 Y-   FLUX = 0.
BOUN C4 Y+   VALU = 0.
/
DECAy half LIFE for C  is 2.455e+05 years      $ U-234  from Nuclear Wallet Cards, BNL
DECAy half LIFE for C2 is 7.538e+04 years      $ Th-230          "
DECAy half LIFE for C3 is 1.620e+03 years      $ Ra-226          "
```

```
DECAy half LIFE for C4 is 1.047e-02 years              $ Rn-222            "
/
REGEnerate  C2 from C    3.257E+00          $  C2/C
REGEnerate  C3 from C2   4.653E+01          $  C3/C2
REGEnerate  C4 from C3   1.547E+05          $  C4/C3
/
PROPerty for C C2 C3 C4 is GEOM mean
MATRIX in Y direction in 3 sweeps using ADI
/
DIAGnostic node for C4 at ( 2, 32) every 100 steps
/
FLUX for C4 in 'run.flx' every 50 stps          $10K-yr Simulation
/
TIME = 0.
/
CONV C4 REFE GLOBal resid = 1.0e-04,  max_iter 10,  min_iter 2,   F_threshold = 1.e-5
/////////////
DISAble FLOW
////////////
/SOLV  C C2 C3 C4 10125 yrs, init 1.e-5, inc 1.005, max 10.0             $10K-yr Simulation
SOLV  C C2 C3 C4 1125 yrs, init 1.e-5, inc 1.005, max 10.0               $1K-yr Simulation
OUTPut C C2 C3 C4 DIFF NOW
/
/SAVE  C C4  in 'run.arc'
END
```

APPENDIX E – ADDITIONAL INFORMATION ON LIMITS CALCULATIONS

For diagnostic purposes and for comparison to previous limits, Table E-1 provides a more detailed presentation of limits calculated for each radionuclide parent including:

- groundwater pathway limit computed for each inventory modeled in PORFLOW
- previous IL vault limits and limiting pathway from Cook (2002b)
- groundwater pathway results for the 1,000 to 10,000 year time period

If a limit is not given for a nuclide and pathway (blank entry), that combination was previously screened (e.g. Cook 2004).

Table E-1. Pathway limits, previous limits, and inventory on 7/2/04 for the IL vaults (+++ denotes screened or >1.e+20; blank entry denotes nuclide screened from corresponding pathway analysis).

nuclide	resident (Ci)	air (Ci)	radon (Ci)	GW1 (Ci)	GW2 (Ci)	GW3 (Ci)	path	limit (Ci)	prev path	prev limit (Ci)	model (Ci)	inventory (Ci)
Ac-227	1.2E+07						resident	1.2E+07				
Ac-228								+++				1.8E-05
Ag-108m	3.9E+04						resident	3.9E+04				
Ag-110m								+++				3.0E-09
Al-26	6.6E+02						resident	6.6E+02				
Am-241				+++	7.6E+09	1.1E+05					0.5	
:	4.1E+10			+++	7.6E+09	1.1E+05	GW2	7.6E+09	resident	3.0E+04		3.5E-01
Am-242m	5.7E+06						resident	5.7E+06	resident	2.7E+07		3.2E-04
Am-243				+++	+++	1.4E+04					0.0005	
:				+++	+++	1.4E+04					0.005	
:				+++	+++	1.4E+04					0.05	
:				+++	+++	3.2E+04					0.5	
:	4.4E+07			+++	+++	1.4E+04	resident	4.4E+07	resident	1.9E+01		4.3E-04
Ba-133	1.7E+09						resident	1.7E+09				
Ba-137m								+++				1.5E+02
Bi-207	4.3E+04						resident	4.3E+04				
Bi-210				+++	+++	+++					0.5	
:				+++	+++	+++		+++				6.1E-07
Bi-211								+++				3.2E-07
Bi-212								+++				1.3E-04
Bi-214								+++				7.7E-01
Bk-249	8.1E+08						resident	8.1E+08				
C-14				+++	9.1E+07	1.7E+04					0.5	
:	+++	4.2E+00		+++	9.1E+07	1.7E+04	air	4.2E+00	air	2.7E+00		3.6E-01
C-14_KB				+++	2.6E+06	6.7E+02					0.5	
:		4.2E+00		+++	2.6E+06	6.7E+02	air	4.2E+00				6.1E-02
Ca-41	+++							+++				
Cd-113m	+++							+++				
Ce-144								+++				4.2E-01
Cf-249				+++	1.9E+11	2.0E+05					0.0005	
:				+++	1.9E+11	2.0E+05					0.005	
:				+++	1.9E+11	2.0E+05					0.05	
:				+++	1.9E+11	2.0E+05					0.5	
:	2.1E+06			+++	1.9E+11	2.0E+05	resident	2.1E+06	resident	8.9E+02		5.6E-07
Cf-250	2.1E+18						resident	2.1E+18				
Cf-251	3.7E+08						resident	3.7E+08	resident	2.7E+04		1.7E-06
Cf-252				+++	+++	4.6E+12					0.0005	
:				+++	+++	4.6E+12					0.005	
:				+++	+++	4.6E+12					0.05	

nuclide	resident (Ci)	air (Ci)	radon (Ci)	GW1 (Ci)	GW2 (Ci)	GW3 (Ci)	path	limit (Ci)	prev path	prev limit (Ci)	model (Ci)	inventory (Ci)
:				+++	+++	1.1E+13					0.5	
:	6.3E+14			+++	+++	4.6E+12	resident	6.3E+14	resident	1.0E+10		
Cl-36	+++							+++				
Cm-242				+++	+++	1.5E+15					0.0005	
:				+++	+++	1.5E+15					0.005	
:				+++	+++	1.5E+15					0.05	
:				+++	+++	1.5E+15					0.5	
:				+++	+++	1.5E+15					5	
:	5.5E+11			+++	+++	1.5E+15	resident	5.5E+11				1.4E-05
Cm-243	9.7E+08						resident	9.7E+08				7.1E-03
Cm-244				+++	+++	4.9E+05					0.0005	
:				+++	+++	4.9E+05					0.005	
:				+++	+++	6.3E+05					0.05	
:				+++	+++	6.3E+06					0.5	
:	2.5E+17			+++	+++	4.9E+05	resident	2.5E+17	resident	4.6E+07		5.9E-01
Cm-245				+++	4.8E+09	8.3E+03					0.0005	
:				+++	4.8E+09	8.3E+03					0.005	
:				+++	4.8E+09	8.3E+03					0.05	
:				+++	4.8E+09	8.3E+03					0.5	
:	8.2E+09			+++	4.8E+09	8.3E+03	GW2	4.8E+09	resident	3.8E+01		7.0E-06
Cm-246				+++	+++	+++					0.5	
:	5.7E+15			+++	+++	+++	resident	5.7E+15	resident	2.4E+05		8.5E-06
Cm-247				+++	6.8E+18	1.5E+05					0.0005	
:				+++	6.8E+18	1.5E+05					0.005	
:				+++	6.8E+18	1.5E+05					0.05	
:				+++	6.8E+18	1.5E+05					0.5	
:	1.4E+06			+++	6.8E+18	1.5E+05	resident	1.4E+06	resident	3.4E+00		2.0E-10
Cm-248				+++	+++	3.5E+07					0.0005	
:				+++	+++	3.5E+07					0.005	
:				+++	+++	3.5E+07					0.05	
:				+++	+++	8.7E+07					0.5	
:	4.6E+09			+++	+++	3.5E+07	resident	4.6E+09	resident	8.1E+02		3.1E-15
Co-57								+++				5.1E-05
Co-58								+++				2.3E+00
Co-60	8.0E+08						resident	8.0E+08	resident	6.3E+08		7.5E+01
Cr-51								+++				8.4E-03
Cs-134								+++				7.7E-01
Cs-135				+++	+++	4.6E+01					0.5	
:	+++			+++	+++	4.6E+01		+++	GW	1.2E+02		
Cs-137	8.3E+05						resident	8.3E+05	resident	6.5E+05		2.2E+02
Eu-152	8.9E+05						resident	8.9E+05				4.1E-05
Eu-154	1.6E+07						resident	1.6E+07	resident	1.1E+07		1.8E-01

nuclide	resident (Ci)	air (Ci)	radon (Ci)	GW1 (Ci)	GW2 (Ci)	GW3 (Ci)	path	limit (Ci)	prev path	prev limit (Ci)	model (Ci)	inventory (Ci)
Eu-155	1.6E+18						resident	1.6E+18				1.2E-02
Fe-55								+++				8.4E+01
Fe-59								+++				1.6E-02
H-3				5.3E+09	5.5E+09	+++					0.5	
:	+++	1.3E+09		5.3E+09	5.5E+09	+++	air	1.3E+09	air	5.5E+07		5.3E+05
Hf-175								+++				1.9E-05
Hf-181								+++				6.1E-03
I-129				4.3E+10	4.6E-04	3.5E+01					0.5	
:	+++			4.3E+10	4.6E-04	3.5E+01	GW2	4.6E-04	GW	5.2E-04		5.1E-05
I-129_ETF-Carbon				1.2E+13	9.7E-02	1.0E-01					0.5	
:				1.2E+13	9.7E-02	1.0E-01	GW2	9.7E-02	GW	1.4E-01		2.0E-03
I-129_KB				+++	6.2E+03	1.2E+00					0.5	
:				+++	6.2E+03	1.2E+00	GW2	6.2E+03				6.0E-06
In-113m								+++				5.0E-06
K-40				2.3E+19	2.0E-01	2.3E+01					0.5	
:	1.5E+04			2.3E+19	2.0E-01	2.3E+01	GW2	2.0E-01				7.8E-07
Kr-85	3.8E+10						resident	3.8E+10				2.0E+01
Mn-54								+++				4.2E-01
Mo-93	+++							+++				
Na-22	1.1E+15						resident	1.1E+15				
Nb-93m	+++							+++				2.7E-03
Nb-94				+++	+++	1.5E+02					0.5	
:	1.3E+04			+++	+++	1.5E+02	resident	1.3E+04				1.1E-03
Nb-95								+++				2.5E-02
Nb-95m				+++	+++	+++					0.5	
:				+++	+++	+++		+++				9.6E-05
Ni-59				+++	+++	1.6E+02					0.5	
:	+++			+++	+++	1.6E+02		+++	GW	3.0E+02		5.4E-02
Ni-63	+++							+++				1.2E+01
Np-237				+++	1.5E+06	2.3E+01					0.5	
:	6.4E+06			+++	1.5E+06	2.3E+01	GW2	1.5E+06	resident	6.0E+00		1.9E-03
Pa-231	5.1E+05						resident	5.1E+05				
Pa-234								+++				1.3E-01
Pa-234m								+++				1.8E-01
Pb-210	5.5E+10						resident	5.5E+10				7.7E-01
Pb-212								+++				1.3E-04
Pb-214								+++				7.7E-01
Pd-107	+++							+++				
Pm-147								+++				2.8E+00
Po-210								+++				6.1E-07

nuclide	resident (Ci)	air (Ci)	radon (Ci)	GW1 (Ci)	GW2 (Ci)	GW3 (Ci)	path	limit (Ci)	prev path	prev limit (Ci)	model (Ci)	inventory (Ci)
Po-212								+++				5.3E-07
Po-214								+++				7.7E-01
Po-216								+++				1.3E-04
Po-218								+++				7.7E-01
Pr-144								+++				3.3E-01
Pr-144m								+++				3.1E-03
Pu-238				+++	+++	7.5E+12					0.0005	
:				+++	+++	7.5E+12					0.005	
:				+++	+++	7.5E+12					0.05	
:				+++	+++	7.5E+12					0.5	
:				+++	+++	7.5E+12					5	
:	2.8E+09		4.2E+06	+++	+++	7.5E+12	radon	4.2E+06	GW	2.2E+10		1.3E+00
Pu-239				+++	+++	6.3E+02					0.0005	
:				+++	+++	6.3E+02					0.005	
:				+++	+++	3.3E+03					0.05	
:				+++	+++	3.3E+04					0.5	
:	3.3E+13			+++	+++	6.3E+02	resident	3.3E+13	resident	2.9E+04		3.6E-01
Pu-240				+++	+++	1.4E+03					0.0005	
:				+++	+++	1.4E+03					0.005	
:				+++	+++	1.7E+03					0.05	
:				+++	+++	1.7E+04					0.5	
:	6.4E+14			+++	+++	1.4E+03	resident	6.4E+14	resident	1.3E+05		4.5E-02
Pu-241				+++	2.3E+11	3.5E+06					0.5	
:	1.2E+12			+++	2.3E+11	3.5E+06	GW2	2.3E+11	resident	8.9E+05		1.5E+00
Pu-242				+++	+++	4.9E+02					0.0005	
:				+++	+++	4.2E+03					0.005	
:				+++	+++	4.2E+04					0.05	
:				+++	+++	4.2E+05					0.5	
:	5.0E+12			+++	+++	4.9E+02	resident	5.0E+12	resident	5.2E+04		3.0E-03
Pu-244				+++	+++	9.2E+04					0.0005	
:				+++	+++	9.0E+05					0.005	
:				+++	+++	7.2E+06					0.05	
:				+++	+++	4.6E+07					0.5	
:	3.7E+04			+++	+++	9.2E+04	resident	3.7E+04	resident	3.1E+00		1.2E-02
Ra-224								+++				1.3E-04
Ra-226				+++	+++	9.6E+01					0.5	
:	1.4E+03		2.6E+00	+++	+++	9.6E+01	radon	2.6E+00				7.7E-01
Ra-228	5.2E+07						resident	5.2E+07				1.8E-05
Rb-87	+++							+++				
Rh-103m								+++				6.9E-05
Rh-106								+++				4.1E-02
Rn-220								+++				1.3E-04

nuclide	resident (Ci)	air (Ci)	radon (Ci)	GW1 (Ci)	GW2 (Ci)	GW3 (Ci)	path	limit (Ci)	prev path	prev limit (Ci)	model (Ci)	inventory (Ci)
Rn-222								+++				7.7E-01
Ru-103								+++				6.9E-05
Ru-106								+++				1.1E-01
Sb-125	2.0E+16						resident	2.0E+16				1.0E-01
Se-79				+++	1.2E+06	3.3E+00					0.5	
:	+++			+++	1.2E+06	3.3E+00	GW2	1.2E+06	GW	2.9E+01		1.0E-04
Sm-151	+++							+++				
Sn-113								+++				5.0E-06
Sn-121m	+++							+++				
Sn-126				+++	+++	7.3E+01					0.5	
:	2.1E+04			+++	+++	7.3E+01	resident	2.1E+04	resident	7.5E-01		4.9E-04
Sr-90				+++	6.1E+11	1.8E+12					0.5	
:	+++			+++	6.1E+11	1.8E+12	GW2	6.1E+11	GW	1.8E+10		2.1E+01
Ta-182								+++				3.4E-05
Tc-99				4.0E+19	1.3E+02	1.9E+01					0.5	
:	7.7E+17			4.0E+19	1.3E+02	1.9E+01	GW2	1.3E+02	GW	2.5E+01		6.1E-02
Tc-99_KB				+++	2.4E+04	1.3E+02					0.5	
:	7.7E+17			+++	2.4E+04	1.3E+02	GW2	2.4E+04				2.0E-02
Te-125m								+++				3.0E-03
Th-228				+++	+++	+++					0.5	
:	2.6E+18			+++	+++	+++	resident	2.6E+18				1.3E-04
Th-229	5.3E+04						resident	5.3E+04				
Th-230				+++	+++	8.8E+01					0.5	
:	3.9E+03		6.8E+00	+++	+++	8.8E+01	radon	6.8E+00				1.8E-05
Th-231								+++				1.9E-03
Th-232				+++	+++	+++					0.5	
:	4.4E+02			+++	+++	+++	resident	4.4E+02	resident	4.1E-01		4.9E-05
Th-234								+++				3.1E-01
Tl-208								+++				1.2E-07
U-232				+++	+++	+++					0.0005	
:				+++	+++	+++					0.005	
:				+++	+++	+++					0.05	
:				+++	+++	+++					0.5	
:	1.3E+03			+++	+++	+++	resident	1.3E+03	resident	9.4E+02		1.1E-04
U-233				+++	+++	1.7E+09					0.0005	
:				+++	+++	1.7E+09					0.005	
:				+++	+++	1.7E+09					0.05	
:				+++	+++	1.7E+09					0.5	
:	5.8E+05			+++	+++	1.7E+09	resident	5.8E+05	resident	7.0E+00		1.1E-02
U-233D				+++	+++	1.7E+09					0.0005	
:				+++	+++	1.7E+09					0.005	
:				+++	+++	1.7E+09					0.05	

nuclide	resident (Ci)	air (Ci)	radon (Ci)	GW1 (Ci)	GW2 (Ci)	GW3 (Ci)	path	limit (Ci)	prev path	prev limit (Ci)	model (Ci)	inventory (Ci)
:				+++	+++	1.7E+09					0.5	
:	5.8E+05			+++	+++	1.7E+09	resident	5.8E+05				1.1E-01
U-234				+++	+++	8.5E+03					0.0005	
:				+++	+++	8.5E+03					0.005	
:				+++	+++	8.5E+03					0.05	
:				+++	+++	8.5E+03					0.5	
:	7.9E+05		1.2E+03	+++	+++	8.5E+03	radon	1.2E+03	radon	1.5E+01		2.4E-01
U-235				+++	+++	4.7E+05					0.0005	
:				+++	+++	5.6E+05					0.005	
:				+++	+++	4.2E+06					0.05	
:				+++	+++	1.2E+07					0.5	
:	2.4E+07			+++	+++	4.7E+05	resident	2.4E+07	resident	6.0E+00		2.4E-03
U-235D				+++	+++	4.7E+05					0.0005	
:				+++	+++	5.6E+05					0.005	
:				+++	+++	4.2E+06					0.05	
:				+++	+++	1.2E+07					0.5	
:	2.4E+07			+++	+++	4.7E+05	resident	2.4E+07				6.1E-03
U-236				+++	+++	2.8E+09					0.0005	
:				+++	+++	2.8E+09					0.005	
:				+++	+++	2.8E+09					0.05	
:				+++	+++	1.1E+10					0.5	
:	9.1E+09			+++	+++	2.8E+09	resident	9.1E+09	resident	3.1E+04		1.7E-03
U-238				+++	+++	2.0E+08					0.0005	
:				+++	+++	1.5E+09					0.005	
:				+++	+++	1.5E+10					0.05	
:				+++	+++	1.2E+11					0.5	
:	7.7E+05		1.1E+06	+++	+++	2.0E+08	resident	7.7E+05	resident	4.9E+01		5.8E-01
W-188	+++							+++				
Y-90								+++				1.6E+01
Zn-65								+++				3.6E-01
Zr-93				+++	+++	5.7E+08					0.5	
:	+++			+++	+++	5.7E+08		+++	GW	9.8E+05		6.4E-06
Zr-95				+++	+++	+++					0.5	
:				+++	+++	+++		+++				1.1E-02

APPENDIX F – DESIGN CHECKING

Design checking of the IL vault Special Analysis was performed by the following technical professionals

- S. Aleman groundwater analysis
- L. Koffman intruder analysis
- T. Hang radon analysis
- E. Wilhite air analysis and overal analysis

Design checking instructions, comments and resolutions are provided below

Design checking instructions for the groundwater, intruder, air and overall analyses

Design Check Instructions for IL Vault Special Analysis (WSRC-TR-2004-00346)

Requirements for performing reviews of technical reports are defined in Procedure Manual E-7, 2.40, "Design Verification and Checking", and the complementary manual WSRC-IM-2002-00011 Rev. 1 "Technical Report Design Check Guidelines" provides additional guidance. General lines of inquiry are defined in Table 1 of the latter. The purpose of these instructions is to define specific lines of inquiry appropriate for the IL Vault Special Analysis. The specific instructions given below are intended to supplement the general lines of inquiry, rather than constrain the scope of design checking.

Groundwater Analysis

Following a general inspection of the groundwater pathway analysis and associated PORFLOW input and output files, the following specific checks are requested. A spot check of one radionuclide and inventory will typically be a sufficient check that pre- and post-processing algorithms/software are working correctly.

<u>general transport</u>

- verify that each Kd value and solubility limit from Table A-1 used in PORFLOW runs can be traced to the PA or a superceding approved document
- verify that each concentration limit from Table A-1 used in the groundwater pathway analysis is correct based on published values for MCLs and 25 mrem/yr concentration values
- verify that first-order transformation parameters have been correctly defined in PORFLOW input files (DECAy and REGEneration keywords)

<u>vadose zone flow</u>

- verify that the infiltration transient proposed by Phifer (2004b) has been appropriately implemented in the flow model
- verify that other aspects of the VZ conceptual model have been preserved with respect to the PA

<u>vadose zone transport</u>

- verify that the initial inventory is correct for the 2D slice being modeled
- verify that solubility limits for U and Pu isotopes have been adequately implemented in the waste zone in PORFLOW input files

<u>aquifer flow</u>

- verify that the volumetric flowrate (FC) and saturation (S) fields computed for the refined zoom-in grid are consistent with those from the GSA_PORFLOW flow model

aquifer transport

- verify that the contaminant flux transient assigned to aquifer source nodes has been correctly computed from vadose zone simulation output
- verify that the aquifer source nodes have been correctly defined
- verify that nodes representing a potential 100 meter well have been adequately identified
- verify that peak sum-of-fraction and limits post-processing steps have been correctly performed

Intruder Analysis

Nearly all of the intruder analysis calculations were performed within a recently developed software tool, which has been design checked (Koffman 2004). The present design check should focus on verifying that inputs to the automated intruder analysis tool are appropriate, and that software results have been transferred to technical report tables (e.g. Tables 3-1 and 6-1) without error. Specific inputs that should be checked include

- the volume of the disposal unit
- the geometry factor for the Resident scenario
- the thickness of the soil/cover layers overlying the disposal unit (Phifer 2004a)

The basis for these inputs is described in Appendix B of the report.

Air Analysis

The primary change to the air analysis with respect to the PA is use of updated dose factors, reflecting average meteorological conditions for the period 1997-2001 measured near H-Area. The PA calculation method was retained for the Special Analysis. The design check should focus on verifying that

- the revised dose factors have been correctly calculated, and transcribed to report Table 4-1
- the air limit calculation summarized in Table 4-1 uses the method and other inputs described in the PA
- limits from the air analysis have been correctly transferred to Table 6-1.

Radon Analysis

Provided in separate document.

Overall Analysis and Technical Report

A high-level review of the overall analysis and technical report should be conducted to ensure that

- the conceptual approach is acceptable
- critical assumptions have been adequately justified and/or referenced
- the proposed limits address all nuclides for which limits are needed
- report text, tables, and appendices are consistent
- adequate background and introductory discussion is provided
- conclusions and recommendations are supported by preceding report discussion

Design checking comments and resolution for groundwater analysis

Document Review Comments — Page 1 of 3

Document No. WSRC-TR-2004-00346 | Rev. 0 | Title: Special Analysis: Revision of Intermediate Level Vault Disposal Limits (U) | Comments Due: 07/13/2004

#	Section/Page/ Paragraph/Line	Comment	Reviewer Initial	Response/Resolution	Reviewer Concur
1	Page v	Incorporate and highlight more of the major changes from the PA in the Executive Summary. For example, mesh refinement and new Pu chemistry.		Executive Summary now explicitly mentions aquifer mesh refinement and the new Pu chemistry in addition to other notable revisions	
2	S1.0/Page 1/P1	Provide reference for Special Analyses.		sentence modified to read "and subsequent Special Analyses cited below" to emphasize that SAs are cited in bullet list below	
3	S2.0/Page 3	In future SA and PA's, I would seriously investigate the possibility of performing a single vadose/aquifer flow and transport simulation for each radionuclide of interest. This would reduce the time to perform a design check by half and eliminate the current handshaking between vadose zone contaminant flux and aquifer source node placement.		added recommendation that this concept be considered in upcoming PA revision	
4	S2.1/Page 3/P3	Due to the close proximity of the low permeability IL vault roof to the ground surface, the one-dimensional infiltration analysis generated by HELP is in question. In this situation, a coupling of the surface water with the groundwater vadose zone is needed. A program like MODFLOW HMS (Huyakorn) is a possible candidate for quantifying the infiltration through the geo synthetic cover over the IL vault.		added recommendation that infiltration analysis be revised in upcoming PA revision to account for the impact of the low permeability IL vault on infiltration and flow through adjacent soil column	
5	Fig 2-1/Page 5	In the legend, should Over ILV and Over Soil units be in cm/yr?		yes, change made	
6	S2.2/Page 7	Please explain, quantify or reference how the sum-of-fractions approach is conservative in respect to establishing radionuclide inventory limits? Is this approach unique to SRS?		added references to EPA and NRC use of the sum-of-fractions approach to show consistency with "industry standard"	
7	S2.2/Page 8/P4	Per Comment 6, please quantify conservative claim with respect to disposal limits based on 1/SOF.		see response to comment #6	
8	S3.0/Page 13	Inadvertent Intruder Analysis not reviewed as part of this design check.		(performed by L. Koffman)	
9	S4.0/Page 17	Air Analysis not reviewed as part of this design check.		(performed by E. Wilhite)	
10	S5.0/Page 19	Radon Analysis not reviewed as part of this design check.		(performed by T. Hang)	

Document Review Comments — Page 2 of 3

Document No. WSRC-TR-2004-00346 | Rev. 0 | Title: Special Analysis: Revision of Intermediate Level Vault Disposal Limits (U) | Comments Due: 07/13/2004

#	Section/Page/ Paragraph/Line	Comment	Reviewer Initial	Response/Resolution	Reviewer Concur
11	S7.0/Page 27	I recommend coupling of the vadose and aquifer flow and transport groundwater simulations. My concerns about the HELP analysis are in agreement with yours and are addressed in comment 4. The timed sum-of-fractions approach using decoupled radionuclide decay chains needs to be shown to provide conservative disposal limits.		recommendation added; see response to comment #6	
12	Page A-4	The implementation of the new Pu chemistry in PORFLOW should be done on a consistent basis across all scenarios addressed in the PA and SA for the GW pathways. For example, for radioactive decay chains that contain Pu and U isotopes use moles instead of activity as the initial inventory for the parent.		recommendation added to use of mole basis rather than activity basis for all nuclides, or at least Pu isotopes, in upcoming PA revision	
13	Page A-9	The implementation of solubility limits for Pu and U isotopes should be through the solubility-limit source for a chemical species.		recommendation added to use solubility limited source PORFLOW option for solubility limited parents in upcoming PA revision	
14	Table A-2/Page A-11	Table A-2 should include the maximum fractional contaminant flux to the water table and the peak time. Maybe replace the element and node numbers.		table containing the peak water table flux added	
15	Table A-2/Page A-11	For each isotope, the end time shown in the last time interval of interest should reflect the actual end time used in the PORFLOW simulation. For example, for I-129 the end time in the final interval is stated as 10000, but the PORFLOW simulation was ended at 1075. Please provide an explanation for early termination of the PORFLOW run prior to 10000 for all isotopes which fall in this category.		changes made as suggested	
16	Fig A-8 to A-94	Replace legend with isotope name or update figure caption to include the whole radioactive decay chain shown in the figures.		explanation added to the effect that a key is provided for up to 6 species, but only the number present in the chain are used in the groundwater concentration plots	

Document Review Comments						Page 3 of 3
Document No. WSRC-TR-2004-00346	Rev. 0	Title: Special Analysis: Revision of Intermediate Level Vault Disposal Limits (U)				Comments Due: 07/13/2004
#	Section/Page/ Paragraph/Line	Comment	Reviewer Initial	Response/Resolution		Reviewer Concur
Reviewer Name	Sebastian Aleman / SEA Print Name / Initials	Signature		Phone / Location: 5-8040 / 773-42A	Date 13-July-04	
Concurrence Signature QA Reviewer	___/___/___ Signature / Print Name / Dept.			Phone / Location:	Date	

Design checking comments and resolution for intruder analysis

Larry Koffman/WSRC/Srs
07/12/2004 03:54 PM

To Gregory Flach/WSRC/Srs@srs
cc
bcc
Subject Design Check of ILV Intruder Analysis

I have completed a design check of the ILV Intruder Analysis contained in your report WSRC-TR-2004-00346_rev0_draftB.pdf sent on 7/7/04. I reviewed Section 3.0 (pp 13-16), Section 6.0 (pp 21-25), and Appendix B (pp B-1 to B-11).

I have one required change: the units for Concentration Limit in Table 3-1 should be microCuries/m3, not Curies/m3. This correction needs to be made in the header on pages 14, 15, and 16. The units for Inventory Limit are correct.

I found one typo: the first line of Appendix B has "primary", which should be "primarily".

I have one suggestion that is not required. In Section 3.1 in the middle of page 13 at the end of the third paragraph, the sentence ends as "and then relies on the computer model to perform pathways calculations at a time increment of 10 years." The time increment is a user input and is not fixed, so I suggest that you end with "calculations at a specified time increment that is nominally 10 years."

In reviewing Appendix B, I checked that your calculation of geometry factor is correct, that the revised volume is consistent with the description in the PA, and that the thickness of the soil/cover layers is consistent with Phifer's document.

I checked that Table 3.1 has the correct values for the given inputs and that Table B-1 is the corresponding detailed table. I also checked that the resident limit column in Table 6-1 has the same values as Table 3.1 when rounded to one decimal place.

Design checking comments and resolution for air analysis

Elmer Wilhite/WSRC/Srs
07/13/2004 04:36 PM

To Gregory Flach/WSRC/Srs@srs
cc Tom Butcher/WSRC/Srs@Srs, Ed Stevens/WSRC/Srs@Srs, Jim Cook/WSRC/Srs@srs
bcc
Subject ILV SA Design Check for Air Pathway

Greg:

I've completed the design check for the air pathway. I confirmed that you had extracted the correct numbers from the EAV PA for the dose limit and the release fractions for tritium and C-14. I also confirmed that you had used the correct dose factors from Simpkins (2004).

Then, I confirmed that your calculations of the dose fractions and the inventory limits were correctly done.

Elmer

Design checking comments and resolution for overall analysis

Comments provided and resolved through hand-marked paper copies of report drafts.

Design checking instructions, comments and resolution for radon analysis

Round 1

Design Check Instructions for evaluation of Radon release from the Slit and Engineered Trenches

The following files are transmitted with these instructions:

Trench Radon Analysis.doc	Text writeup for Trench analysis
Radon Flux.xls	Calculation spreadsheets for analysis
runBOUNDPu238.out	Simulation output for bounding case, Pu238
runBOUNDRa226.out	Simulation output for bounding case, Ra226
runBOUNDTh230.out	Simulation output for bounding case, Th230
runBOUNDU234.out	Simulation output for bounding case, U234
runBOUNDU238.out	Simulation output for bounding case, U238
runTrench.dat	Typical run file for trench simulations

1. Check the input parameters identified in Table 2 of "Trench Radon Analysis.doc" for being reasonable, noting the units used in the model: meters, grams, and years.

A single value of 0.2 was used for porosity in this work. The previous PA (WSRC-RP_94-218, Rev. 1) used different porosity values for different materials, e.g., 0.42 for soil and waste, 0.51 for backfill, 0.38 for drainage, 0.18 for barrier. Some explanation is needed to justify the use of a single porosity.

Text will be added.

2. Examine the "half-life" worksheet in Excel Spreadsheet "RadonFlux.xls" to verify that the appropriate half-lives were used for each isotope that was simulated.

The half-life of 7.538E+04 yrs was used for Th-230 in this report compared to 7.70E+4 yrs given in the PA.

The 7.538E+04 value comes from the Nuclear Wallet Cards, BNL and is regarded as more accurate than other estimates.

3. Spot check the output files for each isotope to verify that the input parameters are correctly represented.

Input parameters are correctly used in the output files for each isotope (i.e., runBOUNDPu238.out, runBOUNDRa226.out, runBOUNDTh230.out, runBOUNDU234.out, runBOUNDU238.out).

OK

4. Examine the typical run file to verify that the logic of the simulation makes sense.

A typical run file (runTrench.dat) was examined. Overall the logic of the simulation makes sense. The following comments result from further examination of all input files for 'non-compaction of waste' case and the input file shown in the Appendix for the 'dynamic compaction of waste' case:

a. Since three nodes are specified in X direction, only two X coordinate values need be specified at cell faces as follows:

COORdinate X:
0.0 1.0

The presence of the additional coordinate does not make a difference in the simulated results, however any future simulations will be changed in accordance with the comment.

b. Rather than from 0 to 7.8m, Y coordinates values should range from 0 to 7.88m as shown in Table 1 and Figure 2 (i.e., compacted waste zone plus soil cover zone excluding topsoil and upper backfill).

The use of a slightly shorter stack was used to round off the numbers when the grid coordinates were generated. The small difference (8 cm or 3.1 inches) is a conservative change. Fluxes will be larger by a very small amount because of the difference in dimensions. The incremental increase in accuracy to be obtained by changing the grid dimensions is not regarded as sufficient justification to spend the time needed implement that change now.

c. For the 'non-compaction of waste' case, the waste zone thickness is 4.9m. Hence the specifications for material zones should be revised as follows:

MATErial type 1 from 1 1 to 3 24 $ WASTE
MATErial type 2 from 1 25 to 3 38 $ SOIL

The use of Y=22 instead of Y=24 to define the Waste Zone thickness in the Bounding Case (no compaction of waste material) makes a small, less conservative, difference for the Bounding Case. Precise adherence to the thickness of the compacted soil thickness is not absolutely necessary since it only impacts how conservative the conservative Bounding Case is. However, since the changes are fairly easy to make, I've made them, recalculated the fluxes and the associated limits and incorporated them into the appropriate tables.

5. Check the Rn-222 instantaneous flux from the output file for each parent isotope and compare to value in the "Trench and ILV" worksheet in the file "Radon Flux.xls" to verify that the correct numbers were utilized in calculating the disposal limits for each of the 4 configuration scenarios. (1000-year case) – actually 1125 years simulated. Note, the flux numbers used in the <u>Bounding</u> case calculations are found in column L for the 1125-year simulations.

Output files (i.e., runBOUNDPu238.out, runBOUNDRa226.out, runBOUNDTh230.out, runBOUNDU234.out, runBOUNDU238.out) for the non-compacted case were examined and the following instantaneous flux values at 1125 yrs are obtained:

Parent Isotope	Instantaneous Rn-222 Flux at Land Surface @ 1125 yrs (Ci/m^2-yr)
Pu-238	4.811168E-6
U-238	1.83563E-5

U-234	1.65922E-2
Th-230	2.961
Ra-226	4.81993

These values are correctly used in cells L21 to L25 in the 'Trench and ILV Flux' worksheet of the file 'Radon Flux.xls' However, the purpose of this work is to determine the disposal limit for each isotope. Hence, rather than the flux at 1125 yrs, the peak flux values must be used. Since no flux files are provided for this design check, it is not clear if the instantaneous flux values at 1125 yrs are also peak values. Only instantaneous flux values for the non-compacted case (i.e., the bounding case) were checked, since no output files for the compacted case are available. It would be strongly recommended that the report include plots of instantaneous fluxes for each parent isotope for both compacted and non-compacted cases.

Agreed. The table shows only Ra-226 with a peak prior to 1125 years. The others peak at the 1125-year point but that is not apparent to the reader. The suggested changes have been incorporated.

Further examination of the 'Trench and ILV Flux' worksheet reveals that the conversion factor (i.e., 1E+12/ 31557600) used in columns G and M to convert 'Ci/m^2-yr' to 'pCi/m^2-s' is incorrect. The correct factor should be 1E+12/31536000. The value 31536000 that is the product of '365 x 24 x 3600' is to convert yr into s.

The value used represents the conversion from years to seconds assuming there are 365.25 days in a year, to account for leap years. I believe this to be more accurate for the purposes of this investigation.

6. Spot check calculations made in the Trench and ILV worksheet to determine the disposal unit limits for each of the 4 Scenarios.

The disposal areas per unit (m^2/disposal unit) are correctly calculated in cells O18, Q18, S18 and U18. The disposal limits for each of the four scenarios are also correctly determined from the instantaneous flux values in cells M21 to M25.

OK

7. Check the numbers in Tables 3 and 4 to be sure the numbers have been correctly transcribed from the "Trench and ILV" worksheet in the file "Radon Flux.xls".

The values shown in Tables 3 and 4 have been correctly transcribed from the 'Trench and ILV' worksheet. In Table 3, the values for Ra-226 have been revised to represent the peak flux that occurs at 64.3 days after source (see comments in item 5 above). The values for Ra-226 in Table 4 need be corrected accordingly.

It has been updated as were the other new values that resulted from re-definition of the Waste Zone from Y = 1 to 22 to Y = 1 to 24 (non-compacted BOUNDING case).

Round 2

Design Check Instructions for evaluation of Radon release from the ILV

The following files are transmitted with these instructions:

ILV Radon Analysis3.doc	Text writeup for Trench analysis
PeakFluxSummary.xls	Spreadsheets of results

1. **Read through the main text – ILV Radon Analysis3.doc, parts that have changed are indicated with blue text.**

The author is provided with a copy of the text that includes all marked suggested editorial changes for revision.

The comments provided have been incorporated in their entirety.

2. **Check the input parameters identified in Table 2 of "ILV Radon Analysis3.doc" to be sure they correspond correctly with values listed in the example input file located in the Appendix.**

Input parameters given in Table 2 have been correctly used in the PorFlow input file shown in the Appendix. In regard to the matrix density, the (solid) quartz was selected. Since the modeled matrix includes both solid and water (saturation), its density should combine both quartz and water density.

A test case was run to evaluate the impact of using a composite matrix density reflecting both the density of quartz and the density of water for the water filled volume. Both densities were incorporated using a weighting factor based on their respective volume percentages. The results were identical to the previous simulations that utilized a matrix density of quartz and therefore no action is required.

3. Compare the results in PeakFluxSummary.xls to be sure they've been correctly transcribed into ILV Radon Analysis3.doc from PeakFluxSummary.xls.

The results have been correctly transcribed from PeakFluxSummary.xls into the 'ILV Radon Analysis3.doc' report.

OK