SCREENING ARGUMENTS FOR RADIONUCLIDES NOT INCLUDED IN THE TPA VERSION 4.1 CODE

Methodology Used to Screen Radionuclides for the TPA Version 4.1 Code

In response to comments made by the external reviewers during the peer review of the TPA Version 3.2 Code (see Weldy, et al., 1999), formal screening arguments have been developed to explain why the set of radionuclides included in the code as the base set of radionuclides was selected. Several different considerations evolve in any effort to screen radionuclides completely from the total system performance assessment analysis. Radionuclides need to be screened not only for the base case, but also for possible disruptive events, such as volcanism or human intrusion. Additionally, due to the process of radioactive decay, radionuclides may become more important or less important throughout the time period of the analysis. Therefore, the screening analysis will be based on the following:

- Separate screening analyses will be performed for the groundwater transport scenario and the volcanism scenario because of the substantially different transport modes. The human intrusion scenario will be included in the groundwater transport scenario by not taking credit for retardation in the invert or the unsaturated zone for those radionuclides being screened.

- The earliest time considered in the analysis is 100 years, which is the estimated time of permanent closure. If there are any waste package failures prior to this time, the consequences will be assessed in the preclosure safety analysis, which is evaluated using a separate code from the TPA Code.

- For the groundwater scenario, biosphere dose conversion factors will be developed by the GENII code for all possible radionuclides. Radionuclides will only be screened if there is another radionuclide in the analysis for which the product of the biosphere dose conversion factor and the inventory of the radionuclide is greater than 100 times the radionuclide to be screened. Additionally, the radionuclide used for the screening must have a longer half-life than the screened radionuclide or not decay significantly in 10,000 years, have a lower retardation coefficient in the saturated zone than the screened radionuclide, and be more soluble than the screened radionuclide. For radionuclides not in the GENII library, the product of the inventory times the inhalation dose conversion factor, the inventory times the ingestion dose conversion factor, and the inventory times the external exposure dose conversion factor of the screened radionuclide must all be less than 1 percent of the corresponding value for the screening radionuclide.

- For the volcanism scenario, because transport to the receptor group location is independent of radionuclides, there are no solubility or retardation considerations in the screening analysis. Screening is performed based on the product of the dose conversion factor times the inventory (in Ci/MTU) at 100 years. If this product for a radionuclide is less than 1 percent of another radionuclide in the fuel for the inhalation, ingestion, and direct exposure pathways, the radionuclide may be screened from further analyses. Again, the radionuclide used for the screening must have a longer half-life than the screened radionuclide or not decay substantially in 10,000 years.

The following is a summary of the process used to identify the radionuclides that needed to be tracked in the TPA Version 4.1 Code.

First, the ORIGEN2 computer code (Oak Ridge National Laboratory, 1991) was used to calculate the inventory of all radionuclides for a medium enrichment (4.0 percent), high burnup pressurized water reactor fuel (70 GWd/MTU) at 100 years. Pressurized water reactor fuel was selected because it has a higher inventory of most radionuclides than boiling water reactor fuel and also has a higher range of burnups than boiling water reactor fuel. A high burnup fuel was selected to generate a large inventory of heavy actinides (Cm, Cf, Bk), to ensure that these radionuclides are not screened inappropriately by using a median burnup fuel, because these radionuclides increase in inventory significantly as burnup increases. The radionuclides used most often for comparison (Np-237, Am-241, and I-129) all increase approximately linearly with burnup. Therefore, the use of the high burnup will not excessively increase the inventory of these radionuclides. Note that the only radionuclides that significantly decrease with burnup are U-235 and its daughters, and a low burnup (10 GWd/MTU) was used for these radionuclides. A median enrichment fuel was used because inventory of most radionuclides is not a strong function of enrichment. The ORIGEN2 code outputs the inventories of about 1,000 radionuclides.

Immediately all radionuclides with an inventory of 0 Ci/MTU at 100 years were screened out. This eliminates approximately 850 radionuclides. Approximately 45 additional radionuclides have short half-lives (< 20 days), but have parents with longer half-lives and, as such, are still present in the fuel in 100 years. These radionuclides will be assumed to be in secular equilibrium with their parent radionuclides and will contribute to the dose from intakes of the parent radionuclides, but their transport does not need to be tracked separately in the TPA Code. These radionuclides are listed in Table I–1.

Table I–1. Radionuclides Not Tracked in the TPA Version 4.1 Code but Assumed to be in Secular Equilibrium with Their Parents for Dose Calculations

^{210}Bi	^{209}Pb	^{210}Po	^{219}Rn	^{206}Tl
^{211}Bi	^{211}Pb	^{211}Po	^{220}Rn	^{209}Tl
^{212}Bi	^{212}Pb	^{212}Po	^{222}Rn	^{208}Tl
^{213}Bi	^{214}Pb	^{213}Po	^{223}Ra	^{207}Tl
^{214}Bi	^{227}Th	^{214}Po	^{224}Ra	^{233}Pa
^{242}Am	^{231}Th	^{215}Po	^{225}Ra	^{234}Pa
^{225}Ac	^{234}Th	^{216}Po	^{221}Fr	^{234m}Pa
^{217}At	^{242}Cm	^{218}Po	^{223}Fr	^{239}Np
^{108}Ag	^{137m}Ba	^{126m}Sb	^{126}Sb	^{90}Y

At this point, about 105 radionuclides remained for consideration for inclusion in the code that could not be screened purely on a half-life argument. For these remaining radionuclides, screening arguments had to be developed for both the groundwater pathway and the direct release scenario.

For the direct release scenario, radionuclides will be released to the environment in the same relative concentrations as found in the fuel. The inhalation and ingestion dose conversion factors were taken from FGR 11 (Oak Ridge National Laboratory, 1988) and the direct exposure

dose conversion factors were taken from FGR 12 for a 15-cm [5.9-in.] layer of uniform contamination. Screening is performed based on the product of the dose conversion factor times the inventory (in Ci/MTU) at 100 years for the inhalation, ingestion, and direct exposure pathways. Note that radionuclides that build up significantly through time (greater than a factor of 5 increase in inventory) were considered separately to ensure that they were not inappropriately screened based on their 100-year inventory. For radionuclides that build up significantly, the peak inventory of the radionuclide in 10,000 years was used instead of the 100-year inventory to determine whether the radionuclide can be screened. The rationale for screening for radionuclides that were screened in this manner is contained in Table I–2.

After this screening step was completed, only the following radionuclides remained that could not be screened: Am-241, Pu-240, Sr-90, Pu-239, Am-243, Pu-242, Cm-245, Np-237, Sn-126, Nb-94, Th-229, Pu-238, Cs-137, and Cm-244. These radionuclides are already considered in the direct release calculations for the TPA Version 4.1 Code, so no further steps are necessary to justify that the set of radionuclides considered in the calculation is sufficient.

For the groundwater scenario, it is better and more efficient to use the GENII code (Napier, et al., 1988) to develop dose conversion factors from the groundwater concentration of radionuclides for all the radionuclides included in the GENII library. Of the radionuclides remaining to be screened, the following radionuclides are not included in the GENII library: Si-32, K-42, Nb-93m, Tc-98, Rh-102, Ag-108m, Ag-109m, La-138, Ce-142, Nd-144, Pm-146, Sm-146, Eu-150, Tm-171, Hf-182, Ir-192m, Pt-193, Ir-194, Pb-205, Bi-208, Bi-210m, Np-236, Pu-236, Np-240m, Bk-250, Cf-249, Cf-250, and Cf-251. The radionuclides in the GENII library will be screened by comparing the GENII dose conversion factor to other radionuclides. However, for the groundwater pathway, transport parameters are significant and must be considered. Two key transport parameters of radionuclides are the solubility of the radionuclide and the retardation of the radionuclide in the alluvium. A radionuclide can only be screened if the product of its GENII dose conversion factor and its inventory at 100 years is less than 1 percent of another radionuclide, and it is not more soluble or less retarded than the radionuclide against which it is compared (both minimum and mean retardation values). Therefore, I-129, which is essentially completely soluble in groundwater and essentially unretarded in the alluvium, can be used to screen any radionuclide with a much smaller inventory times GENII dose conversion factor product. Np-237, however, can only be used to screen radionuclides that are less or equally soluble and more or equally retarded than neptunium. Also, a screening radionuclide has to have a half-life longer than the half-life of the radionuclide being screened or a half-life that is long compared to 10,000 years (e.g., I-129 and Np-237) to ensure that radioactive decay does not inappropriately influence the results. The rationale for screening for radionuclides screened in this manner is contained in Table I–3.

For the radionuclides not in the GENII library, a methodology similar to that for the direct release pathway will be used for screening. Screening is performed based on the product of the dose conversion factor times the inventory (in Ci/MTU) at 100 years. If this product for a radionuclide is less than 1 percent of another radionuclide in the fuel for the ingestion and direct exposure pathways, it may be screened from further analyses. Note that the inhalation pathway was not considered in the screening because LaPlante and Poor (1997) demonstrate that the inhalation pathway is not significant (~1 percent or less of total dose) for any radionuclide considered in

Table I–2. Radionuclide Screening Arguments for the Volcanism Scenario			
Cm	246	Exclude	Dose conversion factor* inventory less than 1% of Am-243 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-243
U	234	Exclude	Dose conversion factor* inventory less than 1% of Am-243 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
U	238	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Tc	99	Exclude	Dose conversion factor* inventory less than 1% of Am-243 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
I	129	Exclude	Dose conversion factor* inventory less than 1% of Am-243 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
C	14	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Se	79	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion; Inventory corrected for half-life of 1.1×10^6 years
Cl	36	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Inhalation and Ingestion; Direct Exposure just exceeds 1% of Pu-239 after approximately 6,000 years due to decay of Pu-239; Peak risk from volcanism occurs before 6,000 years
Th	229	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Inhalation and Ingestion; Direct Exposure just exceeds 1% of Pu-239 after approximately 6,000 years due to decay of Pu-239; Peak risk from volcanism occurs before 6,000 years
Pa	231	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
Th	230	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
Ac	227	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
U	233	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
Pb	210	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years
Ra	226	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion out to 10,000 years.
U	237	Exclude	Dose conversion factor* inventory less than 1% of Pu-240 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Pu-240
Cm	247	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pu	244	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Np	236	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion

Table I–2. Radionuclide Screening Arguments for the Volcanism Scenario (continued)			
Pu	236	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
U	240	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pu	243	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Bi	210M	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Np	240M	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pb	205	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Cf	252	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Bk	250	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pu	241	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Am	242M	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Cm	243	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Ni	63	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Cd	113M	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Sm	151	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
U	236	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Eu	154	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Inhalation and Ingestion; dose conversion factor* inventory less than 10% of Am-241 for Direct Exposure; Dose from direct exposure from Am-241 is small fraction of total dose from Am-241 (<1% in Laplante and Poor, 1997); Half-life less than Am-241
U	232	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
U	235	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Inhalation and Ingestion; Direct Exposure is less than 1% of Am-243 for 10,000 years
Cs	135	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion

Table I–2. Radionuclide Screening Arguments for the Volcanism Scenario (continued)			
Zr	93	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Cf	249	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ni	59	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Cm	248	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Sn	121M	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Co	60	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Eu	152	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Cf	251	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
H	3	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Np	238	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Ho	166M	Exclude	Dose conversion factor* inventory less than 1% of Am-243 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-243
Ag	108M	Exclude	Dose conversion factor* inventory less than 1% of Am-241 for Direct Exposure, Inhalation, and Ingestion; Half-life less than Am-241
Cf	250	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Mo	93	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pd	107	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Eu	155	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ag	108	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ce	142	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Sm	147	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ca	41	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Sm	146	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion

Table I–2. Radionuclide Screening Arguments for the Volcanism Scenario (continued)			
Rb	87	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Tc	98	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pm	146	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Be	10	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Hf	182	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Eu	150	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ta	182	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Bi	208	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion.
P	32	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ir	192	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Si	32	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Sb	125	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pt	193	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Pm	147	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Te	125M	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ir	192M	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
K	40	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Cs	134	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
La	138	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Nd	144	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Fe	55	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion

Table I–2. Radionuclide Screening Arguments for the Volcanism Scenario (continued)			
Rh	102	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Re	187	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ir	194	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
K	42	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Tm	171	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Cd	109	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Ag	109M	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion
Kr	85	Exclude	Gas—will not settle on ground
Ar	39	Exclude	Gas—will not settle on ground
Kr	81	Exclude	Gas—will not settle on ground

Table I–3. Screening Rationale for Groundwater Release for Screened Radionuclides in the GENII Library			
Pa	231	Exclude	GENII dose conversion factor* inventory less than 1% of Np-237; Lower Solubility and Higher Retardation in saturated zone than Np-237; remains less than 1% of Np-237 out to 10,000 years
U	233	Exclude	GENII dose conversion factor* inventory less than 1% of Np-237; Lower Solubility and Higher Retardation in saturated zone than Np-237; remains less than 1% of Np-237 out to 10,000 years
U	237	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Cm	247	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Pu	244	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
U	240	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Pu	243	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Cf	252	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Am	242M	Exclude	GENII dose conversion factor* inventory less than 1% of Am-241; Same Solubility and Retardation in saturated zone as Am-241; Shorter half-life than Am-241
U	235	Exclude	GENII dose conversion factor* inventory less than 1% of Np-237; Lower Solubility and Higher Retardation in saturated zone than Np-237
Zr	93	Exclude	GENII dose conversion factor* inventory less than 1% of Np-237; Lower Solubility and Higher Retardation in saturated zone than Np-237
Cm	248	Exclude	GENII dose conversion factor* inventory less than 1% of Np-237; Lower Solubility and Higher Retardation in saturated zone than Np-237
Sn	121M	Exclude	GENII dose conversion factor* inventory less than 1% of Np-237; Lower Solubility and Higher Retardation in saturated zone than Np-237
H	3	Exclude	GENII dose conversion factor* inventory less than 1% of I-129; If released as a gas, extremely conservative calculation shows that dose from releasing entire contents of all juvenile failure waste packages is less than 10^{-6} rem and the dose from releasing the entire contents of all waste packages failing at 1,000 years is less than 10^{-27} rem
Mo	93	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Eu	155	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Sm	147	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Ca	41	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Rb	87	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Be	10	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Ta	182	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
P	32	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Ir	192	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Sb	125	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Pm	147	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Te	125M	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
K	40	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Cs	134	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Fe	55	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Re	187	Exclude	GENII dose conversion factor* inventory less than 1% of I-129
Cd	109	Exclude	GENII dose conversion factor* inventory less than 1% of I-129

that report. Since that report was released, biosphere modeling has not changed significantly other than the inclusion of buildup of radionuclides in soil, which does not significantly change the results. Also note that for U-234, the ratio of the (inventory*inhalation dose conversion factor) to the (inventory*ingestion dose conversion factor) is almost 500, but in LaPlante and Poor (1997), inhalation contributes less than 1 percent of total dose. No other radionuclide has a ratio much higher than U-234. Therefore, the inhalation pathway is not considered in the groundwater screening. The rationale for screening for nuclides screened in this manner is contained in Table I–4.

After this screening step was completed, only the following radionuclides remained that could not be screened: Ac-227, Am-241, Pu-240, Sr-90, Pu-239, Am-243, Pu-242, Cm-245, Cm-246, Np-237, U-234, Ni-63, Cd-113m, U-236, U-238, Sn-126, Tc-99, Nb-94, I-129, Cs-135, C-14, Cf-249, Ni-59, Se-79, Cf-251, Ho-166m, Ag-108m, Cl-36, Th-230, Pb-210, Ra-226, Th-229, H-3, and Pa-231. There are three additional noble gas radionuclides (Kr-85, Kr-81, and Ar-39) that will be evaluated separately.

Most of the remaining radionuclides are available in the TPA Version 4.1 Code if solubilities, gap fractions, and retardation factors are entered into the *tpa.inp* file. Therefore, the next step is to run the TPA Version 4.1 Code with these additional nonscreened available radionuclides turned on and determine whether they affect the calculated dose. To ensure the analysis is sufficient for both the base case and a human intrusion analysis, the code is run both during nominal unsaturated zone conditions and with the unsaturated zone neutralized. The effect of early waste package failure is included through the use of juvenile failures of the waste package (an average of approximately 30 waste packages per realization) and early failure of the drip shield. No process has been proposed that bypasses the saturated zone except for the igneous scenario discussed previously, so the modeling of the saturated zone is unchanged in this analysis. Additional solubility data for some of these additional elements are taken from the CRWMS M&O (2000) and additional data for the alluvium matrix R_d are taken from Triay, et al. (1997). Additionally, for some radionuclides, Sheppard and Thibault (1990) were consulted. Sheppard and Thibault (1990) present retardation coefficients for many elements in different soil types. If a new element was more strongly retarded than neptunium for all soil types presented (sandy, clay, loam, and organic), it was assumed that the alluvium matrix R_d for that radionuclide was at least equivalent to the alluvium matrix R_d for neptunium. Where data were not available for the additional radionuclides, it was assumed that the radionuclide was essentially infinitely soluble and unretarded in the saturated zone. Additionally, it was assumed that 6 percent of all new fission product and activation product radionuclides was present in the gap, which is the maximum gap fraction in the code for any nonvolatile radionuclide. Actinides were still assumed to be contained in the structure of the fuel. Finally, it was assumed there was no retardation in the invert for these additional radionuclides for which data are not available.

The results of the mean value of the probabilistic screening runs are presented in the following figures. Figure I–1 shows the dose history of radionuclides for the first 10,000 years assuming nominal performance of the unsaturated zone. Figure I–2 shows the dose history of radionuclides for 100,000 years assuming nominal performance of the unsaturated zone. Figure I–3 shows the results for 10,000 years with the unsaturated zone neutralized, and Figure I–4 shows the results for 100,000 years with the unsaturated zone neutralized.

Table I–4. Screening Rationale for Groundwater Release for Screened Radionuclides not in the GENII Library			
Np	236	Exclude	Dose conversion factor* inventory less than 1% of Np-237 for Direct Exposure, Inhalation, and Ingestion; Same Solubility and Retardation in saturated zone as Np-237
Pu	236	Exclude	Dose conversion factor* inventory less than 1% of Pu-239 for Direct Exposure, Inhalation, and Ingestion; Same Solubility and Retardation in saturated zone as Pu-239
Bi	210M	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Np	240M	Exclude	Dose conversion factor* inventory less than 1% of Np-237 for Direct Exposure, Inhalation, and Ingestion; Same Solubility and Retardation in saturated zone as Np-237
Pb	205	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Bk	250	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Nb	93M	Exclude	Dose conversion factor* inventory less than 1% of Np-237 for Inhalation and Ingestion; Lower Solubility and Higher Retardation in saturated zone than Np-237; Direct Exposure dose conversion factor less than 1% of Nb-94
Cf	250	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure and Ingestion
Ce	142	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Inhalation and Ingestion; External exposure is negligible because a curie of Ce-142 only emits 1.5e-3 photons/sec (from ORIGEN2 output file)
Tc	98	Exclude	Dose conversion factor* inventory less than 1% of Tc-99 for Inhalation and Ingestion; Dose conversion factor* Inventory for Direct Exposure is less than 10% of Tc-99; Direct Exposure pathway is a small component of total dose from Tc-99 (20.1 %)*
Sm	146	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Pm	146	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Hf	182	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Eu	150	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Bi	208	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion; dose conversion factor DE from Al-28 due to similar decay characteristics
Si	32	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Pt	193	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion

Table I–4. Screening Rationale for Groundwater Release for Screened Radionuclides not in the GENII Library (continued)			
Ir	192M	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
La	138	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Nd	144	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Rh	102	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Ir	194	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
K	42	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Tm	171	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
Ag	190m	Exclude	Dose conversion factor* inventory less than 1% of I-129 for Direct Exposure, Inhalation, and Ingestion
*LaPlante, P.A. and K. Poor. "Information and Analyses to Support Selection of Critical Groups and Reference Biospheres for Yucca Mountain Exposure Scenarios." CNWRA 97-009. San Antonio, Texas: CNWRA. 1997.			

If a radionuclide does not reach at least 0.1 percent of the peak dose in 10,000 years (the time period specified in 10 CFR Part 63) or 1 percent of the peak dose in 100,000 years, the radionuclide may be excluded. The low threshold associated with the 10,000-year analysis provides confidence that even if new information leads to the reevaluation of input parameters associated with the excluded radionuclides, the peak dose in 10,000 years is unlikely to be substantially underestimated. The higher threshold associated with the longer analysis period is reasonable because this analysis is not associated with specific numerical limits in 10 CFR Part 63 or 40 CFR Part 197 and is conducted to gain information on how the system behaves during a long time frame. Tables I–5 and I–6 show the radionuclides that remain after this screening step.

All these radionuclides are included in the set of radionuclides tracked in the TPA Version 4.1 Code. It is recommended that in addition to these radionuclides, the most significant heavily sorbed radionuclides still be tracked for sensitivity analyses that evaluate the effect of colloids or limited retardation in the unsaturated and saturated zones. The most significant radionuclides considering both initial inventory and half-life include Am-241, Pu-240, Pu-239, and Am-243.

For the remaining radionuclides (Cd-113m, Cf-249m, Cf-251, Ho-166m, and Tc-98), the TPA Version 4.1 Code must be run a second time to evaluate their effects. The remaining radionuclides will be modeled in the TPA Version 4.1 Code by making changes to the input and data files to allow the physical and radiological characteristics of these radionuclides to be represented in the TPA Version 4.1 Code. These radionuclides were conservatively assumed to be soluble, have 6 percent of their inventory in the gap, and be unretarded in the invert, unsaturated zone, and saturated zone. All components in the code were set at their nominal performance, except for the drip shield, which was assumed to fail early. The results of these two runs are presented in the Figures I–5 and I–6 (for 10,000- and 100,000-year calculational periods).

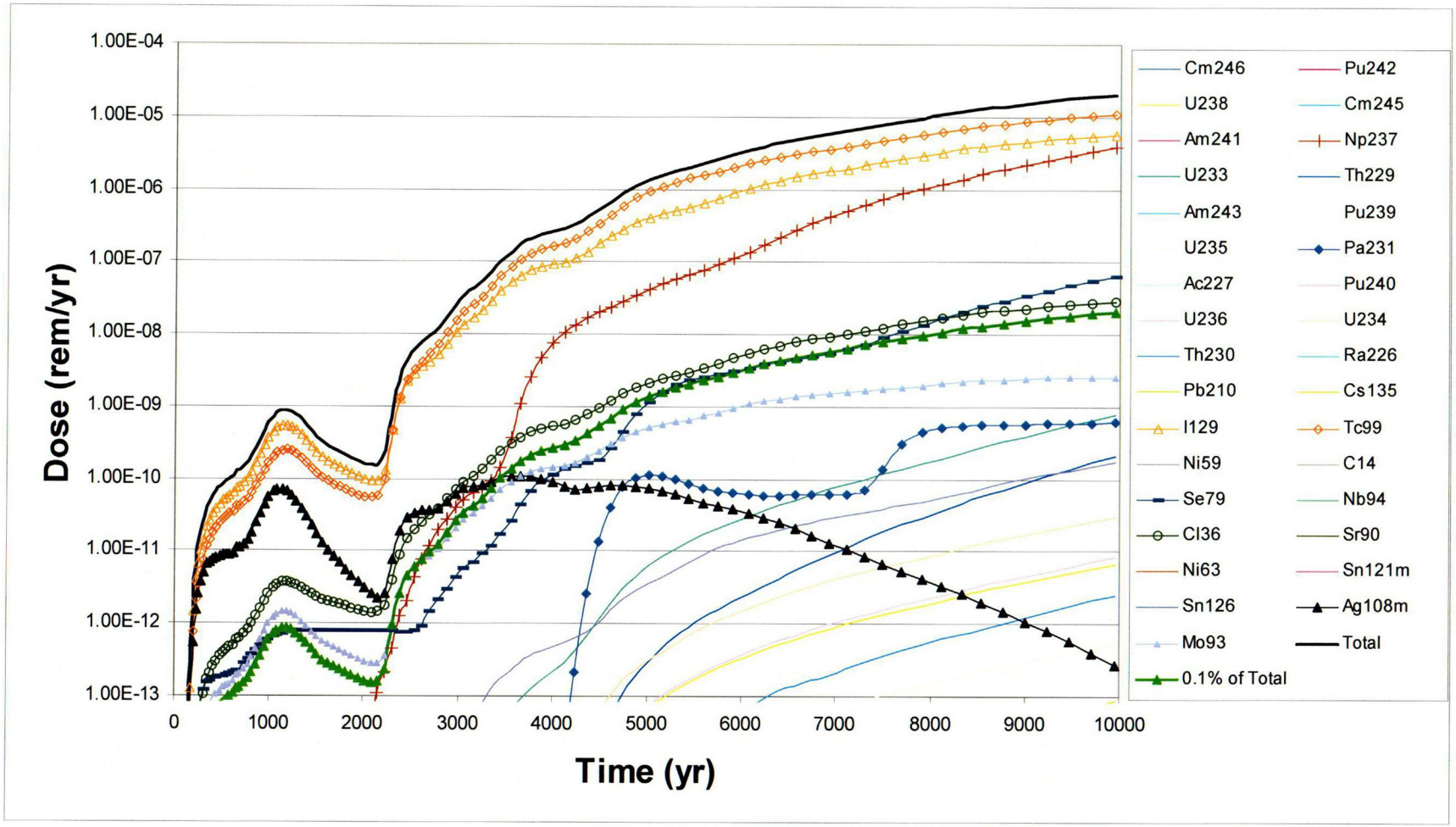

Figure I–1. Results of the TPA Version 4.1 Code under Nominal Conditions for 10,000 Years

C01

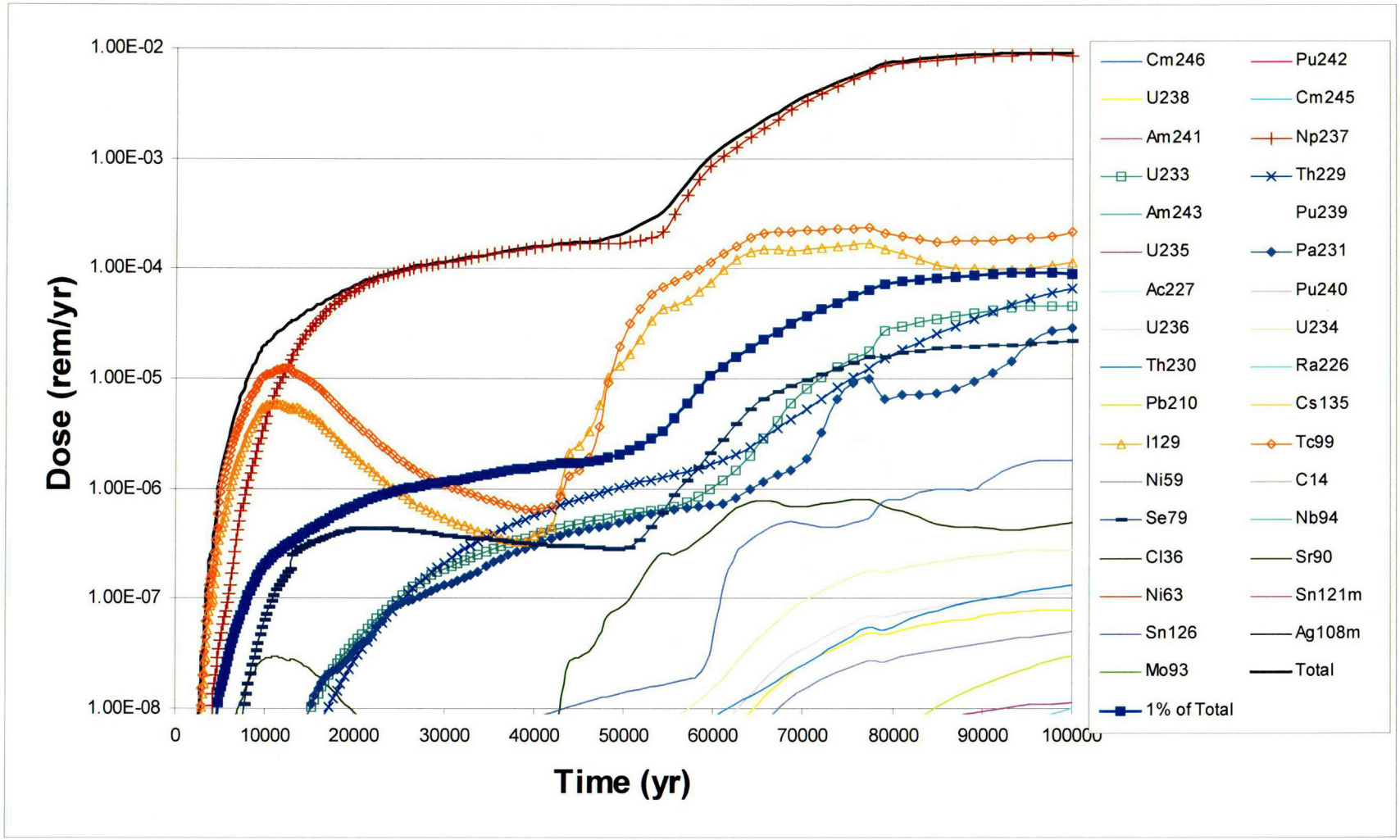

Figure I–2. Results of the TPA Version 4.1 Code under Nominal Conditions for 100,000 Years

C02

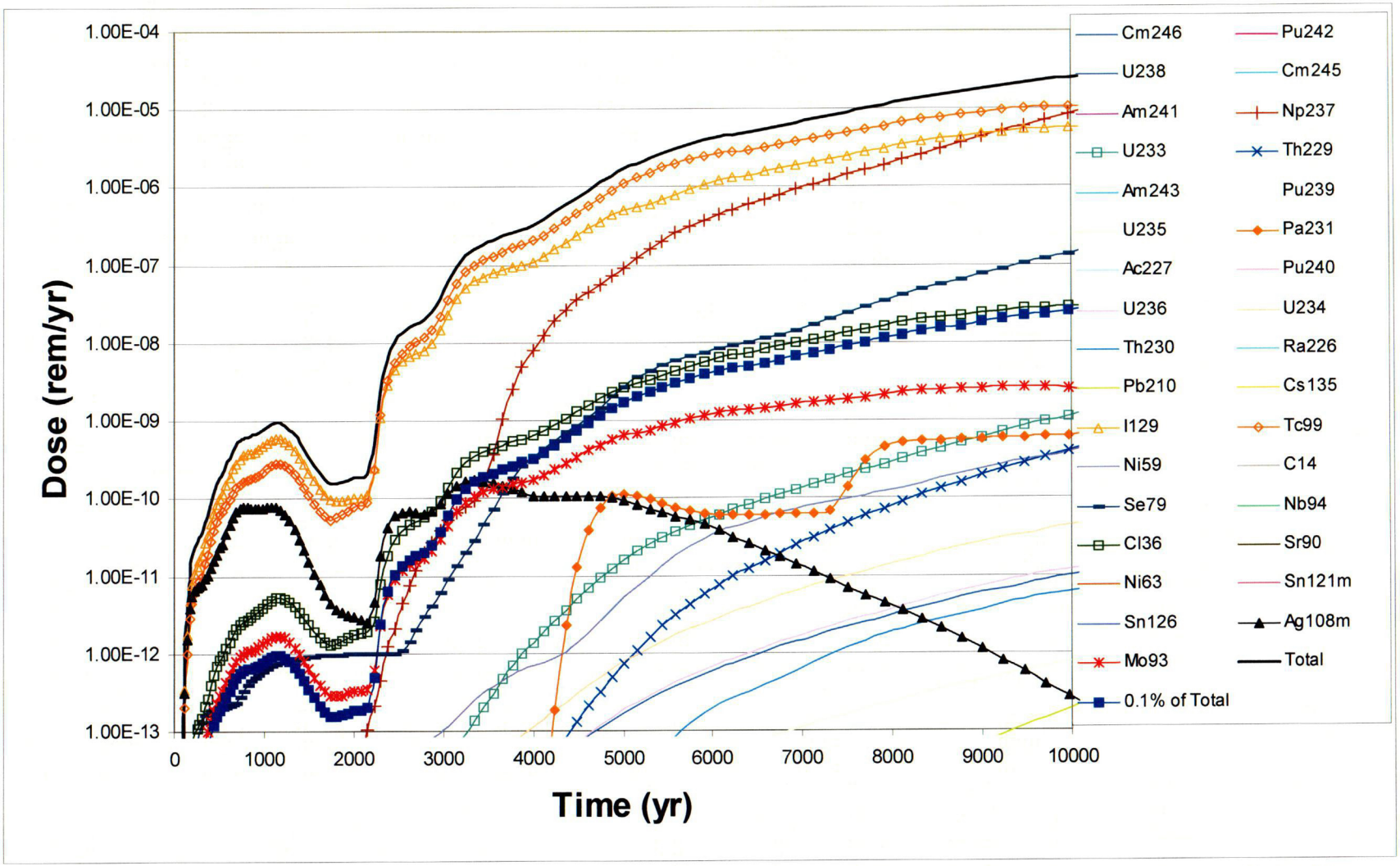

Figure I–3. Results of the TPA Version 4.1 Code with the Drip Shield and Unsaturated Zone Neutralized for 10,000 Years

C03

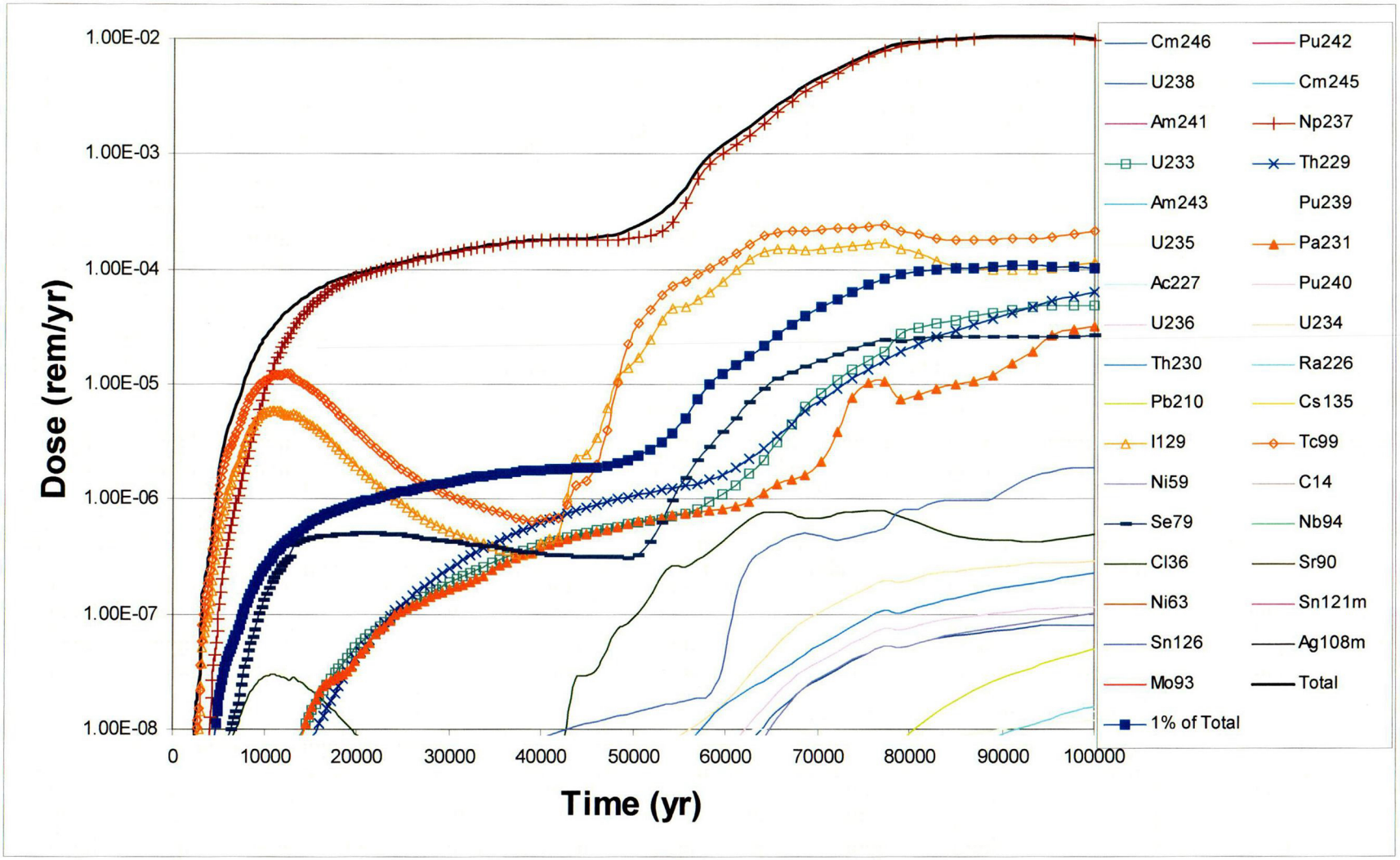

Figure I–4. Results of the TPA Version 4.1 Code with the Drip Shield and Unsaturated Zone Neutralized for 100,000 Years

C04

Table I–5. List of Significant Radionuclides for the Nominal Performance	
Radionuclides That Contribute to the Peak Dose in 10,000 Years—Nominal Unsaturated Zone Performance	**Radionuclides That Contribute to the Peak Dose in 100,000 Years—Nominal Unsaturated Zone Performance**
Tc-99	Np-237
I-129	Tc-99
Np-237	I-129
Se-79	
Cl-36	

Table I–6. List of Significant Radionuclides for the Human Intrusion Analysis	
Radionuclides That Contribute to the Peak Dose in 10,000 Years—Neutralized Unsaturated Zone Performance	**Radionuclides That Contribute to the Peak Dose in 100,000 Years—Neutralized Unsaturated Zone Performance**
Tc-99	Np-237
I-129	Tc-99
Np-237	I-129
Se-79	
Cl-36	

Results of the two runs show that although some of these additional radionuclides modeled using conservative assumptions may contribute (more than 0.1 percent) to the small total doses early in the analysis, even within 10,000 years, none of these additional radionuclides contribute to the peak dose. Therefore, these additional radionuclides can be screened from the analysis.

Finally, it is necessary to screen the gaseous radionuclides separately for the groundwater release scenario. These gaseous radionuclides could be released at the time of waste package failure and travel in gaseous form up through the mountain. They could then be released from the surface of the mountain and be transported by wind to the receptor group location.

Radionuclides that could be released from the repository in gaseous form include H-3, C-14, Ar-39, Kr-81, and Kr-85. A conservative calculation will be performed to model the potential dose from an airborne release of these radionuclides.

The calculation will postulate two release scenarios. First, it will be assumed that every initially defective waste package fails in a single year. Second, it will be assumed that every waste package in the repository fails in a single year at year 20,000. Current results from the TPA Version 4.1 Code indicate that corrosive failures of the waste package are not likely before year

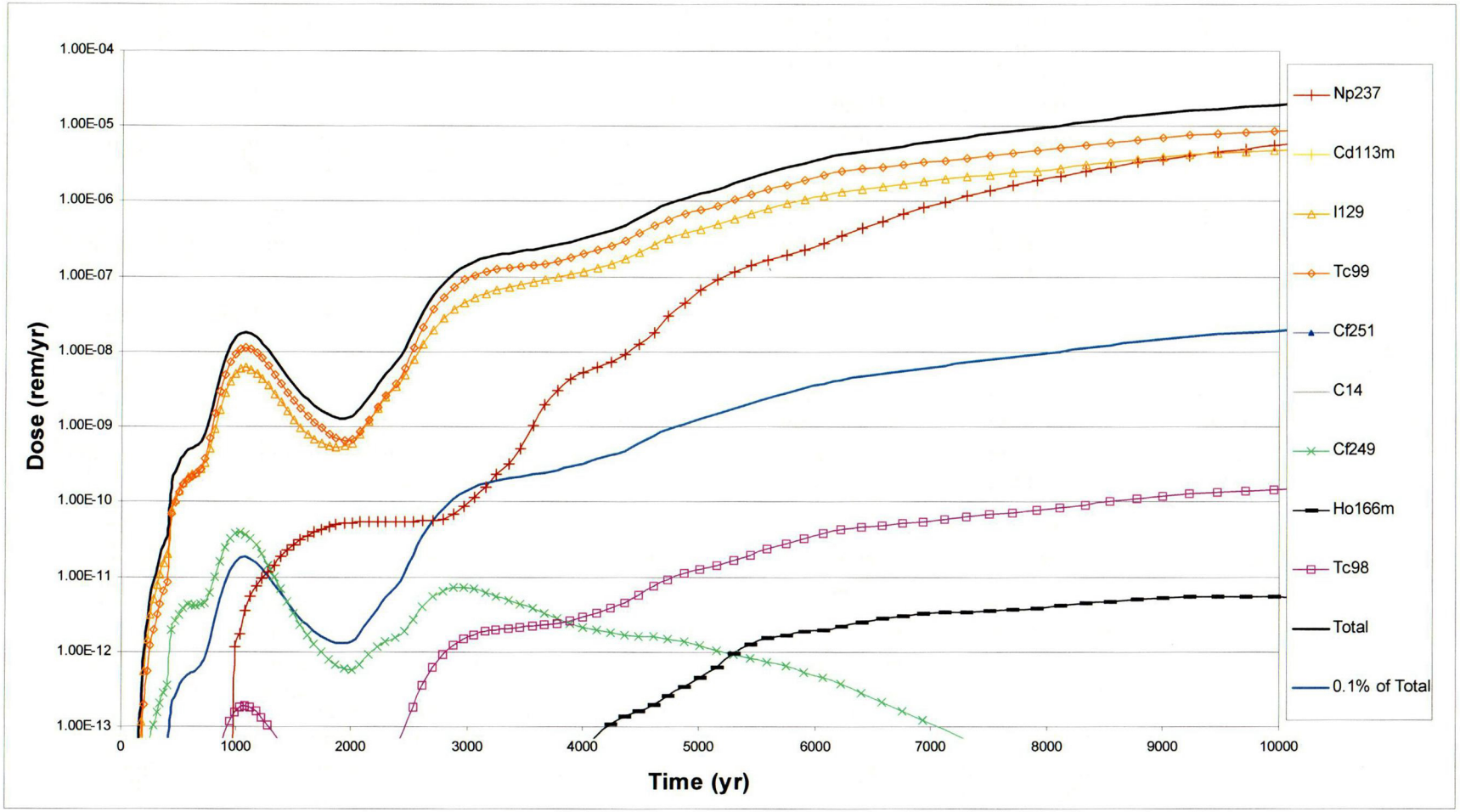

Figure I–5. Contribution of Other Radionuclides to the TPA Version 4.1 Code Results for 10,000 Years

C05

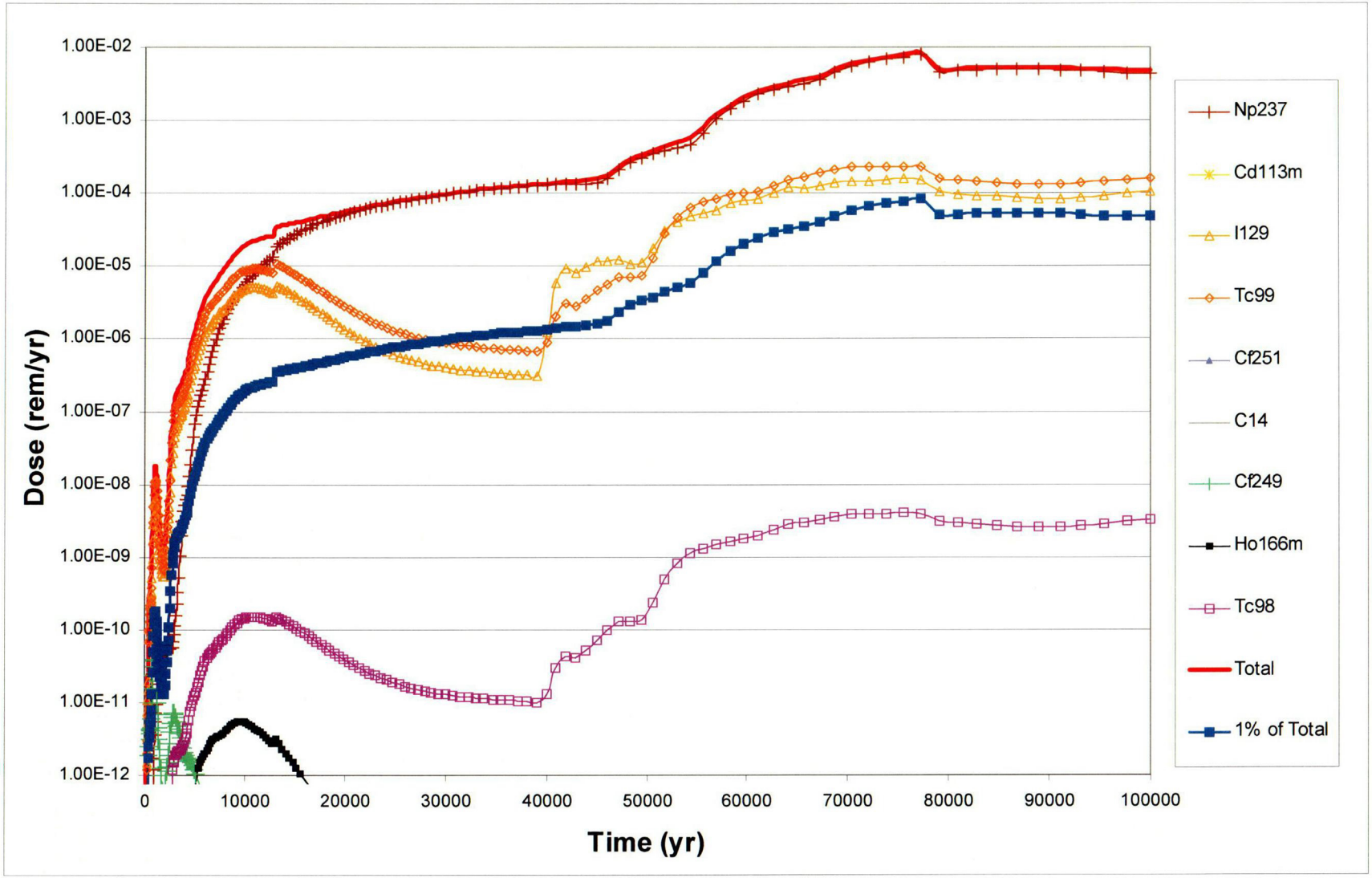

Figure I–6. Contribution of other Radionuclides to the TPA Version 4.1 Code Results for 100,000 Years

C06

Table I–7. Inventories of Gaseous Radionuclides in the Repository at Different Times		
Radionuclide	**Inventory in Repository at Year 100 (Ci)**	**Inventory in Repository at Year 10,000 (Ci)**
H-3	3.59×10^5	0*
C-14	1.01×10^5	3.03×10^4
Ar-39	8.05	0*
Kr-81	0.14	0.14
Kr-85	1.66×10^6	0*
*Zero activities were reported for activities less than 10^{-20} Ci at 10,000 years.		

30,000 and may extend beyond 100,000 years, so this assumption of the failure time of the waste packages is conservative. From Mohanty and McCartin (1998), the mean value of the range of the sampled fraction of waste packages initially defective is 0.00505, and the average inventory of C-14 is 1.44 Ci/MTU. ORIGEN2 (Oak Ridge National Laboratory, 1991) was used to calculate the inventory of the remaining radionuclides for 4.0 percent enriched fuel with a burnup of 70 GWd/MTU at year 100, which is assumed to be the time of repository closure. These fuel characteristics would bound the inventory of these additional radionuclides at the time of repository closure. The calculated total inventories in the repository for the 70,000 MTU of fuel in the repository are listed in Table I–7. Only the fraction of C-14 in the gap and grain boundaries will be available to be released in the year of waste package failure. The C-14 in the cladding and fuel structure cannot be released until the fuel or cladding oxidizes, which is slow compared to the rate of release from the gap and grain boundaries. The fraction of the C-14 in the gap and grain boundaries is 10 percent (Mohanty and McCartin, 1998). It is assumed that 100 percent of the other gaseous radionuclides are released in the year of waste package failure.

Transport of these radionuclides to the critical group location was modeled using a Gaussian plume model described in Regulatory Guide 1.111 [Nuclear Regulatory Commission (NRC), 1977] as shown in Eq. (I–1) assuming a ground level release at a location 18-km [11.2-mi] south of the repository. The weather characteristics are taken from a DOE site characterization document (CRWMS M&O, 1999), from which the frequency of stability classes and the annual average wind speed can be calculated.

$$\frac{\overline{X}}{Q} = 2.032\frac{n}{N x \bar{u} \sigma_z(x)} \qquad \text{(I-1)}$$

where

$\frac{\overline{X}}{Q}$ = Average annual effluent concentration normalized by source strength in a given direction from the source (s/m^3)
n = Number of hours that the wind is blowing in a given direction (h)
N = Total number of hours of data (h)
x = Distance downwind (m)
$\bar{u}$ = Average windspeed (m/sec)
$\sigma_z(x)$ = Vertical plume spread at a distance x (m)

From the Environmental Baseline File Meteorology and Air Quality document (CRWMS M&O, 1999), the fraction of the time that the wind blows from Yucca Mountain toward the critical group location, which is equivalent to n/N, is 18.2 percent. From Regulatory Guide 1.111 (NRC, 1977), the vertical plume spread at 18 km [11.2 mi] for Class F stability conditions is 58 m [190.3 ft]. These data were used with dose conversion factors for submersion and inhalation from Oak Ridge National Laboratory (1988), to calculate the doses shown in Table I–8 for the two release scenarios.

Table I–8. Results of Conservative Calculation of Dose from Gaseous Releases from the Repository

Radionuclide	Dose from Juvenile Failures (1 percent of Inventory at 100 Years) (mrem/yr)	Dose from Corrosion Failures (10 percent of Inventory at 10,000 Years) (mrem/yr)
H-3	2.61×10^{-3}	0
C-14	2.39×10^{-3}	4.23×10^{-2}
Ar-39	1.56×10^{-10}	0
Kr-81	5.26×10^{-11}	9.81×10^{-9}
Kr-85	2.74×10^{-7}	0
Total	5.27×10^{-3}	4.23×10^{-2}

The peak annual dose for aqueous releases in the nominal scenario in 10,000 years is 0.021 mrem and is 10.1 mrem in 100,000 years. Even these conservative calculations show that a large release of gaseous radionuclides from the repository would not lead to a dose that exceeds the dose from aqueous releases of radionuclides at the receptor location. Therefore, it is reasonable to screen the gaseous release of these radionuclides from further consideration in the TPA Code.

Conclusions

It is recommended that the radionuclides listed in Table I–9 continue to be tracked in the TPA Version 4.1 Code for the direct release and groundwater release scenarios.

Table I–9. Radionuclides That Should Be Included in the TPA Version 4.1 Code

Radionuclides to be Included in the Direct Release Scenario	Radionuclides to be Included in the Groundwater Release Scenario
Sr-90	Cl-36
Nb-94	Se-79
Sn-126	Tc-99
Cs-137	I-129
Th-229	Np-237
Np-237	Pu-239
Pu-238	Pu-240
Pu-239	Am-241
Pu-240	Am-243
Am-241	—
Pu-242	—
Am-243	—
Cm-244	—
Cm-245	—

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