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Weapons Plutonium in Los Alamos Soil and Waste: Environmental, Health, and Security Implications

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As always, we, as the authors, remain solely responsible for the contents of this report, its conclusions and recommendations, and any omissions or errors.

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Part I: Sediment Contamination in the South Fork of Acid Canyon

Section One: Introduction

Between 1944 and 1964, multiple liquid radioactive waste streams were released into the South Fork of Acid Canyon from Los Alamos National Laboratory. From 1944 to 1951, "untreated radioactive effluent from former Technical Area (TA) 1 was discharged into the head of the South Fork of Acid Canyon" and from 1951 to 1964 a "radioactive liquid waste treatment plant at former TA-45" discharged its effluent into the canyon. Today, this area is located within 1,000 feet of a residential neighborhood and less than a mile from a local high-school.[1] We chose to examine the remediation of Acid Canyon because; (1) it is a site that is already accessible to the general public, (2) it has already had remediation efforts undertaken based, in part, on analyses conducted by DOE for site-specific exposure scenarios, and (3) it illustrates some of the general concerns that will arise at Los Alamos and other sites which have actinide contamination (uranium, plutonium, neptunium, americium, etc.) as the main driver of risk.

In the South Fork of Acid Canyon the following radionuclides were identified by DOE as being of potential concern:

> Tritium (H-3), Strontium-90, Cesium-137, Uranium-234, Uranium-235, Uranium-238, Plutonium-238, Plutonium-239, and Americium-241.[2]

Given the lack of edible plants in the canyon and that fact that no hunting or fishing is allowed, the authors of the *Interim Report on Sediment Contamination in the South Fork of Acid Canyon* (hereafter the *Interim Report*) considered only the external gamma, soil ingestion, and soil inhalation pathways in conducting their analysis. In light of the proximity of residential areas to the canyon, it was assumed that the canyon could be used by children as an extension of their backyards and that adults could use the hiking/jogging trails in the canyons which cross and pass near contaminated areas.[3] Except for tritium, which is not a major contaminant of concern in Acid Canyon, the extended backyard scenario is the most restrictive scenario evaluated by DOE, and therefore will be the focus of our current review. This is because the present case study is focused on a review of Los Alamos's calculations of the consequences of its remediation strategy.

Of the nine radionuclides considered in the *Interim Report*, plutonium-239 was by far the primary driver of risk with americium-241 and cesium-137 a distant second and third respectively as can be seen in Table 1.[4] This is mostly because the residual concentrations of plutonium-239 in the canyon soil are far higher than the other radionuclides.

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[1] DOE 2000 p. 2 and Figure 1

[2] DOE 2000 p. 7

[3] DOE 2000 p. 6-7

[4] DOE 2000 p. 13 and 16

Table 1: Single radionuclide soil guidelines (SRSGs) for extended backyard scenario and the area averaged surface soil contamination in Acid Canyon as reported by the Department of Energy.[5]

Radionuclide	Extended backyard scenario SRSG (pCi/gm)	Maximum detected value before cleanup (pCi/gm)	Canyon average concentration before cleanup (pCi/gm)	Canyon average concentration after cleanup (pCi/gm)
Tritium (H-3)	38,000	1.86	0.53	0.2
Strontium-90+D	5,500	80	6.86	1.9
Cesium-137+D	210	148	7.50	3.5
Uranium-234	3,000	21.5	2.92	3.6
Uranium-235+D	710	2	0.25	0.2
Uranium-238+D	2,000	16.6	1.92	1.9
Plutonium-238	310	37.3	0.97	0.6
Plutonium-239,240	**280**	**7,780**	**211**	**112**
Americium-241	270	278	13.8	5.4

While the *Interim Report* was "not intended to be a final assessment of the potential risk from contaminants in Acid Canyon, but instead to be an interim report to address specific concerns raised by stakeholders in Fall 1999 and to evaluate the need for immediate remedial action," we chose to examine its analysis in some detail because it was used, along with ALARA (as-low-as-reasonably-achievable) guidelines, to set cleanup goals for remediation efforts that occurred in the summer and fall of 2001.[6]

With respect to the extended backyard scenario used by DOE to set the preliminary remediation guidelines summarized in Table 1, we have found that:

1. Despite the focus of the scenario on protecting children, the authors of the *Interim Report* did not make use of the age-specific dose conversion factors which were available from the International Commission on Radiological Protection and chose instead to incorrectly use the older dose conversion factors derived for the 154 pound adult male worker.
2. The assumption made regarding the length of time children may be exposed to the contamination in Acid Canyon (200 hours per year) is not adequately conservative for a screening calculation.
3. The ingestion of plutonium contaminated soil dominates the risk for the extended backyard scenario. As such, the *Interim Report* fails to adequately take into account the potential for children to intentionally consume large quantities of soil, a behavior known a geophagia or soil pica.
4. The *Interim Report* does not consider the potential for children to track contaminated soil into their homes creating additional routes of exposure for themselves and for the other people in their family.

[5] DOE 2000 p. 12-13 and 16 and DOE 2002 p. 17

[6] DOE 2000 p. 2 and DOE 2002 p. 1

5. Finally, the soil guidelines derived by Los Alamos for this scenario are about right due to the approximate canceling of over and underestimates in the *Interim Report*.

Overall, IEER's principal finding is that significant additional remediation of the South Fork of Acid Canyon will likely be required when the assessment of surface water impacts is made by DOE. We have found that the area averaged plutonium concentrations in the canyon soil are significantly larger than the values which could lead to surface water concentrations above 0.15 pCi per liter if they were present in the stream bed. The level of 0.15 pCi per liter is the current statewide surface water limit for Colorado and has been recommended by IEER and other groups for adoption by the Environmental Protection Agency as the federal drinking water limit. While we have not made specific recommendations for the final remediation guidelines for Acid Canyon in this report, we have concluded that the present level of residual contamination is likely too high by at least a factor of ten. IEER's previous recommendations for the cleanup goal at Rocky Flats (1 to 10 pCi per gram of plutonium in the soil, with the lower end of the range corresponding to the protection of drinking water onsite) is consistent with this conclusion.[7]

Section Two: Generally Protective Assumptions of the Interim Report

To begin we will briefly review the decisions that were made by the authors of the *Interim Report* that we agree are generally protective of public health and have a sound basis for use in quantitative risk assessment. First and most important is their adoption of a 15 millirem per year dose limit as the standard against which compliance was judged. The authors explained their choice as follows:

> The radiation dose limit of 15 mrem/yr follows proposed Environmental Protection Agency (EPA) guidelines, and is more protective of possible human health effects than the dose limit of 25 mrem/yr proposed by the US Nuclear Regulatory Commission for unrestricted use of a site (10 CFR 20, *Standards for Protection Against Radiation*) and the limit of 100 mrem/yr in US Department of Energy (DOE) Order 5400.5, *Radiation Protection of the Public and the Environment*. The dose limit of 15 mrem/year is also consistent with developing guidance from DOE/Albuquerque Operations Office.[8]

The use of a 15 millirem per year dose limit rather than 25 or 100 millirem per year is a good practice for radiation protection standards which will apply to the general public and is consistent with the typical level of "acceptable risk" used in regulating other carcinogens. The use of this lower dose limit is also supported by the 2005 report from the BEIR VII Committee of the U.S. National Academy of Sciences that concluded that exposure to low-dose radiation carries even higher risks of causing cancer than was thought to be the case in 1999 when the EPA published its recommendations on radiation risks in Federal Guidance Report 13.[9] The fact that children are the focus of the extended backyard scenario and are also at significantly higher risk from

[7] Makhijani and Gopal 2001 p. 7-10 and 43-44

[8] DOE 2000 p. 5

[9] NAS/NRC 2005 p. 28 and EPA 1999 p. 182

radiation exposure compared to adults also supports the use of the more protective 15 millirem per year dose limit.

In addition to the 15 millirem per year dose limit from all pathways, however, it is important that all cleanup standards also include a separate sub-limit of 4 millirem per year to the maximally exposed organ from the drinking water pathway. While the drinking water pathway was not evaluated in the *Interim Report* (see section four), such a sub-limit should be generally included in all cleanup goals in order to help ensure that the most restrictive criteria in each particular case will be used to guide the overall remediation efforts. In the case of Acid Canyon, it appears very likely that meeting the surface water standard of 0.15 pCi per liter proposed by IEER will be the controlling factor behind setting the final cleanup levels and that further remediation of the canyon will be required.

Second, the authors of the *Interim Report* chose to use the EPA's recommended "upper-bound values" for the exposure factors considered in the scenarios.[10] The use of upper-bound values is an appropriate choice for this type of screening analysis. While we do not believe that appropriate upper-bound values were used for the amount of time children may spend playing in Acid Canyon or for the amount of soil that they may ingest, other pathways, such as inhalation, did make use of appropriately conservative assumptions. In assessments where plutonium is the major contributor to the risk, the inhalation pathway must be carefully considered due to the higher dose received from plutonium inhaled into the lung compared to the same amount of plutonium ingested (see Table 2 below). For the extended backyard scenario, the authors of the *Interim Report* made adequately conservative assumptions for the typical level of dust loading, which accounts for how much contaminated soil will be resuspended into the air, as well as for the average inhalation rate of the children playing in the canyon.[11] The one important exception to this conclusion regarding the inhalation pathway may be for children engaging in the intentional consumption of soil (see section three). For these children, particular care should be taken to estimate the amount of soil that that is inhaled through the nose and mouth during the close contact that will accompany the ingestion of large amounts of dirt.

Section Three: Some Assumptions of the Interim Report not Adequately Protective of Public Health

Doses to Children

First, despite the very specific focus of the extended backyard scenario on children, the authors of the *Interim Report* chose to use the dose conversion factors developed for a 154 pound adult male workers.[12] The authors justified this choice "[b]ecause dose conversion factors for

[10] DOE 2000 p. 6

[11] DOE 2000 p. 8, NCRP 77 p. 42, Till et al. 2000 p. 6-2, and EPA 1997 p. 5-24

[12] The Reference Man model used to develop the dose conversion factors for adult worker was described by the ICRP as follows:

populations other that adult workers have not been published by DOE."[13] In discussing the potential impact of this choice, however, the author's noted that

> **There are no data to estimate the dose conversion factors for children so this uncertainty must remain qualitative.** However, because of their higher metabolism it can be surmised that children are more sensitive to the carcinogenic effects of ionizing radiation than are adults. Therefore, action may be warranted at lower dose environmental concentrations of radionuclides for children than for adults.[14]

When the *Interim Action Completion Report* was published in September 2002 following the remediation efforts in the canyon, the dose conversion factors for the adult male worker were still being used to evaluate doses to children in the extended backyard scenario.[15]

While it is true that the Department of Energy had not published its own collection of age-specific dose conversion factors, by the time the *Interim Report* was published in April 2000, the International Commission on Radiological Protection had published dose models for five different age groups that had been widely accepted by international radiation protection schemes. The ICRP efforts date back to the aftermath of the Chernobyl disaster which raised awareness within the radiation protection community of the need to accurately calculate doses to people of various ages as a result of internally deposited radionuclides. In March 1987, the Task Group on Age-dependent Dosimetry was created within the ICRP. This Task Group (later renamed the Task Group on Internal Dosimetry), along with the Task Group on Dose Calculations published a series of five ICRP reports between 1989 and 1996 that provide dose conversion factors for a number of radionuclides.[16] The specific age groups that were considered by the ICRP are:

> 3 month old (0 to 1 years old),
> 1 year old (1 to 2 years),
> 5 year old (2 to 7 years old),
> 10 year old (7 to 12 years old),
> 15 year old (12 to 17 years old), and
> Adult (over 17 years old).[17]

Since 2001, the ICRP has also published dose conversion factors for the embryo/fetus and for the breast fed infant.[18] Plutonium, the main contaminant of concern in Acid Canyon, was discussed in four of the five ICRP reports issued prior to the *Interim Report*.[19] These newer age-specific

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> "Reference man is defined as being between 20-30 years of age, weighing 70 kg [154 pounds], is 170 cm [5 feet 7 inches] in height, and lives in a climate with an average temperature of from 10^{o} to 20^{o} C. He is a Caucasian and is Western European or North American in habitat and custom." [ICRP 23 p. 4]

[13] DOE 2000 p. 6

[14] DOE 2000 p. 24 (emphasis added)

[15] DOE 2002 p. 17

[16] ICRP 56, ICRP 67, ICRP 69, ICRP 71, ICRP 72 and ICRP 2005b p. A-1

[17] ICRP 72 p. 11

[18] ICRP 88 and ICRP 95

[19] ICRP 72 p. v

dose models were rapidly accepted by the international radiation protection community. By 1996, the ICRP models had already been incorporated into the European Union's European Basic Safety Standards and the International Atomic Energy Agency's International Basic Safety Standards.[20] The EPA issued its own collection of age specific dose and risk factors in a 2002 CD supplement to its Federal Guidance Report 13. The dose conversion factors in this EPA database are generally the same as those of the ICRP.[21]

It seems hard to justify the claims made by the authors of the *Interim Report* in 2000 that there was "no data to estimate the dose conversion factors for children" and that the values for the adult worker had to be used in the DOE analysis. It stretches credulity to believe that the authors were unaware of the ICRP's efforts, and if they were it would reflect very poorly on their competence to carry out these types of dose calculations.

In the particular case of plutonium, the author's presumption that using age-specific dose conversion factors would tend to increase the dose relative to that estimated for the adult worker turns out, in fact, to be incorrect. Table 2 summarizes the ingestion and inhalation dose conversion factors for plutonium-239 as estimated by the EPA and the ICRP.

Table 2: Dose conversion factors for plutonium-239 as reported by the EPA in Federal Guidance Report 11 for the adult male worker and the age-specific dose conversion factors reported by the EPA in the CD Supplement to Federal Guidance Report 13.[22]

Age Group	Ingestion Dose Conversion Factor (Sv/Bq)	Inhalation Dose Conversion Factor for Class M (Sv/Bq)	Inhalation Dose Conversion Factor for Class S (Sv/Bq)
3 month old	4.19×10^{-6}	8.00×10^{-5}	4.27×10^{-5}
1 year old	4.22×10^{-7}	7.73×10^{-5}	3.85×10^{-5}
5 year old	3.33×10^{-7}	6.04×10^{-5}	2.66×10^{-5}
10 year old	2.71×10^{-7}	4.81×10^{-5}	1.86×10^{-5}
15 year old	2.46×10^{-7}	4.72×10^{-5}	1.68×10^{-5}
adult (25 year old)	2.51×10^{-7}	5.01×10^{-5}	1.60×10^{-5}
FGR 11 (adult male)	9.56×10^{-7}	1.16×10^{-4}	8.33×10^{-5}

It is true than young children will receive a higher dose than a 25 year old adult within the newer dose models. However, due to changes in tissue weighting factors, different assumptions made about the behavior of plutonium in the body, and refinements in the model used to represent the respiratory system, the dose received by inhaling or ingesting plutonium has gone down from the older estimates used in the *Interim Report*. For ingestion, which is the most important pathway in the extended backyard scenario, the dose conversion factor for a 2 to 12 year old child is about three to three and a half times less than the one used in the *Interim Report*.

[20] ICRP 2005b p. A-1

[21] EPA 2002

[22] EPA 2002 and EPA 1988 p. 151 and 177

While this means that the doses estimated by the DOE analysis for plutonium were, in fact, conservative in this regard they were not based on the latest available scientific information. Of potential significance in other remediation situations is the fact that for many other radionuclides, children can receive higher doses than would be estimated using the older adult male model. For example, the EPA and ICRP age-specific dose conversion factors for ingesting strontium-90 are 22 to 88 percent bigger for a 2 to 12 year old than those for the adult worker used in the *Interim Report*.[23] In all future assessments, the DOE should make use of the latest available dose conversion factors that have been published by the International Commission on Radiological Protection or the Environmental Protection Agency.

Finally, for radionuclides (such as cesium-137) for which external radiation is an important exposure pathway, the estimated gamma dose should be modified to account for the smaller size of children and the fact that they often spend a greater amount of time near the ground and are thus in closer proximity to the contamination. While the effect these factors will have depends on the energy of the gamma rays, and thus on the particular radionuclide involved, the National Council on Radiological Protection has recommended scaling the external gamma dose estimated for adults by 1.3 ± 0.1 to get the dose for children up to at least 12 years of age.[24] This type of guidance has been followed by the NRC Staff in the context of evaluating reactor decommissioning plans for the Haddam Neck plant.[25]

Exposure Duration

Second, as discussed above, the authors of the *Interim Report* stated that they sought to use "upper-bound values" for the exposure factors in their analyses. One of the areas in which IEER does not believe that the choice made in the *Interim Report* is adequately conservative was in the length of time children were taken to play in the canyon. The authors of the *Interim Report* assumed that a child would spend 200 hours per year playing in the canyon, which would amount to approximately one hour per day for seven months of the year. They note that this assumption is "based on professional judgement, incorporating input from NMED."[26] However, the 95th percentile value reported by the EPA was that a child age 1 to 11 years old would spend as much as eight or nine hours in outdoor activity per day. Even focusing on just the average values, the study cited by the EPA recommendations estimated that children between two and eleven spend 2.2 hours outdoors at home and an additional 1.9 hours outdoors at parks, etc.[27]

The dose received by a child in the extended backyard scenario is directly proportional to the amount of time the child spends in the canyon. Thus, for a screening calculation which is meant to provide a conservative basis upon which to base the need for or adequacy of cleanup efforts, it is important to make consistent use of "upper-bound values" for all parameters, including exposure duration. The choice of an adequately conservative estimate for the length of time

[23] EPA 2002 and EPA 1988 p. 160

[24] NCRP 129 p. 56-57

[25] NRC 2003 p. 39

[26] DOE 2000 p. 7

[27] DOE 2000 p. 8, EPA 1997b p. 15-187, and EPA 2002b p. 9-48 and 9-59

children may play in the contaminated areas should be made with input from the local residential population. Based on the studies underlying the EPA recommendations, it would be likely that an exposure time of 300 to 400 hours per year would be a more appropriate screening level for the case of Acid Canyon.

Soil Ingestion

Third, soil ingestion is by far the most important exposure pathway in the extended backyard scenario accounting for more than 90 percent of the DOE's estimated total dose from all radionuclides present. Given its dominant role in governing the cleanup goals for Acid Canyon, it is particularly important that the soil ingestion pathway be addressed completely. The authors of the *Interim Report* start with the EPA's recommended 95th percentile soil ingestion figure of 400 milligrams per day and assume that this ingestion of soil occurs uniformly over the entire time the child spends outdoors (5.6 hours per day). The authors than calculate what the total amount of soil ingestion would be during the 200 hours the child is assumed to spend playing in the canyon. As noted above, the dose from soil ingestion will thus be directly proportional to the length of time the child is assumed to play in the canyon. From this, the authors of the *Interim Report* estimate that a child in the extended backyard scenario will consume 14.3 grams of contaminated soil over the course of a year.[28] However, despite the existence of a number of studies examining soil ingestion, there remain significant uncertainties both about the actual long-term rate of ingestion and about the variability between individuals and groups.[29] A review of studies on soil ingestion, published in *Health Physics* following the publication of the EPA's *Exposures Factor Handbook*, recommended using a 95th percentile value for soil ingestion for a suburban lifestyle which was more than four times higher than the 95th percentile value recommended by the EPA.[30]

More important than the uncertainties in the estimated amount of routine soil ingestion, is the issue of how the critical group in the *Interim Report* is defined. In conducting risk assessments, once the exposure scenarios are generally defined, the next step is to identify a group of individuals that are expected to receive the highest doses and that is also "small enough to be relatively homogenous with respect to age, diet and those aspects of behaviour that affect the doses received."[31] As noted by the International Commission on Radiological Protection in its draft 2005 recommendations

> Such a group is chosen to be representative of the most highly exposed individuals as a result of the source. Its characteristics should be derived from the mean of a homogeneous and sustainable group. Additionally, it is important that the habits used in calculating the dose to the individuals are the average habits in the critical group and not the habits of a single extreme individual. The critical group may, however include some

[28] DOE 2000 p. 8

[29] EPA 1997 p. 4-20, Simon 1998 p. 659, and Royal Society 2002 Annexe C p. 2-3

[30] Simon 1998 p. 661-663

[31] ICRP 26 p. 17

> individuals with extreme or unusual habits and should be selected such that all relevant habits are taken into account.[32]

In the draft foundation document on dose calculations supporting these recommendations, the ICRP reiterated that, when conducting probabilistic assessments, "[c]are must be used to include all hypothetical individuals whose dose could possibly be representative of persons receiving the highest dose, including extremes."[33] The ICRP went on to conclude that

> Close attention must be paid to suggestions from members of the public of existing or likely exposure situations that might reflect extremes in the population…. If it can be shown that such a pathway, in combination with other exposure, is likely to affect a few tens of persons and elevate their doses above the dose constraint, then a revision of the analysis must be undertaken. If such a homogeneous group is found to exist above the dose constraint, then the mean dose to this group becomes the basis for compliance.[34]

In the case of soils contaminated with actinides such as plutonium-239 and where children are likely to play or otherwise come into close contact with the soil, particular care must be taken to ensure that the critical group includes the potential for the intentional ingestion of large quantities of soil.[35] If a significant number of children are ultimately determined to be expected to exhibit this kind of behavior, than it must be included in the underlying definition of the critical group against which compliance should be judged.

Geophagia, the intentional ingestion of large quantities of soil, has been documented for centuries and is commonly viewed as a particular manifestation of a behavior known as pica which is the intentional ingestion of all non-food stuffs such as paint, string, and soil. It has been found to occur across "geographic, ethnic and cultural boundaries" and has "been noted not to be a rare event."[36] In its 1985 Superfund Guidance, the EPA acknowledged that short term soil ingestion well above the typical 95th percentile are possible and recommended that risk assessments consider potential exposures of 5 grams per day.[37] In studies of lead poisoning in children, the intentional ingestion of soil and paint chips is commonly viewed as playing a significant role.[38] In their 1997 *Exposure Factors Handbook*, the EPA concluded that "it can be assumed that the incidence rate of deliberate soil ingestion behavior in the general population is low." However, the EPA went on to note that "the prevalence of pica behavior is not known" and that due to the short time period over which children have so far been studied, "[i]t is plausible that many children may exhibit some pica behavior if studied for longer periods of time."[39] As summarized by Calabrese et al.

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[32] ICRP 2005 p. 44

[33] ICRP 2005b p. 17

[34] ICRP 2005b p. 18

[35] Simon 1998 p. 656

[36] Simon 1998 p. 649 and 659

[37] Calabrese et al. 1997

[38] Mielke and Reagan 1998

[39] EPA 1997 p. 4-18 and 4-20

> Realistic estimates of soil pica are problematic. Estimating the frequency, magnitude, variability, and duration of soil pica has not been the object of extensive research. In the course of three soil ingestion studies, we have observed unambiguous soil pica in two children…. These data suggest that soil pica may vary considerably both between and within individuals and are consistent with observations that generalized pica behavior is common in normal children, but may be more prevalent and of longer duration in mentally retarded children.
>
> …The findings also support the hypothesis that there is considerable interindividual variation with respect to soil pica frequency and magnitude. Thus, for the majority of children, soil pica may occur only on a few days of the year, but much more frequently for others. If soil pica is seen as an expected, although highly variable, activity in a normal population of young children, rather than an unusual activity in a small subset of the population, its implications for risk assessment become more significant.[40]

Estimates for the amount of soil that a pica child might intentionally ingest carry even greater uncertainties than estimates of routine ingestion. Accurately estimating the amount of soil ingestion requires "extensive knowledge of the living conditions and cultural attitudes of the population of interest."[41] Generally, however, the assumptions that have been made are that a child experiencing pica will consume between 5 and 10 grams per day. This has been the assumption adopted by risk assessments and recommendations of the Environmental Protection Agency, the Centers for Disease Control, and the Agency for Toxic Substances and Disease Registry.[42] In 1997, the EPA officially recommended the use of 10 grams per day as the ingestion rate for a pica child.[43] However, smaller estimates (one to five grams per day) and larger estimates (26 to 85 grams per day) have been considered by other sources.[44] For the purposes of screening calculations in which soil ingestion in a major pathway, an acute exposure from the consumption of at least 30 to 40 grams of soil per year, occurring on a small number of days, should be considered in addition to the chronic exposure from routine, inadvertent soil ingestion.

Finally, given that intentional soil ingestion events are most likely to be short-term, acute exposures, the inhomogeneous distribution of the radionuclide contamination should be considered in estimating the potential impact of pica events. This is particularly true for transuranic elements which are known to result in highly inhomogeneous contamination patterns from studies of fallout around Chernobyl and the Marshall Islands.[45] In the case of Acid Canyon, for example, there were hot-spots with a combined area of 50 m^2 (4.5 percent of the contaminated land in the canyon) which had an average plutonium-239 concentration of 2,740

[40] Calabrese et al. 1997

[41] Simon 1998 p. 659

[42] EPA 1997 p. 4-20 and Simon 1998 p. 661

[43] EPA 1997 p. 4-20 and 4-25

[44] Simon 1998 p. 661-663 and Royal Society 2002 Annexe C p. 4

[45] Simon 1998 p. 666

pCi per gram.[46] A single pica event in which a child consumed 10 grams of soil from these hot-spots would have alone resulted in a dose greater than 25 millirem. Although no mention was made of the potential for such acute doses from pica, these two areas of contamination were subsequently removed during the summer and fall of 2001 as part of attempts to maintain doses as low as reasonably achievable.[47] While both the probability and the consequences of acute exposures need to be considered in risk assessments, the potential for pica children consuming large amounts of the most heavily contaminated soils should be addressed in the process of setting the final remediation guidelines. In the case of Acid Canyon, the application of other criteria lead to a cleanup level that does not pose a radiologically significant threat from acute soil ingestion of plutonium, but this may not always be the case for other sites or for other radionuclides.[48]

Transported Soil as a Potential Exposure Potential Pathway

Our fourth concern with the extended backyard scenario relates to the fact that it does not consider what may be a potential pathway of exposure, namely the fact that children may track contaminated soil into their homes. This type of pathway has been noted by the EPA and ATSDR in some cases for exposures to lead, mercury, arsenic, polychlorinated biphenyls (PCBs), and other toxic chemicals.[49] In addition to increasing the exposure of the older children who tracked in the soil, this pathway creates the possibility that infants at home could be exposed despite never traveling to the canyon if they have older siblings who play there. This potential exposure pathway may be important to consider because the ingestion dose conversion factor for infants is more than four times larger than the dose conversion factor used in the *Interim Report* (see Table 2) and infants have heightened hand-to-mouth behavior and spend much of their time in contact with furniture or the floor which can bring them into increased contact with contaminated dust.

Typical household dust is made up of a mixture of soil from outdoors, paint, plaster, biological material such as dead skin, and other materials. What fraction of household dust is dirt from outside is highly variable and depends on a variety of site specific factors. For example, three different studies estimated the fraction of soil in household dust to be 14 to 15 percent, 30 to 40 percent, and 75 to 100 percent respectively.[50] Significant variations have been found from one contaminant to another and from one house to the next. For example, one of the most heavily studied contaminants with respect to soil ingestion is lead. Estimates for the amount of lead in household dust that is attributable to soil from outside range from 20 to 95 percent. Some studies found the level of indoor lead to be associated with the level of lead outdoors while other studies found no such correlation. In light of these uncertainties, the EPA's Integrated Exposure Uptake

[46] DOE 2000 p. 16

[47] DOE 2002 p. 1 and 17

[48] For example, the consideration of a child ingesting 30 to 40 grams of soil would lower the single radionuclide soil guidelines for uranium-234, uranium-238, and strontium-90 reported in the *Interim Report* for the extended backyard scenario. Even these modified cleanup guidelines, however, would be far above the levels of contamination reported as measured in the canyon. [DOE 2000 p. 16 and DOE 2002 p. 17]

[49] EPA 1999c, EPA 2005, ATSDR 1994, ATSDR 1998, and ATSDR 2002

[50] Wong et al. 2000 p. 443 and Royal Society 2002 Annexe C p. 1

Biokinetic Model for Lead in Children makes the default assumption that 70 percent of dust is made up of dirt from outside.[51] In its assessment of the health risks from depleted uranium munitions the UK Royal Society made a similar assumption and concluded that "a value of 75% [of household dust being soil from outside] would seem appropriate, even though this is almost certainly cautious in many cases."[52]

In addition, when dealing with the transfer of contamination from outside to inside, there are a number of factors that may act to enhance the concentration of contaminants in dust. These factors include the fact that there are fewer ways for contaminants on household dust to degrade or be transported away compared to outdoors, the fact that carpets can act to store dust over long times, and the fact that some dust is derived from biological material such as molds and fungi that can act to bioaccumulate certain contaminants.[53] Studies of these effects, however, have shown significant variability. For example one study found no significant enhancement of lead indoors but did find an enhancement of copper on household dust.[54] Another study, however, found significantly higher concentration of "lead, cadmium, antimony and mercury" in household dust compared to either street dust or garden soil, but found the opposite trend for "aluminum, barium and thallium."[55] A third study found the levels of arsenic and lead to be higher indoors than outdoors for residences on or near fruit orchards which had used lead arsenate insecticide, and concluded that this enhancement was associated with soil having been tracked in from outside.[56] The lack of any generally applicable rules regarding the possible correlation between indoor and outdoor contaminant levels makes it difficult to make any generic assumptions which can be used in risk assessments. In order to determine if this potential pathway is of importance in such cases as Acid Canyon, measurements in and around local residences will be required.

In performing these measurements, one additional complication that must be dealt with is the issue of pets. Studies have found that elevated levels of lead in children correlate with elevated levels of lead in their pets. While it is not fully understood if the pets are a route of exposure or not, it has been noted that "houses that had dogs and cats appeared to have a higher level of metals" and that "[t]his may due in part to the fact that pets usually bring in dust from outdoors" given that "[t]hey stay close to the ground… and spend most of their time playing with dirt or dust."[57] In addition, pets may increase a child's access to soil for either ingestion or inhalation "by digging or by accumulating soil and dust in their fur."[58] The choice of sampling locations should take note of the existence of pets and whether they can go outdoors in order to establish any potential impact they may have on the importance of this exposure pathway.

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[51] Wong et al. 2000 p. 443 and Rasmussen, Subramanian, and Jessiman 2001 p. 126 and 136

[52] Royal Society 2002 Annexe C p. 1

[53] Tong 1998 p. 130, Wong et al. 2000 p. 443-444, and Rasmussen, Subramanian, and Jessiman 2001 p. 137

[54] Tong 1998 p. 123

[55] Rasmussen, Subramanian, and Jessiman 2001 p. 130

[56] Wolz et al. 2003 p. 293, 296-297

[57] Wong et al. 2000 p. 447 and 449 and Tong 1998 p. 128-129

[58] Wong et al. 2000 p. 444

Section Four: Surface Water Assessment

The scope of the *Interim Report* explicitly excluded an analysis of "[w]ater-related exposure pathways" due to "the lack of surface water data from Acid Canyon."[59] The authors went on to note that the assessments of "risk from contamination in surface water are pending further data analysis and interpretation."[60] When this assessment of potential surface-water impacts is carried out it will be important that it consider the most up to date science on plutonium health risks. As detailed in the IEER report *Bad to the Bone: Analysis of the Federal Maximum Contaminant Levels for Plutonium-239 and Other Alpha-Emitting Transuranic Radionuclides in Drinking Water*, the science underlying the current drinking water limit for gross alpha-activity (which would include plutonium activity) is more than four decades old and is no longer a satisfactory basis for the protection of public health. IEER has recommended reducing the concentration limit for plutonium and other long-lived alpha emitting transuranic elements from its current value of 15 pCi per liter to 0.15 pCi per liter. IEER and other groups have requested that the EPA take this information into account as part of their 2006 review of the Safe Drinking Water Act standards, and the EPA has agreed to consider the findings of the IEER report.[61] Of particular significance in the present case, we note that the State of Colorado has already adopted a 0.15 pCi per liter state-wide surface water standard for plutonium.[62] We also note that New Mexico governor Bill Richardson has written to the EPA and encouraged them to lower the allowable limit for plutonium in drinking water along the lines recommended by IEER.[63]

To illustrate the potential significance of the surface water impacts from the known contamination in Acid Canyon, we considered the typical levels of plutonium in stream sediment that would lead to an equilibrium concentration of 0.15 pCi per liter in the surface water. Table 3 summarizes our results using typical values of the partition coefficient for plutonium for various soil types.

[59] DOE 2000 p. 6

[60] DOE 2000 p. 25

[61] Makhijani 2005 p. 6-9 and Blette 2005

[62] Makhijani 2005 p. 21 and Colorado Reg. 31, 2005/08/08 p. 25 and 64

[63] Richardson 2005

Table 3: Concentrations allowable in the stream sediment for different soil types in order to maintain the equilibrium concentration of the surface water below the 0.15 pCi per liter limit recommended by IEER.[64]

Partition Coefficient (K_d)	Plutonium concentration in water (pCi/L)	Plutonium Concentration in sediment (pCi/gm)
550 (geometric mean value for sand)	0.15	0.083
2,000 (ResRad default value)	0.15	0.30
5,100 (geometric mean value for clay)	0.15	0.77

Given that the average concentration of plutonium-239 in the canyon's soil as reported by the DOE, even after the remediation that took place in 2001, was 112 pCi per gram, the potential for this contamination to adversely affect the surface water is clear. The issue of the impact of residual plutonium in the soil on surface and ground water at the Los Alamos site must be carefully addressed by the DOE in all aspects of waste management and cleanup activities. No remediation guideline should be accepted that would not maintain the concentration of all long-lived alpha emitting transuranic elements in both surface and ground water below the limit of 0.15 pCi per liter. In the specific case of Acid Canyon, the requirement to protect the surface water will almost certainly be a more restrictive criterion than the extended backyard scenario, and will thus likely determine the final remediation goals for this location.

Section Five: Conclusion

In summarizing the results of the *Interim Report*, the authors concluded that

> Although we did not perform a quantitative uncertainty analysis on these parameters it is highly likely that actual doses would be less than those calculated in this evaluation because upper end exposure assumptions were made for key parameters (like exposure time).[65]

However, we have found that both for the question exposure duration and for the issue of intentional soil ingestion, the *Interim Report* is not adequately conservative. While the appropriate upper-bound estimate for the length of time children may spend playing in the canyon should ultimately be guided by input from local residents as well as expert judgment, values from 50 to 100 percent longer than those used in the *Interim Report* seem reasonable based on existing EPA guidance. In addition, the value of 14.3 grams per year used for the total amount of contaminated soil that a child might consume may be less than the amount of soil

[64] EPA 1999b p. 2.16 and Yu et al. 2001 p. E-9 to E-13

[65] DOE 2000 p. 24

consumed by a pica child in a single event in some instances.[66] In cases such as Acid Canyon, where soil ingestion dominates the risks, the critical group should consist of children who will display pica behavior in addition to the inadvertent soil ingestion considered by the authors of the *Interim Report*. Using current EPA recommendations, a reasonable value for these acute exposures would likely be on the order of 30 to 40 grams for exposures lasting a few days per year. Finally, a voluntary measurement program should be conducted in the local communities to gauge the potential radiological significance, if any, of children tracking contaminated soil into their homes.

While not addressed by the *Interim Report*, we have found that considerations of plutonium's impact on the surface water in Acid Canyon is likely to lead to a far more restrictive cleanup criteria than the extended backyard scenario used to guide the 2001 remediation efforts. Information on the level of plutonium contamination that may impact the surface water is not available in the *Interim Report*, however, the levels of contamination remaining the soil of Acid Canyon are likely to be too high by at least a factor of ten if the amount of plutonium and other transuranic elements in the surface water is to be maintained below 0.15 pCi per liter over the long term. This concentration is the current statewide surface water limit for Colorado, and has been recommended by IEER and other groups for adoption by the EPA as the federal drinking water limit. While we have not proposed specific remediation guidelines for Acid Canyon pending further assessment by the Department of Energy, we note that IEER has previously recommended setting a cleanup goal at Rocky Flats of between 1 and 10 pCi per gram of transuranic elements in the soil with the lower end of the range corresponding to the protection of drinking water onsite.[67] This recommendation is consistent with our expectations for the level of residual contamination that will ultimate be set for Acid Canyon.

[66] Calabrese et al. 1997 and Royal Society 2002 Annexe C

[67] Makhijani and Gopal 2001 p. 7-10 and 43-44

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Part II: Plutonium in Los Alamos Waste – Environmental, Health, and Security Implications

Section One: Summary and Conclusions

Main findings

1. There are major discrepancies in the materials accounts for weapons plutonium in Los Alamos Waste. An analysis of official data indicates that the unaccounted for plutonium amounts to at least 300 kilograms and could be over 1,000 kilograms, though the higher figure appears unlikely.

2. If much or most of the plutonium was disposed of as buried low-level waste and buried transuranic waste, the long term radiation doses would far exceed any allowable limits. Remediation would be necessary but very complex due to the unknown disposal patterns.

3. It is possible that more plutonium is going to the Waste Isolation Pilot Plant than indicated by DOE documentation. If so, this has major implications for the oversight of the operations of WIPP. IEER review of waste characterization documents prepared for the New Mexico Attorney General's Office in 1998 indicated many areas of missing and incomplete waste documentation.

4. If only part of the unaccounted for plutonium is missing, this would have major security implications. As a reference point, North Korea's entire stock of separated plutonium is only about 15 percent of the lowest estimate of unaccounted for LANL plutonium.

5. Appeals to DOE and LANL authorities have failed to elicit a serious response or investigation.

Recommendations

An urgent, independent investigation of the problem of discrepancies in LANL accounts of plutonium in waste is necessary to address the findings of this report and to resolve the uncertainties.

Closer oversight of the characterization of the weapons plutonium content of containers being sent to WIPP is essential and urgent. Since waste containers cannot be checked once they are disposed of, more certain characterization and an investigation into the state of the accuracy and completes of WIPP documentation is essential for environmental as well as security reasons.

Section Two: Plutonium in Waste by the Numbers

In 1996, the DOE published an historical report on weapons plutonium, often called the "50 Years Report" because it contained data on the first fifty years of plutonium production in the

United States.[68] The report contained data on plutonium production history as well as details on the inventories of plutonium at various DOE sites around the country. As part of the preparation of this historic document, which was part of the Openness Initiative of then-Energy Secretary Hazel O'Leary, the DOE also made an effort to assess how much plutonium was contained in waste generated in the course of producing and processing plutonium from the inception of the nuclear weapons complex during the Manhattan Project.

Since the report was essentially a materials inventory of weapons plutonium, the inclusion of amounts of plutonium discharged in waste was a normal part of the way in which nuclear materials are accounted for in the weapons complex. However, in the course of compiling the data, the DOE found that the plutonium inventories in waste that were part of the materials accounting documentation at DOE Headquarters, which were used to prepare the Fifty Years Report, did not match the plutonium inventories in waste generated by DOE Operations Office or the Sites that were used to compile waste data. Surprisingly, the discrepancies were large in some cases, with Los Alamos having the largest discrepancy by far.

The size of the discrepancies led to an internal memorandum, prepared for the Secretary of Energy, that detailed the discrepancies between the two accounts.[69] That memorandum is reproduced in Appendix A. Moreover, neither of these accounts appears to match other data – notably the data that are part of the formal process of sending wastes to the Waste Isolation Pilot Plant (WIPP – the deep geologic repository to which retrievably stored transuranic wastes are being sent for disposal). WIPP was licensed to receive the waste under a long and costly process overseen by the U.S. Environmental Protection Agency, with advisory scientific reports being prepared by various bodies, including the National Research Council.

IEER has undertaken this detailed analysis of plutonium in waste at Los Alamos because (i) the discrepancies in the data have immense implications for environmental management, long-term stewardship and monitoring of the site, the operation and closure of the WIPP, and security of weapons usable nuclear materials, and (ii) so far as public evidence indicates, the DOE has utterly failed to perform the needed follow-up.

The data from that memorandum pertaining to Los Alamos and the two other sites where the waste from plutonium pit manufacture was stored and/or dumped, Rocky Flats and Idaho National Laboratory,[70] are summarized in Table 1 below:.

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[68] DOE 1996. Unless otherwise specified, the reference to "plutonium" in this chapter is to the mix of plutonium isotopes in weapons plutonium in the DOE complex that is dominated by plutonium-239 and plutonium-240 in terms of weight. The mass quantities given, therefore, should be interpreted as Pu-239/Pu-240, unless otherwise specified.

[69] Guimond and Beckner 1996

[70] It is now called Idaho National Laboratory (INL). It was originally Idaho National Engineering Laboratory (INEL) and then Idaho National Engineering and Environmental Laboratory (INEEL). For convenience, we will use INL in this report, regardless of the period.

Table 1: Discrepancies in data on plutonium in waste, 3 sites with weapons processing waste

Site	50 years report	IDB report	IDB report	IDB report	IDB report
	kg	total kg	kg in HLW	kg retrievable (WIPP)	kg in buried waste
LANL	610.00	1,375.30		1,323.70	51.60
INL	1,051.00	1,131.00	80.00	694.00	357.00
Rocky Flats	47.00	191.91		191.91	
Total, 3 sites	1,708.00	2,698.21	80.00	2,209.61	408.60

Source: Guimond and Beckner 1996, Attachment B and for last three columns Attachment C.
Notes: 1. The values are reported to two decimal places in Guimond and Beckner 1996.
2. The Attachment B IDB value for Idaho does not include the plutonium in high-level waste (HLW).
3. Data are as of September 1994.
4. IDB stands for "Integrated Database"

Table 1 shows that there are two sets of plutonium accounts so far as estimates of the amounts that have been discharged to the waste are concerned. Los Alamos has by far the largest discrepancy between these accounts, amounting to about 765 kilograms (we ignore the false accuracy of the DOE reporting of the data to the nearest 0.01 kilograms), which is enough to make more than 150 nuclear bombs.[71] IEER has pointed to these discrepancies for many years, beginning with its 1997 report on environmental remediation in the nuclear weapons complex.[72] IEER also called attention to the problem during the independent audit of Los Alamos compliance (or lack thereof) with the Clear Air Act.[73] Finally, IEER initiated a letter, signed by two New Mexico groups, to LANL director Peter Nanos calling his attention to the environmental and security aspects of the discrepancies and asking for an investigation to reconcile plutonium accounts to reduce discrepancies. That letter is reproduced in Appendix B.

Since IEER did not obtain a substantive response, we decided to undertake an analysis of the problem to the extent possible with public data on waste. IEER has compiled the available data on plutonium in waste original in weapons manufacturing processing. That is, we undertook to develop estimates of how much waste is generated in the course of making plutonium pits, once separated plutonium is available. This is the main kind of plutonium waste that would be expected to be generated at Los Alamos.[74]

The first observation from Table 1 is that the discrepancy in the LANL plutonium accounts in waste between the 50 Years Report and the Integrated Data Base Report (IDB) is about 765 kilograms or about 150 bombs worth of plutonium, assuming 5 kilograms per warhead.

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[71] Unless otherwise specified, we will consider that a bomb can be made of 5 kg. of weapons grade plutonium. It can be done with somewhat less. The Nagasaki bomb had just over 6 kilograms of plutonium in it.

[72] Fioravanti and Makhijani 1997.

[73] Makhijani and Franke 2000, Makhijani and Franke 2000b, Makhijani and Franke 2002

[74] Experiments that had other isotopes predominant in them, notably plutonium-242, have also been done at LANL. This analysis is focused on the discrepancies in weapons plutonium, which consists almost entirely of Pu-239 and Pu-240 (by weight).

However, this is not a true indication of the discrepancies in the plutonium in LANL waste. This is because it is not clear whether either number (610 kilograms or 1,375 kilograms is correct). There are clear indications that neither figure is accurate. Hence, estimating the amount of unaccounted for plutonium in LANL waste requires more data and analysis.

The DOE has acknowledged that the waste data in the IDB, as well as other waste data for buried transuranic waste produced prior to the IEER 1997 report *Containing the Cold War Mess*, was not founded on a scientific assessment of the problem. This conclusion in IEER's report regarding buried transuranic waste data was based on a review of reported amounts of buried TRU waste at various sites. The values for LANL shown in that report are reproduced in Figure 1.

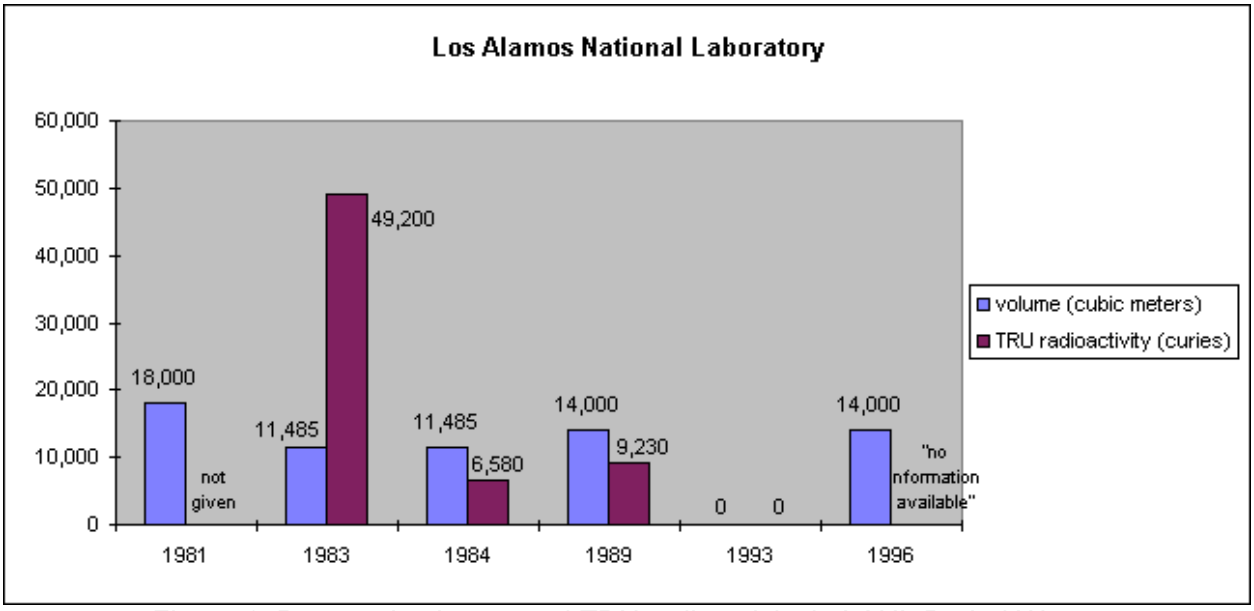

Figure 1: Reported volumes and TRU radioactivity in LANL Buried Waste.
Source: Fioravanti and Makhijani 1997. The Environmental Evaluation Group of the State of New Mexico has also reported similar discrepancies in buried TRU waste data.

After IEER's 1997 report was issued, the DOE initiated a multi-year review of its conclusions, including its findings on waste. As part of the review, the DOE issued a new report on buried TRU waste (DOE 2000). Further, the then-Assistant Secretary of Environmental Management, Carolyn Huntoon, sent a letter in July 2000 to IEER about DOE's revised waste numbers to IEER, which included the following statement:

> Your 1997 report indicated that DOE's "Official data on the volume, mass, and radioactivity of buried transuranic waste and transuranic soil are inconsistent and contradictory. There *does not appear to be any scientific basis on which data are entered and changed from one year to the next*, and one document to the next." *The DOE agreed with this criticism* and, in response, committed to "undertake a review and update of its information on its inventory of buried TRU wastes as well as the status of remedial decisions proposed or made to date." The DOE further committed to update the information using consistent and documented assumptions. The results from this study have been compiled and analyzed by

> my staff and are presented in the enclosed main report and data base in fulfillment of the March 1998 commitment.[75]

Given that the buried TRU waste data were unreliable up to and including 1996, we looked at the revised DOE report for buried waste data as well as the data on retrievably stored TRU waste that is slated to go to the Waste Isolation Pilot Plant, a deep geologic repository in New Mexico as well as the revised data on buried TRU waste published by the DOE in response to IEER's criticisms of waste data.

A perspective on the reasonableness of the data on plutonium in waste can be gained from publicly available estimates of how many warheads and therefore how many pits, most of which would be expected to contain plutonium, were made at LANL. The values of plutonium in waste can be checked for reasonableness by estimating the waste per pit at LANL. A point of comparison for waste per pit is obtained by compiling comparable data on plutonium in waste associated with pit production at Rocky Flats.

The approach requires TRU waste data from three sites:

- LANL,
- Rocky Flats, and
- Idaho National Laboratory (INL)

Data from the Idaho National Laboratory are needed because the bulk of the plutonium containing waste from Rocky Flats was shipped to INL. Prior to 1970, the TRU waste was shipped from Rocky Flats to INL in cardboard boxes, 55-gallon drums, and wooden boxes and dumped in open pits and trenches. It was all designated as "low-level" waste then. The category "transuranic waste" waste was created after a fire at Rocky Flats in 1969.[76]

Data on retrievably stored waste are better documented at least in terms of volume, since the number of containers is easily identifiable. Extensive waste characterization has been necessary in order to qualify the waste for shipment to WIPP. Hence, WIPP data, sorted by origin of the waste, provide a third point of reference regarding plutonium in waste, with the first two being the 50 Year Report and DOE revised Integrated Database for buried TRU waste (DOE 1999 and DOE 2000).

Table 2 shows data on retrievably stored TRU waste that has been, or is destined to be sent to WIPP for the three sites that are relevant to this study: LANL, Rocky Flats, and INL. The data include all TRU waste slated to be disposed of in WIPP until closure, which is now scheduled for 2030. While the figures include future TRU waste that will be generated to the time of WIPP closure, the vast majority of the waste has already been generated, notably during the production of tens of thousands of warheads during the Cold War.

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[75] Huntoon 2000, emphasis added.

[76] Makhijani and Boyd 2001. This report addresses buried waste and water protection issues at INL.

Table 2: TRU Waste Disposed of or Slated to Be Disposed of in WIPP for Three Sites.

WIPP Plutonium total CH and RH for Three Sites						
	Idaho	Rocky Flats	LANL	Idaho	Rocky Flats	LANL
	Curies	Curies	Curies	kg	kg	kg
Pu-239	57,035	74,000	11,003	909	1,179	175
Pu-240	7,633	17,000	3,700	33	74	16
Pu-241	51,066	180,000	31,000	0.5	1.7	0.3
Pu-242	12	1.7	0.8	3.0	0.4	0.2
Total	115,746	271,002	45,704	945	1,255	192

Source: DOE 2004. Values are reported as decay-corrected to December 31, 2001.
Note: CH = contact handled waste and RH = remote handled waste. Almost all the plutonium content of the waste in this table is attributable to contact handled waste.

The first noteworthy item is that the total figure for plutonium in retrievably stored waste at LANL is far lower than either figure for plutonium in waste reported in Guimond and Beckner 1996 (see Table 1 above). Since the Guimond and Beckner 1996 memorandum includes all wastes, estimates of plutonium in low-level waste and buried transuranic waste must be added to the figure of 192 kilograms to determine if a significant weapons plutonium accounting issue exists at LANL and, if so, what its implications might be.

In 1999, the DOE published datasheets containing revised estimates for all wastes containing transuranic radionuclides, except for the retrievably stored wastes.[77] These datasheets were summarized in a report that the DOE issued in June 2000.[78] Since the latter are covered by the compilation shown in Table 2 above, a complete set of estimates for plutonium in wastes requires the addition of the data contained in these two reports. In other words, the waste that tis retrievably stored or has been sent to WIPP already must be added to the waste that was buried without the expectation that it would be recovered and sent to a geologic repository. We have done this for all three sites shown in Table 2.

DOE 2000 reports that LANL had a total of about 21,000 curies of alpha-emitting transuranic radionuclides in buried TRU and low-level waste.[79] The LANL section of DOE 1999 reports that almost all of this (20,844 curies) was buried at LANL in trenches or pits. The value is not decay-corrected and there are no data on isotopic content of the waste.[80] Strangely, DOE 1999 states that all of the radioactivity can be considered as plutonium-239 because "no [isotopic]

[77] DOE 1999

[78] DOE 2000

[79] DOE 2000, Table 5.

[80] DOE 1999, page 43 of the LANL section. This datasheet is reported as being generated on December 17, 1999. The volume of the emplaced waste is reported as being 184,000 m^3 and the radioactivity context is reported as being the "initial (emplaced) values."

inventory data are available."[81] This is undoubtedly an incorrect assumption. While Pu-241 accounts for only a small portion of the weight of weapon-grade plutonium, it generally accounts for a significant portion of the radioactivity. It decays rather rapidly, with a half-life of 14.4 years, compared to the other plutonium isotopes of concern here, which have half-lives of thousands of years. The radioactivity of Pu-239, Pu-240, and Pu-242 can be assumed to be constant over the time periods of interest here (a few decades), while the activity of Pu-241 declines considerably. As Pu-241 declines, americium-241 builds up, since the former decays into the latter, which has a half-life of 432 years.

The data in table 2 indicate that the relative amount of Pu-241 contained in the mix of plutonium isotopes slated to be sent to WIPP was about 44 percent (INL), about 66 percent (Rocky Flats), and about 68 percent (LANL) for wastes that were decay corrected to December 31, 2001. In other words, the proportion of Pu-239/Pu-240 by radioactivity content was about one-half to one-third of the total plutonium radioactivity. Moreover, there was also a significant amount of Am-241 in LANL waste (almost half the radioactivity of Pu isotopes, decay-corrected to December 31, 2001). The proportion of Pu-241 in originally emplaced waste (before the generation of a significant amount of Am-241 due to Pu-241 decay) would likely be ~90 percent of the total non-decay-corrected plutonium radioactivity.

The above analysis indicates that proportion of Pu-239/Pu-240 in the estimated 21,000 curies of buried waste at LANL was highly unlikely to have been more than one-third – or about 7,000 curies of Pu-239/Pu-240, even if the initial emplacement value of Am-241 is ignored. This amount of weapons plutonium would have a mass of about 120 kilograms. It is much more likely that the amount of Pu-239/240 in the buried waste at LANL was ~2,000 curies, or about 30 kilograms, based on an initial emplacement value of 21,000 curies.

Since one goal of this report is to determine the smallest amount of unaccounted for plutonium at LANL for the purpose of estimation of its implications, we have used a maximum plausible value of 100 kilograms of plutonium in buried waste at LANL in the analysis that follows. Table 3 shows the total amounts of plutonium-239/240 in buried as well as retrievably stored waste at LANL.

Table 3: Total amounts of weapons plutonium in waste at INL, Rocky Flats, and LANL

Total Buried and WIPP TRU						
	Idaho	Rocky	LANL	Idaho	Rocky	LANL
	Curies	Curies	Curies	kg	kg	kg
Pu-239	120,435	74,240	18,003	1,918	1,183	275
Pu-240	20,313	17,000	3,700	88	74	16
Total	140,748	91,240	21,703	2,007	1,257	291

Sources: DOE 2004 (see Table 2 above), DOE 1999, and DOE 2000 Table 5.

The total of 291 kilograms of weapons plutonium is far lower than either figure in the memorandum prepared in 1996 calling the attention of the Energy Secretary to discrepancies regarding plutonium in waste. The 50 Years Report (DOE 1996) is the official plutonium account in the United States. It was prepared in order to inventory plutonium in the U.S. nuclear

[81] DOE 1999, LANL Section, p. 43.

weapons complex. The above analysis indicates that the figure of 610 kilograms of plutonium in LANL waste is very likely to be wrong and an overestimate by over 300 kilograms. Seen in this light, the figure of 1375 kilograms in the IDB report, cited by Guimond and Beckner in 1996 (see Table 1 above) is also very likely to be wrong. In this analysis, there would appear to be an unaccounted for plutonium value of at least 300 kilograms, and possibly upwards of 1,000 kilograms, depending on how the various values of plutonium in waste were actually integrated into materials accounts in 1996.

3. Plutonium Waste per Warhead

Some perspective can be thrown on the above result (that at least 300 kilograms of plutonium appear to be unaccounted for at LANL) by examining the waste that one might expect per plutonium pit. LANL was not routinely a mass manufacturing site for plutonium pits. That role was played in the nuclear weapons complex by Rocky Flats. On the other hand LANL did fabricate the early warheads that contained more plutonium per warhead. Many of the warheads made at LANL were produced in the early days, when manufacturing methods were still undergoing development. In light of these complex realities, can one make an assessment of whether a value of 610 kilograms of weapons plutonium in waste is a reasonable value for LANL? If so, then the result would automatically shed light on the other value of 1,375 kilograms cited by Guimond and Beckner in their 1996 memorandum.

Table 4 shows the total plutonium in waste generated during pit production at Rocky Flats where an estimated 70,000 pits were manufactured, and LANL, where a total of about 600 pits were fabricated over five decades. It also shows the waste per warhead and waste as a percentage of plutonium processed.

Table 4: Total Plutonium Waste, percent in Waste, and Waste Per Warhead

	kg waste	Warheads, #	kg Pu processed	% Pu in waste	Waste per warhead, kg
Rocky Flats + INL, 4 kg. warhead	3,263	70,000	280,000	1.17%	0.047
LANL, 5 kg/warhead, WIPP	291	600	3,000	9.71%	0.486
LANL, 5 kg/warhead 50 Yrs	610	600	3,000	20.33%	1.017
LANL, 5 kg/warhead, 1996 IDB	1375	600	3,000	45.83%	2.292

Sources for warhead data: Ackland 1999 (for Rocky Flats) and Mann and McDonald 2001 (for LANL).
Notes: Idaho and Rocky Flats wastes are considered together for Rocky Flats production since Rocky Flats TRU waste was sent to INL. A small amount, 4 kg, (small in this context) has been added to Rocky Flats waste to account for residual plutonium in the soil based on 100,000 m^3 of soil contaminated to 10 nanocuries per gram. This was done mainly to check whether the resulting waste and percentage values are sensitive to residual radioactivity. Since they are not, the result can be regarded as robust, to the extent that the retrievable and buried waste numbers for INL are valid.

In order to provide a perspective on the utter implausibility of 610 kilograms being in waste at LANL, a value of 5 kilograms per warhead has been assumed for LANL and 4 kilograms per warhead has been assumed for Rocky Flats. If one takes the highest value of plutonium in waste

based on WIPP data and DOE 2000 (amounting to 291 kilograms), the percentage of plutonium in waste at LANL amounts to almost 10 percent of the amount processed. Such a large percentage of plutonium in waste would normally have caused materials accounting issues, criticality concerns, and also triggered recovery efforts, given the high cost of producing plutonium. By contrast, the waste data show Rocky Flats producing warheads with just over 1 percent of the plutonium winding up in the waste. Even if the plutonium in 10 percent waste were not recoverable, it would likely be stored in a secure place in containers, as was done at Rocky Flats, rather than discharged into the waste.[82]

In this light, a figure of 610 kilograms of plutonium in waste looks utterly implausible. It would represent about 1 kilogram of plutonium wasted per warhead – a phenomenal amount that would have resulted in many security and safety investigations. Waste containing such large amounts of plutonium would have been subject to criticality controls as well as plutonium recovery efforts. Further, a figure of 1,375 kilograms of plutonium in waste seems even more incredible. In view of this, as well as the fact that 610 kilograms of plutonium in waste is the basis for the official materials account, we have concluded that there is a plutonium materials accounting discrepancy of at least 300 kilograms at LANL. If the IDB figure of 1,375 kilograms is the basis for a plutonium account, the waste per warhead processed increases to a fantastic 2 kilograms.[83] Such figures carry huge environmental, safety, health, and security implications, no matter what combination of explanations one might come up with for the result. Table 5 summarizes the results for the unaccounted for plutonium in waste at LANL.

Table 5: Summary of plutonium in waste accounts for LANL

	50 yrs report	IDB/EM	WIPP and DOE 2000 based estimate	Minimum Unaccounted for Plutonium	Maximum Unaccounted for Plutonium
	kg	kg	kg	kg	kg
LANL	610.00	1,375.30	291	319	1,084.30 (unlikely)

Given the sorry state of waste data, we cannot rule out that there are an added 300 or more kilograms of plutonium in LANL waste. The additional plutonium might be in shallow land burial at LANL, for instance in Area G, in containers that have been sent to WIPP or destined to go there, implying underestimates of official WIPP plutonium estimates. If the WIPP accounts are accurate and the buried waste data are not wholly off the mark again, the huge amount of unaccounted for plutonium, enough to make at least 60 warheads, raises severe security issues.

[82] DOE 1994. At Rocky Flats, 23 percent of the plutonium stored there was identified by this DOE assessment of vulnerabilities as "mixture/scrap/res" where "res" stands for residues. Volume II, Part 1, Chart 3.9-1.

[83] IEER has no information that it is, but none that it is not. It is unlikely, in our view to be the basis for a materials account for security purposes, but given the sorry state of waste and accounting data, as well as the failure of the DOE or LANL to initiate an investigation into the problem of accounting for plutonium in waste, such a possibility cannot be ruled out *a priori*.

Section 4: Environmental Implications

One possible explanation for the discrepancies is that the unaccounted for plutonium is in some combination of retrievable and buried waste. This possibility is raised by the continued poor state of the buried waste data, even after the DOE spent three years examining the problem. In her letter to IEER, then-Assistant Secretary of Energy characterized the revised data as follows:

> The main results for the updated buried TRU study are as follows:
>
> …
>
> - Due to the *lack of adequate records on, and the lack of formal waste characterization of, the buried TRU wastes*, staff at field sites by necessity used back-extrapolations from process knowledge and facility accountability records to derive estimates of the buried TRU inventories. These types of information bases lead to *generally low confidence in the reported numbers*. [emphasis added]

Hence, even the revised data are not reliable. There has been no significant improvement in the quality of these data since the year 2000. This does raise the possibility that a large amount of the 300 or more kilograms could be in the TRU waste that was buried at LANL before 1970 (it was all called low-level waste then). Were this to be true, it would have very significant environmental and health implications. We performed a RESRAD analysis of an additional 300 kilograms of plutonium buried in Area G at a depth of 4 feet, with the very low erosion rate that is used by LANL in its calculations (5 to 50 times slower than typical for semiarid areas).[84] Even these assumptions oriented to low impact results, indicate that once the surface is eroded away sufficiently for the roots of plants to reach the waste the resultant doses in the very long term (more than 10,000 years) could be about a 100 times larger than the maximum dose target of 15 mrem/per year set by LANL. If a faster erosion rate is considered, as is reasonable, high doses would result much faster.

The RESRAD run and the assumptions and parameter values on which the results are based are shown in Appendix C.

It is also possible that the additional plutonium could be in containers that have been sent to or are slated to go to WIPP. In a 1998 evaluation done for the New Mexico Attorney General's office, IEER found that the data characterizing the initial 36 containers to be sent to WIPP contained many deficiencies, including missing and incomplete documentation:

> 3.1 Missing Documentation
>
> There are two types of missing documentation. The first is when a data package is missing a form in its entirety. For example, Drum LA 55666 is missing the

[84] See memorandum by James Carr and other analysis in Makhijani and Smith 2005.

Waste Origination and Disposition Form for one of the waste packages in the drum….

…

- Waste Drum Report/Printed TWSR. Some information (such as confirmatory assays) are only presented on these forms and do not appear on their written counterparts. In cases where these cover sheets were missing *it was impossible to determine if there was agreement between estimates of the amount of Special Nuclear Material in the drum (see below)*.

The second type of missing documentation is when a portion of a form is missing. A number of drum data packages are missing the second page of the Transuranic Waste Storage Record and/or the Waste Profile Form.

3.2 Incomplete Documentation

Incomplete documentation consists of sections of forms being incomplete, missing signatures, or missing data entries. *One example of incomplete forms is the second page of the Transuranic Waste Storage Record. It is blank for all drums (except those in which the second page is completely missing). It is not clear at this time why this page is always either blank or missing. Again, this shows a lack of documentation on the storage of TA-55-43 waste at the TA-55 storage area.* Signatures are missing from a number of Document Traveler forms, as well as TRU Waste Manifest forms and one DWLS.

The following are examples of missing data entries:

…

- The weight measurements of individual packages are not always complete. *In many cases the gross weight was either not measured and/or not recorded. Furthermore, blank entries are assumed to be zero in adding the gross weights and therefore the total of the gross weight is in error in these cases.* In at least one case the gross weight was measured and recorded on the WODF but not on the DWLS printout.[85]

Given that these deficiencies existed in packages that the DOE had spent large amounts of money to characterize, it might safely be assumed that the state of the documentation for the rest of the packages destined for WIPP would not be vastly superior. It is possible therefore that the wastes going to WEIPP from LANL have considerably more plutonium than is indicated by the WIPP documentation published by the DOE (DOE 2004). This raises troubling questions of oversight, safety, transportation emergency response, and WIPP repository performance assessment. Such questions are beyond the scope of this report but would need to be addressed in any investigation of the LANL plutonium-in-waste issue.

The remediation and long term stewardship implications of such large amounts of additional plutonium in shallow land burial for instance in Area G is immense. Evidently the dose calculations indicate that it could no be left in the soil. The average concentration of plutonium-239 could be approximately 23 nanocuries per gram. Hot spots might run far higher.

[85] Franke and Zerriffi 1998, pp. 10-11, emphasis added.

At the same time recovery of vast amounts of soil with unknown hot spots would be very expensive and pose considerable safety challenges, mainly due to the unknown dispersal of the plutonium and unknown disposal patterns. If the material is not recovered, the long term stewardship implications would not only involve environmental monitoring but also security issues.

For these reasons, it is imperative that the issues of the unaccounted for plutonium be addressed if only to rule out that vast amounts were put in shallow land burial.

Section Five: Security Implications

The data and analysis above raise the clear possibility that some or all of the plutonium that is not accounted for (300 kilograms or more) may not be in the waste. This is a very distinct possibility, since the comparison waste per unit of plutonium processed and per warhead indicates that it is improbable that as much as 300 kilograms of plutonium above the amount indicated by WIPP and buried waste data would have resulted from LANL pit production operations. The security implications of a loss of even a few percent of 300 kilograms are extremely serious, since less than two percent of the lowest unaccounted for plutonium is enough to make one nuclear bomb.

In 2004, when LANL was shut down for a security reasons, three organizations[86] sent a letter to LANL Director Peter Nanos raising concerns about the environmental and security implications of the discrepancies in plutonium in waste accounts reported in Guimond and Beckner 1996. That letter is reproduced in Appendix B. Guimond and Beckner mention that a DOE task force to look into the plutonium accounting problem was established. But no account of its work has been forthcoming since 1996. It is unknown whether it did any work or analysis and if so what.

The apparent failure of LANL or the DOE to address such a vast security issue is puzzling and troubling, to say the least. It raises questions about the origins of the data presented in the 50 Years Report, the nature of plutonium accounting, and the apparent lack of vigilance on the part of the authorities regarding large discrepancies in plutonium accounts. A small fraction of the discrepancy is large enough to cause concerns of the highest magnitude. For perspective, 300 kilograms is roughly seven times the amount of plutonium that North Korea is supposed to possess that has rightly been the object of immense concern to the United States and other countries as well as the International Atomic Energy Agency.[87] Why the large amount of unaccounted for plutonium has not excited significant concern remains a mystery. It can only be addressed by an urgent, independent, and thorough investigation.

[86] IEER, Concerned Citizens for Nuclear Safety, and Nuclear Watch of New Mexico.

[87] The most recent estimate of North Korea's plutonium stock is 40 to 55 kilograms as of mid-2005. ISIS 2005. International concerns were already high when North Korea's plutonium stock was estimated to be in the 20 to 30 kilogram range.

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Appendix A

DOE F 1325.8
(8-89)
EFG (07-90)

United States Government **Department of Energy**

memorandum

DATE: JAN 30 1996

REPLY TO
ATTN OF: Jenny Craig, EM-24

SUBJECT: Plutonium in Waste Inventories

TO: Distribution

The purpose of this memorandum is twofold: (1) to inform you of information to be released at the Secretary's Press Conference as part of the Department's Openness Initiative scheduled for February 6; and (2) to request your assistance in analyzing the causes and recommending corrections for differences between systems that track plutonium inventories. The Department will be releasing a report entitled "Plutonium: The First Fifty Years," which includes an appendix on how much plutonium the Department has in waste. The information for this appendix was taken from the Nuclear Materials Management and Safeguards System (NMMSS) database, and presents a 0.5 metric ton inconsistency between what is considered waste and what is considered "normal operating losses" (NOL). In addition, the waste numbers in NMMSS do not always correspond to waste information in the Office of Environmental Management's Integrated Database and other site-specific sources.

We have been working with your staff on these waste data differences, but realistically these inconsistencies cannot be completely resolved before the Openness Initiative press conference. Therefore, the Secretary has established a working group to study the different accounting methods for plutonium data, to resolve differences from these methods, and to make recommendations on the appropriateness of making changes to how the Department tracks its plutonium inventories.

You should be aware that the news media and public may contact your site with questions about these inconsistencies. The primary difference between waste and NOL as reported in NMMSS is found at Hanford; inconsistencies between waste as reported in NMMSS and waste as tracked by the Environmental Management program are found primarily at five sites: Savannah River Site; Los Alamos National Laboratory; Oak Ridge National Laboratory; Idaho National Engineering Laboratory; and Rocky Flats Environmental Technology Site.

For your information, we have attached:

(1) Table of plutonium waste data from NMMSS that will be released to the public on February 6 (attachment A);

(2) A side-by-side table of the report's data and the Environmental Management data for you to better understand the inconsistencies between NMMSS data and IDB and other site data (attachment B);

(3) A more detailed breakdown of the Environmental Management estimates (attachment C).

We request that you continue to resolve the differences in accounting for how much plutonium in waste is reported at your site. Attachment D presents a list of contacts at the five sites. As the working group is more formally established, you will receive a request for an initial report on the different plutonium waste numbers.

The Department's preliminary explanation for (1) the inconsistency within NMMSS of plutonium waste and NOL; and (2) the inconsistency between waste data in NMMSS and other sources, such as the IDB, is summarized below:

1. Plutonium in "Waste" Estimates Compared with "Normal Operating Losses".

Plutonium that is technically or economically unrecoverable and intentionally sent to waste is referred to as "normal operating losses" (NOL) and is removed from the DOE/DoD plutonium inventory. The plutonium in waste is not subject to the same degree of rigorous safeguards and security as the DOE/DoD plutonium inventory.

- The quantities of plutonium removed from the DOE/DoD inventory and placed in waste as NOL are determined by either direct measurement or estimated based on measured sampling methods and practices -- for example, all liquid wastes are sampled and analyzed prior to being sent to a waste tank. The NMMSS indicates that a total of 3.4 metric tons (MT) of plutonium were sent to waste by way of NOL.

- The method used to estimate plutonium in waste burial sites and tanks was based on extrapolation from direct measurements of the waste -- for example, a small sample of radioactive waste is taken from a waste tank, the amount of plutonium in that sample is analyzed, and the amount of plutonium is estimated by multiplying this small sample times its relative proportion in the larger waste volume. The total amount of plutonium in NMMSS waste accounts is 3.9 MT.

Because the NMMSS was originally designed for safeguards purposes for nuclear materials, there was no need to reconcile the NOL quantities with the later quantities recorded in the NMMSS waste accounts. The 0.5 MT difference in NMMSS between the NOL estimate (3.4 MT) and the "waste" estimate (3.9 MT) is attributable to two primary causes:

(a) Waste inventories are tracked for environmental, safety and health reasons, and are therefore not necessarily calculated like normal operating losses. Waste inventory calculations and normal operating losses both rely on independent measured estimates,

which lead to some degree of uncertainty in each. The normal operating losses are used for safeguards and security purposes and may not include all the information that may be required for waste inventories.

In the early 1970s, sites began reporting details of plutonium in waste for the first time in NMMSS. At most sites the estimates of the amount of plutonium estimated to be in "waste" were based on direct measurement of waste and provided confirmation of the NOL estimates of waste. In the case of Hanford, however, the 1974 estimate indicated 0.4 MT more plutonium in waste than in normal operating losses. This difference could be either: (i) an accounting error at the site, such as reporting plutonium already included in the normal operating losses; or (ii) additional plutonium not captured by the normal operating losses tracking system, and therefore likely reported as "inventory differences." While site records do not allow the Department to determine the source of this inconsistency at this time, the Department has performed additional analysis supporting the higher estimate of plutonium in waste and, using this higher estimate, has determined that there are no imminent health, safety, or environmental risks. Since 1974, the normal operating losses and waste inventories have tracked very closely.

(b) Waste includes off-site sources, including plutonium waste from the Navy and from licensed commercial facilities. Most commercial waste came from two facilities that fabricated fuel for reactors: the Nuclear Fuel Services at Erwin, Tennessee, and Cimarron Corporation at Cresent, Oklahoma. Normal operating losses include only waste generated from on-site production. Since 1974, the remaining 0.1 MT inconsistency tracks closely to wastes received from sources outside of the Department.

(2) "Waste" Estimates in the NMMSS System Compared to Other "Waste" Inventories.

In addition to the difference between waste and normal operating losses within NMMSS, the amount of plutonium waste in this report may not reflect the amount of waste reported in other Departmental sources, such as the Integrated Database (IDB) or site-specific waste tracking systems. Two primary reasons for these apparent inconsistencies include: (1) the NMMSS waste data reflect only fissile plutonium inventories (i.e., Pu-239), while other sources include all isotopes of plutonium; and (2) the IDB does not differentiate between waste that requires nuclear material safeguards, and therefore is still recorded as part of the inventory, and waste that is physically sent to a waste burial site. Because of different intended uses of these databases, differing quantities of plutonium in waste can arise.

As stated earlier, the Department's working group will examine these issues and make recommendations on the appropriateness of integrating the various inventory systems or developing a new tracking system for all forms of plutonium.

If you have any questions, please contact Jenny Craig at (202) 586-8106 in the Office of Planning, Policy and Budget (EM-24). For specific information on the Environmental Management estimates of plutonium waste inventories, please contact Matt Zenkowich,

Office of Waste Management (EM-35) at (301) 903-7126; for information on estimates of other plutonium inventories managed by EM-funded activities and facilities, please contact Rick Martinez, Office of Nuclear Materials and Facilities Stabilization (EM-65) at (301) 903-4484; and for questions on the data in the report "Plutonium: The First Fifty Years," please contact Len Myers, Office of Defense Programs, at (301) 903-5366.

Richard J. Guimond, Admiral
Assistant Surgeon General, USPHS
Principal Deputy Assistant Secretary
for Environmental Management

Everet H. Beckner
Principal Deputy Assistant Secretary
for Defense Programs

Attachments

ATTACHMENT A : "50 YEARS OF PLUTONIUM" APPENDIX

Table 16. DOE Plutonium In Waste Inventory

Location	kg Pu	Description
Savannah River Site Burial Ground	193	Solid waste stored in containers. Waste consists of many forms when packaged - nitrates, fluorides, oxides, and oxalates. Over time, the oxidizing conditions force the chemistry of the metals to their most stable form. At this time, the primary form of material in the containers is an oxide or a complex form involving oxygen.
	382	Liquid waste in high level waste tanks. This material will eventually be converted to a glass form for long term storage.
Los Alamos National Laboratory Burial Ground	610	Solid waste in various forms.
Nevada Test Site Burial Ground	16	Solid waste received from Rocky Flats Plant and Pantex Plant is stored in retrievable land burial or in above ground containers.
Argonne National Laboratory-West	2	Plutonium embedded in irradiated reactor test loops and reactor blanket assemblies stored in dry storage tubes underground.
Hanford Site	455	High level waste in the tank farms.
	875	Solid waste in the burial grounds.
	192	Low level waste in cribs, trenches and ponds.
Oak Ridge National Laboratory	41	Particulate waste, as sediment in a settling basin, dry solids and oxides in above and below surface burial grounds, and solution and sludge in storage tanks.
Idaho, Waste Management	1,026	Solid waste in drums and boxes received primarily from Rocky Flats Plant is stored in above ground pads covered with earthen berms.
Idaho, Idaho Chemical Processing Plant Waste Farm	8	Solutions stored in tank farms.
	72	Calcined waste stored in bins.
Rocky Flats - Awaiting Disposition	47	Solid waste packaged in drums and crates awaiting shipment to a burial site.
Total	3,919	

ATTACHMENT B

INCONSISTENCIES IN THE AMOUNT OF PLUTONIUM IN WASTE (KG OF PU SHOULD BE REPORTED AS OF SEPTEMBER 1994)

SITE	"50 Years" Report	IDB/other EM sources	Why difference in accounting?
Savannah River Site (1) Solid waste in containers	193.00	184.50	Report table may include #3 in this category, which would make difference of 1.7 kg.
(2) Liquid HLW in tanks	382.00	774.60	SRS waste management agrees with higher number.
(3) Buried TRU		6.80	Might be included under #1.
Los Alamos NL Solid waste in various forms	610.00	1,375.30	EM number includes 1,323.7 in stored TRU and 51.6 in buried waste. AL waste management agrees with higher number. Is full difference due to what is still managed under safeguards and security?
Nevada Test Site Solid waste	16.00	13.00	
Argonne NL - West Pu embedded in irradiated reactor test loops and rector blanket assemblies stored in dry storage tubes underground.	2.00		Maybe this amount was reported for Idaho?
Argonne NL - East Pu in stored TRU		0.57	Not mentioned in report table.
Hanford Site (1) HLW in tanks	455.00	455.00	No difference
(2) Solid waste in burial grounds *and in storage*	875.00	875.00	No difference.
(3) Waste in cribs, trenches, ponds	192.00	192.00	No difference.
Oak Ridge NL (1) Particulate waste, as sediment in a settling basin, dry solids and oxides in above and below surface burial grounds, and solution and sludge in storage tanks.	41.00		Same category as #2?
(2) Pu stored in TRU		21.82	Same category as #1?
Idaho NEL (1) Solid waste	1,026.00	1,051.00	Does EM number include 2 kgs. reported under Argonne West?

SITE	"50 Years" Report	IDB/other EM sources	Why difference in accounting?
(2) High-level waste (in tanks and calcined)	80.00	80.00	No difference.
Rocky Flats Solid waste ("awaiting shipment to a burial site")	47.00	191.91	RF waste management agrees with higher number. Is full difference due to Pu still managed under safeguards and security?
WVDP High-level waste		0.50	Not mentioned in report table
Lawrence Livermore Pu in stored TRU		2.63	Not mentioned in report table
TOTAL WASTE	3,919.00	5,224.63	

Note: Sites with less than .5 kg not included: Lawrence Berkeley NL, Paducah, Pantex, ETEC, and Mound.

ATTACHMENT C

ENVIRONMENTAL MANAGEMENT ESTIMATES OF PLUTONIUM (Pu) IN WASTE AS OF SEPTEMBER 1994 (a)

Site	Pu in High Level Waste (kg)	Pu in Stored Transuranic Waste (kg) (b)	Pu in Buried Waste (kg) (c)	Pu in Soils (e.g., cribs) (kg)	Total Pu in Waste (kg)
Argonne -East		0.57			0.57
Argonne -West					
Hanford	455.00	515.00 (d)	360.00 (d)	192.00 (d)	1,522.00
Idaho Nat'l Eng. Lab.	80.00 (f)	694.00	357.00 (e)		1,131.00
Lawrence Livermore NL		2.81			2.81
Los Alamos NL		1,323.70	51.60	0.12	1,375.42
Nevada Test Site		7.26	5.73		12.99
Oak Ridge NL		21.82			21.82
Rocky Flats		191.91			191.91
Savannah River Site	774.60	184.50(g)	6.80 (g)		965.90
West Valley	0.50	<0.01			0.51
TOTAL	1,310.10	2,941.58	781.13	192.12	5,224.93

(a) All information from Integrated Database (IDB) Report Revision 11 (Sept. '95) except as noted. This table does not include sites with less than 0.5 kg of Pu in waste: ETEC, Lawrence Berkeley NL, Mound, Paducah, and Pantex. It also does not include "materials in inventory" that have not been declared waste but that are not longer needed for their original purposes.
(b) Post-1970 transuranic (TRU) waste in storage, both contact-handled and remote-handled.
(c) Pre-1970 buried TRU waste.
(d) Richland Operations Office, Solid Waste Information Tracking System.
(e) IDB Report Revision 8 (Oct. 1992).
(f) Idaho National Engineering Laboratory (INEL).
(g) Savannah River Site communication (1/96).

Appendix B

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INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

August 10, 2004

G. Peter Nanos
Director, Los Alamos National Laboratory
P. O. Box 1663
Los Alamos, NM 87545

Dear Director Nanos,

Thank you very much for the difficult decision you made to stand down operations at the Los Alamos National Laboratory (LANL) so that serious security and safety issues could be addressed.

There is, however, another critical security and safety problem that the staffs of LANL and Department of Energy (DOE) headquarters have ignored for several years. It relates to an immense discrepancy in the accounts for how much plutonium is in the waste at LANL. We suggest that this issue be considered and resolved before LANL resumes full-scale operations.

The problem was discovered in January 1996 when then-Secretary of Energy Hazel O'Leary published a report entitled Plutonium: The First Fifty Years as part of her openness initiative. At that time Admiral Richard J. Guimond, then Principal Deputy Assistant Secretary for Environmental Management, and Principal Deputy Assistant Secretary for Defense Programs Everet H. Beckner prepared a memorandum detailing plutonium accounting discrepancies throughout the nuclear weapons complex. That memorandum is attached to this letter.

The Guimond-Beckner memorandum shows that the security-related nuclear materials accounts do not agree with the waste accounts. The Department of Energy reported a discharge to waste from LANL of 610 kilograms of plutonium; Los Alamos indicates a figure of 1,375 kilograms (Attachment B of the memorandum). Evidently, there is a discrepancy of 765 kilograms, the equivalent of 150 nuclear weapons. This is unacceptable by any imaginable standards and constitutes a crucial security, environmental, and safety issue.

Attachment B to the memorandum also clearly shows that the plutonium accounting discrepancy is by far the largest for Los Alamos. The second largest discrepancy of 391 kilograms is at Savannah River Site, mainly relating to the high-level waste tanks.

The huge discrepancy at LANL is especially troubling and puzzling because Los Alamos was not continuously an industrial-scale production site. If the LANL number is anywhere close to correct, then there may be very serious implications regarding the lack of due care in minimizing losses of an extremely expensive, proliferation-sensitive, and dangerous material.

On the other hand, if the 1,375 kilograms that is now booked as waste is not, in fact, in the waste, the security implications are obvious. They are at least as serious as those of loss of nuclear weapon design information. As you know, the difficulty of obtaining fissile materials is generally considered the most important barrier to proliferation.

As the Guimond-Beckner memorandum states, Secretary O'Leary set up a working group to address the issue and urged individual sites to do so as well. The DOE working group seems to have melted away in the bureaucracy. To the best of our knowledge, LANL has yet to explain the large plutonium accounting discrepancy or address its security implications.

It is completely unacceptable for a discrepancy of 150 bombs worth of plutonium to remain on the books eight years after it was first discovered. We hope that you agree. Since you have already stood down LANL on other security and safety issues, we request that you seize this moment and immediately appoint an independent task force to investigate this issue until it is resolved. We believe it is important to continue the stand down of all plutonium operations,

including those at TA-55 and the Chemistry and Metallurgy Research building, until the accounting discrepancy is sorted out and LANL's plutonium books are reconciled.

We look to you to take this courageous and necessary action now. Please address questions regarding the memorandum to Arjun Makhijani at 301-270-5500 or 301-365-6723 or arjun[at]ieer.org. You can reach Jay Coghlan 505-989-7342 or jay[at]nukewatch.org and Joni Arends at (505) 986-1973 or jarends[at]nuclearactive.org.

Yours Sincerely,

Arjun Makhijani, Ph.D.
President, Institute for Energy and Environmental Research

Jay Coghlan
Executive Director, Nuclear Watch of New Mexico

Joni Arends
Executive Director, Concerned Citizens for Nuclear Safety

cc: Secretary of Energy Spencer Abraham
U.S. Senator Pete Domenici
U.S. Senator Jeff Bingaman
U.S. Representative Tom Udall
U.S. Representative Heather Wilson
U.S. Representative Steve Pearce
New Mexico Governor Bill Richardson
National Nuclear Security Administration Administrator Linton Brooks
University of California President Robert Dynes
U.S. Representative Sherwood Boehlert, Chairman, House Science Committee
U.S. Representative Bart Gordon, Ranking Member, House Science Committee
U.S. Representative Duncan Hunter, Chairman, House Armed Services Committee
U.S. Representative Ike Skelton, Ranking Member, House Armed Services Committee
U.S. Representative Joe Barton, Chairman, House Energy and Commerce Committee
U.S. Representative John Dingell, Ranking Member, House Energy and Commerce Committee

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Also on this site:

- 1996 DOE memorandum identifying LANL's plutonium accounting issue
- Press release
- Radio commentary: Los Alamos and plutonium

Institute for Energy and Environmental Research

Comments to Outreach Coordinator: ieer[at]ieer.org
Takoma Park, Maryland, USA

Posted August 11, 2004
Radio commentary added August 12, 2004

Appendix C

RESRAD Calculations for Disposal of Plutonium and Americium in Area G

Summary of non-default parameters used in ResRad calculations of plutonium discrepancy impacts

ResRad Parameter	Value	Source
plutonium-239 concentration	23.1 nCi/gm	300 kilograms of plutonium WIPP data indicates that for Los Alamos, Pu-239 makes up 91.4 percent of the mass of plutonium isotopes. (DOE 2004 Appendix DATA, Attachment F p. 59) 17,277 curies of Pu-239 volume of waste = 4.68×10^5 m^3 (see below) mass of waste = 7.49×10^{11} grams (see below)
plutonium-240 concentration	2.12 nCi/gm	300 kilograms of plutonium WIPP data indicates that for Los Alamos, Pu-240 makes up 8.42 percent of the mass of plutonium isotopes. (DOE 2004 Appendix DATA, Attachment F p. 59) 1,592 curies of Pu-240 volume of waste = 4.68×10^5 m^3 (see below) mass of waste = 7.49×10^{11} grams (see below)
americium-241 concentration	11.7 nCi/gm	300 kilograms of plutonium WIPP data indicates that for every curie of plutonium-239/240 there will be 0.463 curies of Am-241. (DOE 2004 Appendix DATA, Attachment F p. 59-60) 8,729 curies of Am-241 volume of waste = 4.68×10^5 m^3 (see below) mass of waste = 7.49×10^{11} grams (see below)
area of contaminated zone	33,445 m^2	Transuranic waste is reported to have been disposed of in six Area G waste disposal pits. For illustrative purposes we have assumed the unaccounted for plutonium is uniformly mixed into six pits, each 600 feet long by 100 feet wide. (Purtymun and Kennedy 1971 p. 10, Shuman, Jennrich, and Merrell 1991 p. 3-1, and Allen 2003 p. 12-13)
depth of contaminated zone	14 m	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
length parallel to aquifer	366 m	Length of two waste disposal pits. (For simplicity this assumes the pits are arranged three wide and two long on the mesa. This assumption does not affect the projected doses since the contaminants do not reach the water table.)
cover depth	1.22 m	(Purtymun and Kennedy 1971 p. 10 and Shuman, Jennrich, and Merrell 1991 p. 3-1)
cover erosion rate	2.2×10^{-5} m/yr	(Purtymun and Kennedy 1971 p. 9)
density of contaminated zone	1.6 gm/cm^3	(WCS 2004 p. 8.0-6-32)

ResRad Parameter	Value	Source
contaminated zone erosion rate	2.2×10^{-5} m/yr	(Purtymun and Kennedy 1971 p. 9)
evapotranspiration	0.982	Yields a net infiltration rate of 1 mm per year for precipitation and irrigation. This is also consistent with the measured values from long-term assessment of landfill covers. (Breshears, Nyhan, and Davenport 2005 p. 801, Birdsell et al. 2005 p. 629, and Robinson et al. 2005 p. 733)
precipitation	0.457 m/yr	(Purtymun and Kennedy 1971 p. 8 and Breshears, Nyhan, and Davenport p. 801)
irrigation	0.1 m/yr	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
runoff coefficient	0	Evapotranspiration rate sets proper level of water infiltration through the cover.
thickness of unsaturated zone	366 m	(Purtymun and Kennedy 1971 p. 8-9 and Allen 2003 p. 9)
inhalation rate	8,000 m^3/yr	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
mass loading for inhalation	1.8×10^{-4} gm/m^3	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
indoor time fraction	0.43	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
outdoor time fraction	0.27	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
fruit, vegetable, and grain consumption	176 kg/yr	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
leafy vegetable consumption	18 kg/yr	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
milk consumption	112 kg/yr	(Shuman, Jennrich, and Merrell 1991 p. 3-10)
meat and poultry consumption	85 kg/yr	(Shuman, Jennrich, and Merrell 1991 p. 3-10)

DOSE: All Nuclides Summed, Component Pathways

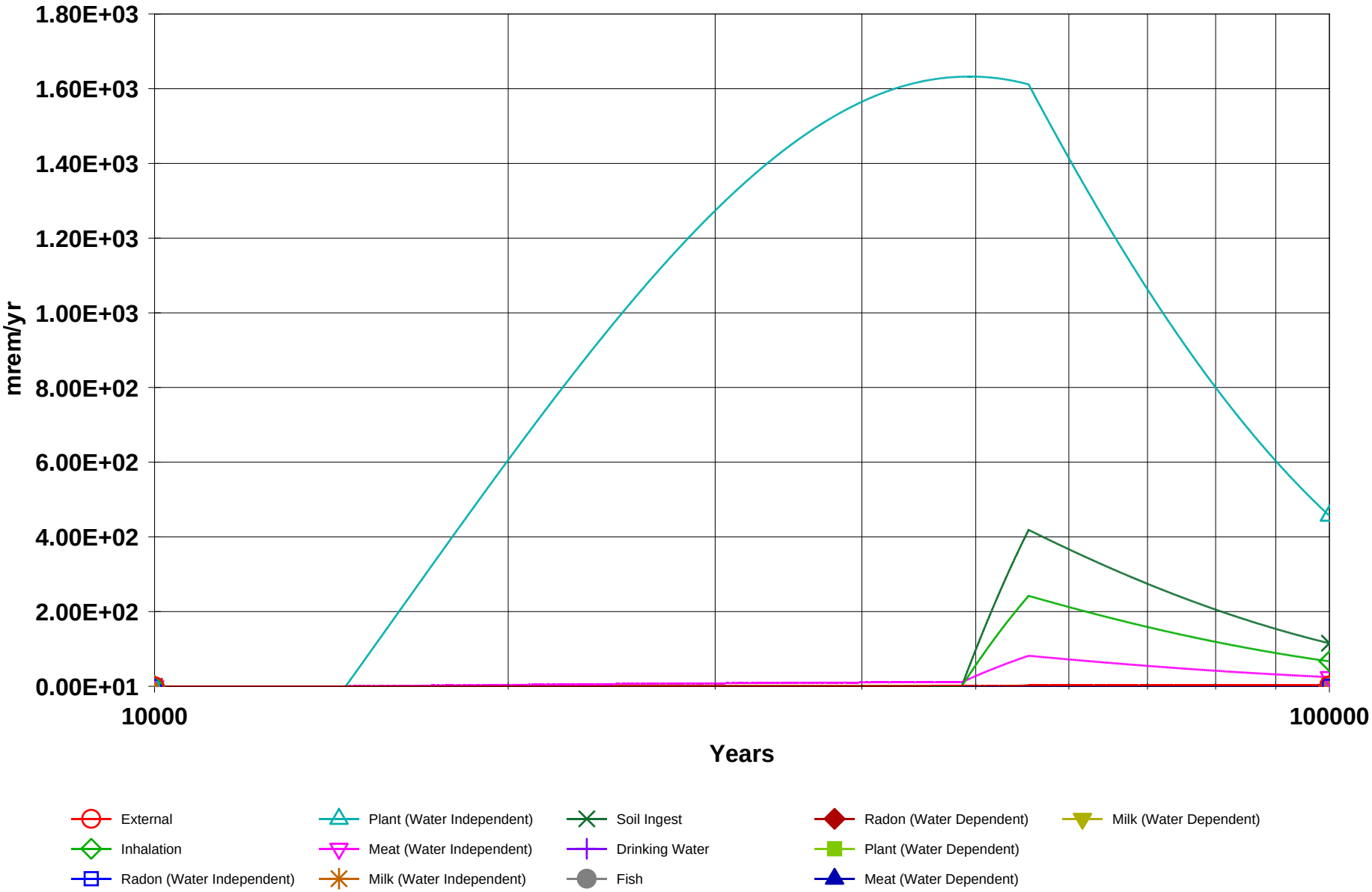

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Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

Dose Conversion Factor (and Related) Parameter Summary
File: FGR 13 MORBIDITY

Menu	Parameter	Current Value	Base Case*	Parameter Name
B-1	Dose conversion factors for inhalation, mrem/nCi:			
B-1	Ac-227+D	6.724E+03	6.700E+03	DCF2(1)
B-1	Am-241	4.440E+02	4.440E+02	DCF2(2)
B-1	Np-237+D	5.400E+02	5.400E+02	DCF2(3)
B-1	Pa-231	1.280E+03	1.280E+03	DCF2(4)
B-1	Pu-239	4.290E+02	4.290E+02	DCF2(5)
B-1	Pu-240	4.290E+02	4.290E+02	DCF2(6)
B-1	Ra-228+D	5.078E+00	4.770E+00	DCF2(8)
B-1	Th-228+D	3.454E+02	3.420E+02	DCF2(9)
B-1	Th-229+D	2.169E+03	2.150E+03	DCF2(10)
B-1	Th-232	1.640E+03	1.640E+03	DCF2(11)
B-1	U-233	1.350E+02	1.350E+02	DCF2(12)
B-1	U-235+D	1.230E+02	1.230E+02	DCF2(13)
B-1	U-236	1.250E+02	1.250E+02	DCF2(14)
D-1	Dose conversion factors for ingestion, mrem/nCi:			
D-1	Ac-227+D	1.480E+01	1.410E+01	DCF3(1)
D-1	Am-241	3.640E+00	3.640E+00	DCF3(2)
D-1	Np-237+D	4.444E+00	4.440E+00	DCF3(3)
D-1	Pa-231	1.060E+01	1.060E+01	DCF3(4)
D-1	Pu-239	3.540E+00	3.540E+00	DCF3(5)
D-1	Pu-240	3.540E+00	3.540E+00	DCF3(6)
D-1	Ra-228+D	1.442E+00	1.440E+00	DCF3(8)
D-1	Th-228+D	8.086E-01	3.960E-01	DCF3(9)
D-1	Th-229+D	4.027E+00	3.530E+00	DCF3(10)
D-1	Th-232	2.730E+00	2.730E+00	DCF3(11)
D-1	U-233	2.890E-01	2.890E-01	DCF3(12)
D-1	U-235+D	2.673E-01	2.660E-01	DCF3(13)
D-1	U-236	2.690E-01	2.690E-01	DCF3(14)
D-34	Food transfer factors:			
D-34	Ac-227+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(1,1)
D-34	Ac-227+D , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	2.000E-05	2.000E-05	RTF(1,2)
D-34	Ac-227+D , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	2.000E-05	2.000E-05	RTF(1,3)
D-34				
D-34	Am-241 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(2,1)
D-34	Am-241 , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	5.000E-05	5.000E-05	RTF(2,2)
D-34	Am-241 , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	2.000E-06	2.000E-06	RTF(2,3)
D-34				
D-34	Np-237+D , plant/soil concentration ratio, dimensionless	2.000E-02	2.000E-02	RTF(3,1)
D-34	Np-237+D , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	1.000E-03	1.000E-03	RTF(3,2)
D-34	Np-237+D , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	5.000E-06	5.000E-06	RTF(3,3)
D-34				
D-34	Pa-231 , plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF(4,1)
D-34	Pa-231 , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	5.000E-03	5.000E-03	RTF(4,2)
D-34	Pa-231 , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	5.000E-06	5.000E-06	RTF(4,3)
D-34				
D-34	Pu-239 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(5,1)
D-34	Pu-239 , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	1.000E-04	1.000E-04	RTF(5,2)
D-34	Pu-239 , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	1.000E-06	1.000E-06	RTF(5,3)
D-34				

Dose Conversion Factor (and Related) Parameter Summary (continued)
File: FGR 13 MORBIDITY

Menu	Parameter	Current Value	Base Case*	Parameter Name
D-34	Pu-240 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(6,1)
D-34	Pu-240 , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	1.000E-04	1.000E-04	RTF(6,2)
D-34	Pu-240 , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	1.000E-06	1.000E-06	RTF(6,3)
D-34				
D-34	Ra-228+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(8,1)
D-34	Ra-228+D , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	1.000E-03	1.000E-03	RTF(8,2)
D-34	Ra-228+D , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	1.000E-03	1.000E-03	RTF(8,3)
D-34				
D-34	Th-228+D , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(9,1)
D-34	Th-228+D , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	1.000E-04	1.000E-04	RTF(9,2)
D-34	Th-228+D , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	5.000E-06	5.000E-06	RTF(9,3)
D-34				
D-34	Th-229+D , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(10,1)
D-34	Th-229+D , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	1.000E-04	1.000E-04	RTF(10,2)
D-34	Th-229+D , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	5.000E-06	5.000E-06	RTF(10,3)
D-34				
D-34	Th-232 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(11,1)
D-34	Th-232 , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	1.000E-04	1.000E-04	RTF(11,2)
D-34	Th-232 , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	5.000E-06	5.000E-06	RTF(11,3)
D-34				
D-34	U-233 , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(12,1)
D-34	U-233 , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	3.400E-04	3.400E-04	RTF(12,2)
D-34	U-233 , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	6.000E-04	6.000E-04	RTF(12,3)
D-34				
D-34	U-235+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(13,1)
D-34	U-235+D , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	3.400E-04	3.400E-04	RTF(13,2)
D-34	U-235+D , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	6.000E-04	6.000E-04	RTF(13,3)
D-34				
D-34	U-236 , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(14,1)
D-34	U-236 , beef/livestock-intake ratio, (nCi/kg)/(nCi/d)	3.400E-04	3.400E-04	RTF(14,2)
D-34	U-236 , milk/livestock-intake ratio, (nCi/L)/(nCi/d)	6.000E-04	6.000E-04	RTF(14,3)
D-5	Bioaccumulation factors, fresh water, L/kg:			
D-5	Ac-227+D , fish	1.500E+01	1.500E+01	BIOFAC(1,1)
D-5	Ac-227+D , crustacea and mollusks	1.000E+03	1.000E+03	BIOFAC(1,2)
D-5				
D-5	Am-241 , fish	3.000E+01	3.000E+01	BIOFAC(2,1)
D-5	Am-241 , crustacea and mollusks	1.000E+03	1.000E+03	BIOFAC(2,2)
D-5				
D-5	Np-237+D , fish	3.000E+01	3.000E+01	BIOFAC(3,1)
D-5	Np-237+D , crustacea and mollusks	4.000E+02	4.000E+02	BIOFAC(3,2)
D-5				
D-5	Pa-231 , fish	1.000E+01	1.000E+01	BIOFAC(4,1)
D-5	Pa-231 , crustacea and mollusks	1.100E+02	1.100E+02	BIOFAC(4,2)
D-5				
D-5	Pu-239 , fish	3.000E+01	3.000E+01	BIOFAC(5,1)
D-5	Pu-239 , crustacea and mollusks	1.000E+02	1.000E+02	BIOFAC(5,2)
D-5				
D-5	Pu-240 , fish	3.000E+01	3.000E+01	BIOFAC(6,1)
D-5	Pu-240 , crustacea and mollusks	1.000E+02	1.000E+02	BIOFAC(6,2)
D-5				

Dose Conversion Factor (and Related) Parameter Summary (continued)
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Menu	Parameter	Current Value	Base Case*	Parameter Name
D-5	Ra-228+D , fish	5.000E+01	5.000E+01	BIOFAC(8,1)
D-5	Ra-228+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(8,2)
D-5				
D-5	Th-228+D , fish	1.000E+02	1.000E+02	BIOFAC(9,1)
D-5	Th-228+D , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(9,2)
D-5				
D-5	Th-229+D , fish	1.000E+02	1.000E+02	BIOFAC(10,1)
D-5	Th-229+D , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(10,2)
D-5				
D-5	Th-232 , fish	1.000E+02	1.000E+02	BIOFAC(11,1)
D-5	Th-232 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(11,2)
D-5				
D-5	U-233 , fish	1.000E+01	1.000E+01	BIOFAC(12,1)
D-5	U-233 , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(12,2)
D-5				
D-5	U-235+D , fish	1.000E+01	1.000E+01	BIOFAC(13,1)
D-5	U-235+D , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(13,2)
D-5				
D-5	U-236 , fish	1.000E+01	1.000E+01	BIOFAC(14,1)
D-5	U-236 , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(14,2)

*Base Case means Default.Lib w/o Associate Nuclide contributions.

Site-Specific Parameter Summary

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R011	Area of contaminated zone (m**2)	3.344E+04	1.000E+04	---	AREA
R011	Thickness of contaminated zone (m)	1.400E+01	2.000E+00	---	THICK0
R011	Length parallel to aquifer flow (m)	3.660E+02	1.000E+02	---	LCZPAQ
R011	Basic radiation dose limit (mrem/yr)	2.500E+01	3.000E+01	---	BRDL
R011	Time since placement of material (yr)	0.000E+00	0.000E+00	---	TI
R011	Times for calculations (yr)	1.000E+04	1.000E+00	---	T(2)
R011	Times for calculations (yr)	1.000E+05	3.000E+00	---	T(3)
R011	Times for calculations (yr)	not used	1.000E+01	---	T(4)
R011	Times for calculations (yr)	not used	3.000E+01	---	T(5)
R011	Times for calculations (yr)	not used	1.000E+02	---	T(6)
R011	Times for calculations (yr)	not used	3.000E+02	---	T(7)
R011	Times for calculations (yr)	not used	1.000E+03	---	T(8)
R011	Times for calculations (yr)	not used	0.000E+00	---	T(9)
R011	Times for calculations (yr)	not used	0.000E+00	---	T(10)
R012	Initial principal radionuclide (nCi/g): Am-241	1.170E+01	0.000E+00	---	S1(2)
R012	Initial principal radionuclide (nCi/g): Pu-239	2.310E+01	0.000E+00	---	S1(5)
R012	Initial principal radionuclide (nCi/g): Pu-240	2.120E+00	0.000E+00	---	S1(6)
R012	Concentration in groundwater (nCi/L): Am-241	not used	0.000E+00	---	W1(2)
R012	Concentration in groundwater (nCi/L): Pu-239	not used	0.000E+00	---	W1(5)
R012	Concentration in groundwater (nCi/L): Pu-240	not used	0.000E+00	---	W1(6)
R013	Cover depth (m)	1.220E+00	0.000E+00	---	COVER0
R013	Density of cover material (g/cm**3)	1.500E+00	1.500E+00	---	DENSCV
R013	Cover depth erosion rate (m/yr)	2.200E-05	1.000E-03	---	VCV
R013	Density of contaminated zone (g/cm**3)	1.600E+00	1.500E+00	---	DENSCZ
R013	Contaminated zone erosion rate (m/yr)	2.200E-05	1.000E-03	---	VCZ
R013	Contaminated zone total porosity	4.000E-01	4.000E-01	---	TPCZ
R013	Contaminated zone field capacity	2.000E-01	2.000E-01	---	FCCZ
R013	Contaminated zone hydraulic conductivity (m/yr)	1.000E+01	1.000E+01	---	HCCZ
R013	Contaminated zone b parameter	5.300E+00	5.300E+00	---	BCZ
R013	Average annual wind speed (m/sec)	2.000E+00	2.000E+00	---	WIND
R013	Humidity in air (g/m**3)	not used	8.000E+00	---	HUMID
R013	Evapotranspiration coefficient	9.820E-01	5.000E-01	---	EVAPTR
R013	Precipitation (m/yr)	4.570E-01	1.000E+00	---	PRECIP
R013	Irrigation (m/yr)	1.000E-01	2.000E-01	---	RI
R013	Irrigation mode	overhead	overhead	---	IDITCH
R013	Runoff coefficient	0.000E+00	2.000E-01	---	RUNOFF
R013	Watershed area for nearby stream or pond (m**2)	1.000E+06	1.000E+06	---	WAREA
R013	Accuracy for water/soil computations	1.000E-03	1.000E-03	---	EPS
R014	Density of saturated zone (g/cm**3)	1.500E+00	1.500E+00	---	DENSAQ
R014	Saturated zone total porosity	4.000E-01	4.000E-01	---	TPSZ
R014	Saturated zone effective porosity	2.000E-01	2.000E-01	---	EPSZ
R014	Saturated zone field capacity	2.000E-01	2.000E-01	---	FCSZ
R014	Saturated zone hydraulic conductivity (m/yr)	1.000E+02	1.000E+02	---	HCSZ
R014	Saturated zone hydraulic gradient	2.000E-02	2.000E-02	---	HGWT
R014	Saturated zone b parameter	5.300E+00	5.300E+00	---	BSZ
R014	Water table drop rate (m/yr)	1.000E-03	1.000E-03	---	VWT
R014	Well pump intake depth (m below water table)	1.000E+01	1.000E+01	---	DWIBWT
R014	Model: Nondispersion (ND) or Mass-Balance (MB)	ND	ND	---	MODEL

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R014	Well pumping rate (m**3/yr)	2.500E+02	2.500E+02	---	UW
R015	Number of unsaturated zone strata	1	1	---	NS
R015	Unsat. zone 1, thickness (m)	3.660E+02	4.000E+00	---	H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	1.500E+00	1.500E+00	---	DENSUZ(1)
R015	Unsat. zone 1, total porosity	4.000E-01	4.000E-01	---	TPUZ(1)
R015	Unsat. zone 1, effective porosity	2.000E-01	2.000E-01	---	EPUZ(1)
R015	Unsat. zone 1, field capacity	2.000E-01	2.000E-01	---	FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	5.300E+00	5.300E+00	---	BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	1.000E+01	1.000E+01	---	HCUZ(1)
R016	Distribution coefficients for Am-241				
R016	Contaminated zone (cm**3/g)	2.000E+01	2.000E+01	---	DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	2.000E+01	2.000E+01	---	DCNUCU(2,1)
R016	Saturated zone (cm**3/g)	2.000E+01	2.000E+01	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.221E-05	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Pu-239				
R016	Contaminated zone (cm**3/g)	2.000E+03	2.000E+03	---	DCNUCC(5)
R016	Unsaturated zone 1 (cm**3/g)	2.000E+03	2.000E+03	---	DCNUCU(5,1)
R016	Saturated zone (cm**3/g)	2.000E+03	2.000E+03	---	DCNUCS(5)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.238E-07	ALEACH(5)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(5)
R016	Distribution coefficients for Pu-240				
R016	Contaminated zone (cm**3/g)	2.000E+03	2.000E+03	---	DCNUCC(6)
R016	Unsaturated zone 1 (cm**3/g)	2.000E+03	2.000E+03	---	DCNUCU(6,1)
R016	Saturated zone (cm**3/g)	2.000E+03	2.000E+03	---	DCNUCS(6)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.238E-07	ALEACH(6)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(6)
R016	Distribution coefficients for daughter Ac-227				
R016	Contaminated zone (cm**3/g)	2.000E+01	2.000E+01	---	DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	2.000E+01	2.000E+01	---	DCNUCU(1,1)
R016	Saturated zone (cm**3/g)	2.000E+01	2.000E+01	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.221E-05	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for daughter Np-237				
R016	Contaminated zone (cm**3/g)	-1.000E+00	-1.000E+00	2.574E+02	DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	-1.000E+00	-1.000E+00	2.574E+02	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	-1.000E+00	-1.000E+00	2.574E+02	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	1.738E-06	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
R016	Distribution coefficients for daughter Pa-231				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(4)
R016	Unsaturated zone 1 (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCU(4,1)
R016	Saturated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCS(4)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	8.925E-06	ALEACH(4)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(4)

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R016	Distribution coefficients for daughter Ra-228				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC(8)
R016	Unsaturated zone 1 (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCU(8,1)
R016	Saturated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCS(8)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	6.380E-06	ALEACH(8)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(8)
R016	Distribution coefficients for daughter Th-228				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(9)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(9,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(9)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	7.460E-09	ALEACH(9)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(9)
R016	Distribution coefficients for daughter Th-229				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(10)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(10,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(10)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	7.460E-09	ALEACH(10)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(10)
R016	Distribution coefficients for daughter Th-232				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(11)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(11,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(11)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	7.460E-09	ALEACH(11)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(11)
R016	Distribution coefficients for daughter U-233				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(12)
R016	Unsaturated zone 1 (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCU(12,1)
R016	Saturated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCS(12)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	8.925E-06	ALEACH(12)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(12)
R016	Distribution coefficients for daughter U-235				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(13)
R016	Unsaturated zone 1 (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCU(13,1)
R016	Saturated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCS(13)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	8.925E-06	ALEACH(13)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(13)
R016	Distribution coefficients for daughter U-236				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(14)
R016	Unsaturated zone 1 (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCU(14,1)
R016	Saturated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCS(14)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	8.925E-06	ALEACH(14)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(14)
R017	Inhalation rate (m**3/yr)	8.000E+03	8.400E+03	---	INHALR
R017	Mass loading for inhalation (g/m**3)	1.800E-04	1.000E-04	---	MLINH

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R017	Exposure duration	3.000E+01	3.000E+01	---	ED
R017	Shielding factor, inhalation	4.000E-01	4.000E-01	---	SHF3
R017	Shielding factor, external gamma	7.000E-01	7.000E-01	---	SHF1
R017	Fraction of time spent indoors	4.300E-01	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	2.700E-01	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	1.000E+00	1.000E+00	>0 shows circular AREA.	FS
R017	Radii of shape factor array (used if FS = -1):				
R017	Outer annular radius (m), ring 1:	not used	5.000E+01	---	RAD_SHAPE(1)
R017	Outer annular radius (m), ring 2:	not used	7.071E+01	---	RAD_SHAPE(2)
R017	Outer annular radius (m), ring 3:	not used	0.000E+00	---	RAD_SHAPE(3)
R017	Outer annular radius (m), ring 4:	not used	0.000E+00	---	RAD_SHAPE(4)
R017	Outer annular radius (m), ring 5:	not used	0.000E+00	---	RAD_SHAPE(5)
R017	Outer annular radius (m), ring 6:	not used	0.000E+00	---	RAD_SHAPE(6)
R017	Outer annular radius (m), ring 7:	not used	0.000E+00	---	RAD_SHAPE(7)
R017	Outer annular radius (m), ring 8:	not used	0.000E+00	---	RAD_SHAPE(8)
R017	Outer annular radius (m), ring 9:	not used	0.000E+00	---	RAD_SHAPE(9)
R017	Outer annular radius (m), ring 10:	not used	0.000E+00	---	RAD_SHAPE(10)
R017	Outer annular radius (m), ring 11:	not used	0.000E+00	---	RAD_SHAPE(11)
R017	Outer annular radius (m), ring 12:	not used	0.000E+00	---	RAD_SHAPE(12)
R017	Fractions of annular areas within AREA:				
R017	Ring 1	not used	1.000E+00	---	FRACA(1)
R017	Ring 2	not used	2.732E-01	---	FRACA(2)
R017	Ring 3	not used	0.000E+00	---	FRACA(3)
R017	Ring 4	not used	0.000E+00	---	FRACA(4)
R017	Ring 5	not used	0.000E+00	---	FRACA(5)
R017	Ring 6	not used	0.000E+00	---	FRACA(6)
R017	Ring 7	not used	0.000E+00	---	FRACA(7)
R017	Ring 8	not used	0.000E+00	---	FRACA(8)
R017	Ring 9	not used	0.000E+00	---	FRACA(9)
R017	Ring 10	not used	0.000E+00	---	FRACA(10)
R017	Ring 11	not used	0.000E+00	---	FRACA(11)
R017	Ring 12	not used	0.000E+00	---	FRACA(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	1.760E+02	1.600E+02	---	DIET(1)
R018	Leafy vegetable consumption (kg/yr)	1.800E+01	1.400E+01	---	DIET(2)
R018	Milk consumption (L/yr)	1.120E+02	9.200E+01	---	DIET(3)
R018	Meat and poultry consumption (kg/yr)	8.500E+01	6.300E+01	---	DIET(4)
R018	Fish consumption (kg/yr)	not used	5.400E+00	---	DIET(5)
R018	Other seafood consumption (kg/yr)	not used	9.000E-01	---	DIET(6)
R018	Soil ingestion rate (g/yr)	3.650E+01	3.650E+01	---	SOIL
R018	Drinking water intake (L/yr)	5.100E+02	5.100E+02	---	DWI
R018	Contamination fraction of drinking water	1.000E+00	1.000E+00	---	FDW
R018	Contamination fraction of household water	not used	1.000E+00	---	FHHW
R018	Contamination fraction of livestock water	1.000E+00	1.000E+00	---	FLW
R018	Contamination fraction of irrigation water	1.000E+00	1.000E+00	---	FIRW
R018	Contamination fraction of aquatic food	not used	5.000E-01	---	FR9
R018	Contamination fraction of plant food	-1	-1	0.500E+00	FPLANT
R018	Contamination fraction of meat	-1	-1	0.100E+01	FMEAT
R018	Contamination fraction of milk	-1	-1	0.100E+01	FMILK

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R019	Livestock fodder intake for meat (kg/day)	6.800E+01	6.800E+01	---	LFI5
R019	Livestock fodder intake for milk (kg/day)	5.500E+01	5.500E+01	---	LFI6
R019	Livestock water intake for meat (L/day)	5.000E+01	5.000E+01	---	LWI5
R019	Livestock water intake for milk (L/day)	1.600E+02	1.600E+02	---	LWI6
R019	Livestock soil intake (kg/day)	5.000E-01	5.000E-01	---	LSI
R019	Mass loading for foliar deposition (g/m**3)	1.000E-04	1.000E-04	---	MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01	---	DM
R019	Depth of roots (m)	9.000E-01	9.000E-01	---	DROOT
R019	Drinking water fraction from ground water	1.000E+00	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	not used	1.000E+00	---	FGWHH
R019	Livestock water fraction from ground water	1.000E+00	1.000E+00	---	FGWLW
R019	Irrigation fraction from ground water	1.000E+00	1.000E+00	---	FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	7.000E-01	7.000E-01	---	YV(1)
R19B	Wet weight crop yield for Leafy (kg/m**2)	1.500E+00	1.500E+00	---	YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	1.100E+00	1.100E+00	---	YV(3)
R19B	Growing Season for Non-Leafy (years)	1.700E-01	1.700E-01	---	TE(1)
R19B	Growing Season for Leafy (years)	2.500E-01	2.500E-01	---	TE(2)
R19B	Growing Season for Fodder (years)	8.000E-02	8.000E-02	---	TE(3)
R19B	Translocation Factor for Non-Leafy	1.000E-01	1.000E-01	---	TIV(1)
R19B	Translocation Factor for Leafy	1.000E+00	1.000E+00	---	TIV(2)
R19B	Translocation Factor for Fodder	1.000E+00	1.000E+00	---	TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01	---	RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01	---	RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01	---	RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01	---	RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01	---	RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01	---	RWET(3)
R19B	Weathering Removal Constant for Vegetation	2.000E+01	2.000E+01	---	WLAM
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05	---	C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02	---	C12CZ
C14	Fraction of vegetation carbon from soil	not used	2.000E-02	---	CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01	---	CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01	---	DMC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07	---	EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10	---	REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01	---	AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01	---	AVFG5
C14	DCF correction factor for gaseous forms of C14	not used	0.000E+00	---	CO2F
STOR	Storage times of contaminated foodstuffs (days):				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01	---	STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00	---	STOR_T(2)
STOR	Milk	1.000E+00	1.000E+00	---	STOR_T(3)
STOR	Meat and poultry	2.000E+01	2.000E+01	---	STOR_T(4)
STOR	Fish	7.000E+00	7.000E+00	---	STOR_T(5)
STOR	Crustacea and mollusks	7.000E+00	7.000E+00	---	STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00	---	STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00	---	STOR_T(8)
STOR	Livestock fodder	4.500E+01	4.500E+01	---	STOR_T(9)

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R021	Thickness of building foundation (m)	not used	1.500E-01	---	FLOOR1
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00	---	DENSFL
R021	Total porosity of the cover material	not used	4.000E-01	---	TPCV
R021	Total porosity of the building foundation	not used	1.000E-01	---	TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02	---	PH2OCV
R021	Volumetric water content of the foundation	not used	3.000E-02	---	PH2OFL
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06	---	DIFCV
R021	in foundation material	not used	3.000E-07	---	DIFFL
R021	in contaminated zone soil	not used	2.000E-06	---	DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00	---	HMIX
R021	Average building air exchange rate (1/hr)	not used	5.000E-01	---	REXG
R021	Height of the building (room) (m)	not used	2.500E+00	---	HRM
R021	Building interior area factor	not used	0.000E+00	---	FAI
R021	Building depth below ground surface (m)	not used	-1.000E+00	---	DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01	---	EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01	---	EMANA(2)
TITL	Number of graphical time points	1024	---	---	NPTS
TITL	Maximum number of integration points for dose	17	---	---	LYMAX
TITL	Maximum number of integration points for risk	1	---	---	KYMAX

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	active
2 -- inhalation (w/o radon)	active
3 -- plant ingestion	active
4 -- meat ingestion	active
5 -- milk ingestion	active
6 -- aquatic foods	suppressed
7 -- drinking water	active
8 -- soil ingestion	active
9 -- radon	suppressed
Find peak pathway doses	suppressed

Contaminated Zone Dimensions		Initial Soil Concentrations, nCi/g	
Area:	33445.00 square meters	Am-241	1.170E+01
Thickness:	14.00 meters	Pu-239	2.310E+01
Cover Depth:	1.22 meters	Pu-240	2.120E+00

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+04	1.000E+05
TDOSE(t):	5.853E-11	6.798E-08	6.655E+02
M(t):	2.341E-12	2.719E-09	2.662E+01

Maximum TDOSE(t): 2.357E+03 mrem/yr at t = 55449 ± * years

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 5.545E+04 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	1.535E+00	0.0007	2.274E-01	0.0001	0.000E+00	0.0000	1.809E+01	0.0077	1.470E+00	0.0006	1.330E-02	0.0000	2.718E-01	0.0001
Pu-239	1.194E+00	0.0005	2.415E+02	0.1024	0.000E+00	0.0000	1.591E+03	0.6750	8.012E+01	0.0340	1.028E+00	0.0004	4.176E+02	0.1772
Pu-240	4.875E-04	0.0000	3.117E-01	0.0001	0.000E+00	0.0000	2.038E+00	0.0009	1.021E-01	0.0000	5.791E-03	0.0000	5.318E-01	0.0002
Total	2.729E+00	0.0012	2.420E+02	0.1027	0.000E+00	0.0000	1.612E+03	0.6836	8.169E+01	0.0347	1.047E+00	0.0004	4.184E+02	0.1775

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 5.545E+04 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.161E+01	0.0092
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.333E+03	0.9896
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.990E+00	0.0013
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.357E+03	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	4.272E-13	0.0073	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-239	5.811E-11	0.9927	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-240	2.500E-19	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	5.853E-11	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.272E-13	0.0073
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.811E-11	0.9927
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.500E-19	0.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.853E-11	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+04 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	6.186E-08	0.9101	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-239	6.074E-09	0.0894	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-240	3.777E-11	0.0006	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	6.798E-08	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+04 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.186E-08	0.9101
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.074E-09	0.0894
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.777E-11	0.0006
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.798E-08	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+05 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	1.562E+00	0.0023	2.583E-01	0.0004	0.000E+00	0.0000	1.659E+01	0.0249	1.346E+00	0.0020	1.431E-02	0.0000	2.680E-01	0.0004
Pu-239	7.169E-01	0.0011	6.653E+01	0.1000	0.000E+00	0.0000	4.398E+02	0.6609	2.319E+01	0.0349	2.914E-01	0.0004	1.148E+02	0.1726
Pu-240	5.189E-05	0.0000	6.702E-03	0.0000	0.000E+00	0.0000	3.490E-02	0.0001	2.254E-03	0.0000	3.049E-03	0.0000	6.466E-03	0.0000
Total	2.279E+00	0.0034	6.680E+01	0.1004	0.000E+00	0.0000	4.565E+02	0.6859	2.454E+01	0.0369	3.088E-01	0.0005	1.151E+02	0.1730

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+05 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.004E+01	0.0301
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.454E+02	0.9698
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.343E-02	0.0001
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.655E+02	1.0000

*Sum of all water independent and dependent pathways.

Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions Indicated

Parent (i)	Product (j)	Thread Fraction	DSR(j,t) At Time in Years (mrem/yr)/(nCi/g) 0.000E+00	1.000E+04	1.000E+05
Am-241	Am-241	1.000E+00	2.776E-24	7.373E-27	0.000E+00
Am-241	Np-237+D	1.000E+00	3.651E-14	2.164E-09	1.641E+00
Am-241	U-233	1.000E+00	1.502E-24	4.755E-15	4.789E-03
Am-241	Th-229+D	1.000E+00	4.611E-22	3.123E-09	6.706E-02
Am-241	∑DSR(j)		3.651E-14	5.288E-09	1.713E+00
Pu-239	Pu-239	1.000E+00	2.515E-12	1.619E-10	2.766E+01
Pu-239	U-235+D	1.000E+00	2.038E-18	3.209E-12	9.064E-03
Pu-239	Pa-231	1.000E+00	2.122E-22	2.335E-12	1.977E-01
Pu-239	Ac-227+D	1.000E+00	1.230E-22	9.546E-11	7.292E-02
Pu-239	∑DSR(j)		2.515E-12	2.629E-10	2.794E+01
Pu-240	Pu-240	4.950E-08	5.836E-27	2.685E-24	6.057E-10
Pu-240	Pu-240	1.000E+00	1.179E-19	5.424E-17	1.224E-02
Pu-240	U-236	1.000E+00	1.977E-25	1.590E-18	1.295E-02
Pu-240	Th-232	1.000E+00	1.739E-36	3.496E-25	4.667E-07
Pu-240	Ra-228+D	1.000E+00	5.634E-24	6.214E-13	8.238E-06
Pu-240	Th-228+D	1.000E+00	2.064E-23	1.719E-11	4.893E-06
Pu-240	∑DSR(j)		1.179E-19	1.781E-11	2.520E-02

The DSR includes contributions from associated (half-life ≤ 180 days) daughters.

Single Radionuclide Soil Guidelines G(i,t) in nCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+04	1.000E+05
Am-241	*3.431E+09	*3.431E+09	1.460E+01
Pu-239	*6.214E+07	*6.214E+07	8.948E-01
Pu-240	*2.278E+08	*2.278E+08	9.920E+02

*At specific activity limit

Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(nCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in nCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 55449 ± * years

Nuclide (i)	Initial (nCi/g)	tmin (years)	DSR(i,tmin)	G(i,tmin) (nCi/g)	DSR(i,tmax)	G(i,tmax) (nCi/g)
Am-241	1.170E+01	55518 ± *	1.847E+00	1.353E+01	1.847E+00	1.353E+01
Pu-239	2.310E+01	55449 ± *	1.010E+02	2.476E-01	1.010E+02	2.476E-01
Pu-240	2.120E+00	23972 ± *	6.236E+00	4.009E+00	1.411E+00	1.772E+01

Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	THF(i)	DOSE(j,t), mrem/yr t= 0.000E+00	1.000E+04	1.000E+05
Am-241	Am-241	1.000E+00	3.247E-23	8.627E-26	0.000E+00
Np-237	Am-241	1.000E+00	4.272E-13	2.532E-08	1.920E+01
U-233	Am-241	1.000E+00	1.757E-23	5.564E-14	5.603E-02
Th-229	Am-241	1.000E+00	5.395E-21	3.654E-08	7.846E-01
Pu-239	Pu-239	1.000E+00	5.811E-11	3.741E-09	6.390E+02
U-235	Pu-239	1.000E+00	4.709E-17	7.413E-11	2.094E-01
Pa-231	Pu-239	1.000E+00	4.901E-21	5.395E-11	4.567E+00
Ac-227	Pu-239	1.000E+00	2.841E-21	2.205E-09	1.685E+00
Pu-240	Pu-240	4.950E-08	1.237E-26	5.692E-24	1.284E-09
Pu-240	Pu-240	1.000E+00	2.499E-19	1.150E-16	2.594E-02
Pu-240	∑DOSE(j)		2.499E-19	1.150E-16	2.594E-02
U-236	Pu-240	1.000E+00	4.191E-25	3.372E-18	2.746E-02
Th-232	Pu-240	1.000E+00	0.000E+00	7.412E-25	9.894E-07
Ra-228	Pu-240	1.000E+00	1.194E-23	1.317E-12	1.746E-05
Th-228	Pu-240	1.000E+00	4.376E-23	3.645E-11	1.037E-05

THF(i) is the thread fraction of the parent nuclide.

Individual Nuclide Soil Concentration
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	THF(i)	S(j,t), nCi/g t= 0.000E+00	1.000E+04	1.000E+05
Am-241	Am-241	1.000E+00	1.170E+01	1.015E-06	0.000E+00
Np-237	Am-241	1.000E+00	0.000E+00	2.286E-03	1.899E-03
U-233	Am-241	1.000E+00	0.000E+00	8.902E-05	4.971E-04
Th-229	Am-241	1.000E+00	0.000E+00	3.067E-05	4.739E-04
Pu-239	Pu-239	1.000E+00	2.310E+01	1.728E+01	1.268E+00
U-235	Pu-239	1.000E+00	0.000E+00	1.885E-04	4.015E-04
Pa-231	Pu-239	1.000E+00	0.000E+00	1.921E-05	2.830E-04
Ac-227	Pu-239	1.000E+00	0.000E+00	1.909E-05	2.828E-04
Pu-240	Pu-240	4.950E-08	1.049E-07	3.626E-08	2.548E-12
Pu-240	Pu-240	1.000E+00	2.120E+00	7.326E-01	5.148E-05
Pu-240	∑S(j):		2.120E+00	7.326E-01	5.148E-05
U-236	Pu-240	1.000E+00	0.000E+00	3.668E-04	2.634E-04
Th-232	Pu-240	1.000E+00	0.000E+00	1.084E-10	1.802E-09
Ra-228	Pu-240	1.000E+00	0.000E+00	1.082E-10	1.802E-09
Th-228	Pu-240	1.000E+00	0.000E+00	1.082E-10	1.802E-09

THF(i) is the thread fraction of the parent nuclide.

RESCALC.EXE execution time = 7.70 seconds