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Institute for Energy and Environmental Research (IEER)

Arjun Makhijani

Institute for Energy and Environmental Research (IEER)

Brice Smith

Institute for Energy and Environmental Research (IEER)

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**INSTITUTE FOR ENERGY AND
ENVIRONMENTAL RESEARCH**

6935 Laurel Avenue, Suite 201
Takoma Park, MD 20912

Phone: (301) 270-5500
FAX: (301) 270-3029
e-mail: ieer@ieer.org
<http://www.ieer.org>

**Dangerous Discrepancies:
Missing Weapons Plutonium in Los Alamos National
Laboratory Waste Accounts**

Arjun Makhijani, Ph.D.
Brice Smith, Ph.D.

November 29, 2005
Reissued with Corrections April 21, 2006

Takoma Park, Maryland

Dangerous Discrepancies

Errors were corrected and parts of the analysis were redone in April 2006, when this report was re-issued.

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This study was undertaken as part of a Citizens' Monitoring and Technical Assessment Fund Grant Agreement MTA-05-010, administered by RESOLVE, Inc. We have greatly benefited from the support of Louise Gant, Manager of the MTA Fund at RESOLVE and Brad Lewis, the Chief Financial Officer. It is one of two case studies on remediation and long-term stewardship that IEER is preparing under this grant. The other case study relates the uranium processing plant near Fernald, Ohio which has now been decommissioned.

We would like to that Annie Makhijani, IEER Project Scientist, who checked many of the calculations, and Lois Chalmers who helped with the bibliographic research and the references.

As always, we, as the authors, remain solely responsible for the contents of this report, its conclusions and recommendations, and any omissions or errors. As it happens there was an error in the analysis of plutonium accounts issued on November 29, 2005. The mistake was pointed out to us by someone whom we know only by an e-mail address and first name. We are very grateful for the message, which enabled us not only to correct the error but also to catch a few other problems and to do a more complete analysis. The errors turned out to be minor in their impact on the actual results; therefore, the main findings of the report are essentially unchanged from the original November version. **This revised report is *not* an update.** Correspondence about this report subsequent to its release on November 29, 2005, with officials at Los Alamos, the Department of Energy, including its National Nuclear Security Administration, and the Defense Nuclear Facilities Safety Board is posted on IEER's website, www.ieer.org. Updates will be provided on that website and/or in printed matter.

Arjun Makhijani
Brice Smith
Takoma Park, Maryland
November 29, 2005
Revision April 21, 2006

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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 about 300 kilograms.¹ This estimate takes into account all sources of data for plutonium discharged into waste streams (stored, shallow burial, soil, intermediate depth) as well as the hydronuclear tests that were conducted at the Los Alamos site in 1960-61. Plutonium accounting data in the safeguards account (the Nuclear Materials Management and Safeguards System (NMMSS)) show that discharges from processing areas to waste were particularly high in the 1980s. We have not been able to discover the reason for these high losses to the waste but have provided some indications of possible explanations.
2. If much or most of the unaccounted for plutonium was disposed of as buried low-level waste and buried transuranic waste on site at Los Alamos, the long term radiation doses would far exceed any allowable limits. Remediation would be necessary but would be very complex due to the unknown disposal patterns. Further, in that case the NMMSS plutonium account would be wrong, since it shows less than 50 kilograms of waste before 1980, the period that accounts for almost all the documented buried waste containing significant amounts of plutonium.
3. It is possible that significantly more plutonium is going to the Waste Isolation Pilot Plant (WIPP) than indicated by DOE documentation. If so, this has major implications for the oversight of the operations of WIPP. The 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. If the NMMSS account is deemed as correct in the annual reported totals of plutonium in waste, the possibility that WIPP accounts are incorrect appears to be significant. Over 90 percent of 610 kilograms of plutonium in waste in NMMSS is attributed to the 1980s and 1990s.
4. Even if only a part of the unaccounted for plutonium is actually missing, this would have major security implications. As a reference point, North Korea's entire stock of plutonium is only about 15 percent of our estimate for the plutonium unaccounted for at LANL.

¹ Weights of plutonium in this report refer to the sum of plutonium-239 and plutonium-240, unless otherwise specified.

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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 practically checked once they are disposed of, more certain characterization and an investigation into the state of the accuracy and completeness 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 a 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.² 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 since 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 Offices or the Sites that were used to compile waste data. The discrepancies were surprisingly 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.³ That memorandum is reproduced in Appendix A. Moreover, neither of these accounts appear to match other data that is available – 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) and data that the DOE has collected on plutonium in other

² 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.

³ Guimond and Beckner 1996

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types of wastes. WIPP was licensed to receive 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 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,⁴ are summarized in Table 1 below.

Table 1: Discrepancies in data on plutonium in waste at Los Alamos

Site	50 years report (Note 4)	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

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. Data are as of September 1994.
3. IDB stands for "Integrated Database"
4. The 50 Years Report states that plutonium data are for plutonium-239 alone (p. 79). However, the production charts may be for total plutonium content.

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.⁵ IEER has pointed to these discrepancies for many years, beginning with its 1997 report on environmental remediation in the nuclear weapons complex.⁶ IEER also called attention to the problem during the independent audit of Los Alamos compliance (or lack thereof) with the Clean Air Act.⁷ Finally, IEER initiated a letter, co-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

⁴ 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.

⁵ 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. For comparison, the Nagasaki bomb had just over 6 kilograms of plutonium in it.

⁶ Fioravanti and Makhijani 1997.

⁷ Makhijani and Franke 2000, Makhijani and Franke 2000b, Makhijani and Franke 2002

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reconcile plutonium accounts and reduce the discrepancies. That letter is reproduced in Appendix B.

Since IEER did not obtain a substantive response to any of these efforts, 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 originating 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.⁸

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. 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. It is possible that neither figure is accurate. Current official waste data, discussed below, indicate that the 1,375 kilogram figure is incorrect.

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 Los Alamos shown in that report are reproduced in Figure 1.

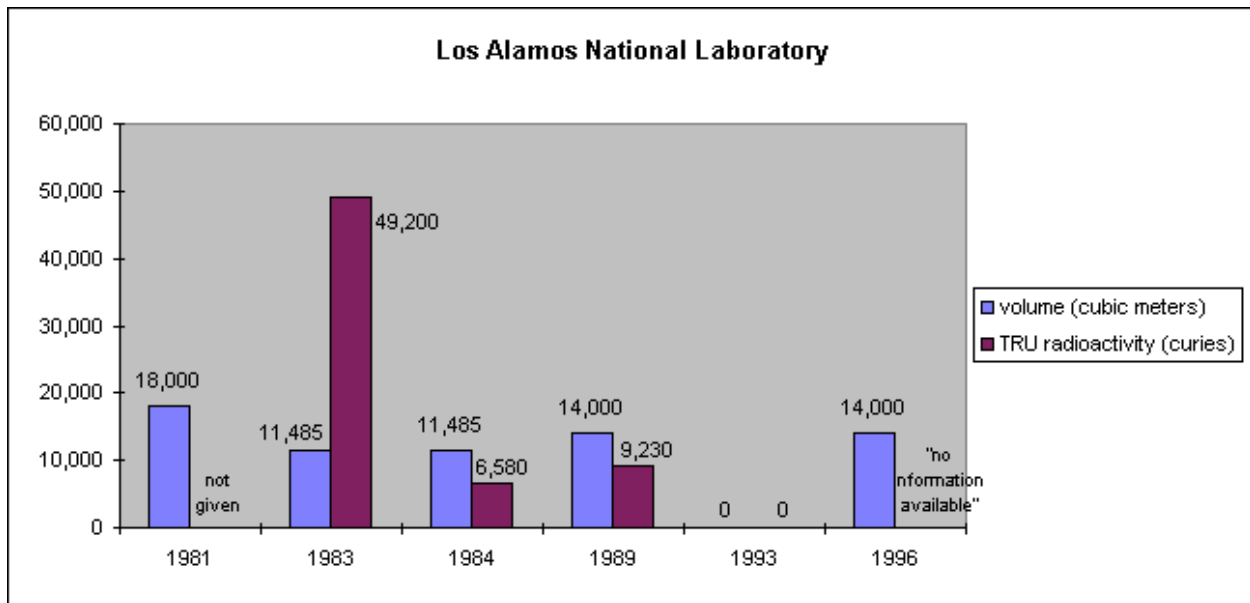


Figure 1: Reported volumes and TRU radioactivity in LANL Buried Waste.

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.

⁸ 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).

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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 that 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, 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.⁹

Given that the buried TRU waste data were unreliable up to and including 1996, we looked at the revised data on buried TRU waste published by the DOE in response to IEER's criticisms of waste data, the datasheets that were the basis for the report, 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.

A perspective on the reasonableness of the data on plutonium in waste can be gained from publicly available estimates of how many pits and experimental devices, most of which would be expected to contain plutonium, were made at LANL. The values of plutonium in waste can then be checked for reasonableness by estimating the amount of waste per pit or device at LANL. A point for comparison would be the 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 1969.¹⁰

⁹ Huntoon 2000, emphasis added.

¹⁰ Makhijani and Boyd 2001. This report addresses buried waste and water protection issues at INL.

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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 Years Report and the revised DOE 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 pits during the Cold War.

Table 2: TRU Waste 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. All values are rounded to the nearest kilogram. These amounts do not include wastes already disposed of. See below.

In addition to the waste destined for WIPP detailed in Table 2, by September 30, 2002, there was already a total of 2,322 kilograms of plutonium-239/240 that had been emplaced in WIPP from Rocky Flats, INL, Los Alamos, and the Savannah River Site. Of the shipments that had been completed by that time, roughly 98 percent of the waste mass and nearly 94 percent of the waste volume had been sent by Rocky Flats and INL while only about 1.1 percent of the waste mass and 3.5 percent of the volume had been sent by Los Alamos. The WIPP Waste Information System reports that approximately 2,600 curies of TRU activity was shipped from LANL to WIPP prior to September 30, 2002. By combining these data with the isotopic composition for all WIPP emplaced waste given in DOE 2004, we estimate that roughly 10 kilograms of plutonium-239/240 was sent from Los Alamos in these shipments. In addition, we will add approximately 2,290 kilograms of plutonium to the waste accounts of Rocky Flats and INL in order to account for the amount of waste that had already been emplaced in WIPP when the estimates in Table 2 were made.

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The first noteworthy item is that the total figure for plutonium in retrievably stored waste at LANL is far lower than the corresponding number for plutonium in waste reported in Guimond and Beckner 1996 (1,323.70 kilograms -- see Table 1 above). There has therefore been a drastic reduction, by over 1,000 kilograms – one metric ton – of plutonium in the estimate of plutonium in retrievably stored waste. Similar discrepancies exist for other sites. For this report we have, therefore, used the most recent estimates for the amount of waste emplaced in or destined for WIPP.

In addition to retrievably stored waste, there were several other areas that contained plutonium waste, with two of them accounting for significant amounts of plutonium in subsurface areas in Los Alamos. We use the term subsurface disposal to include all categories of disposal at Los Alamos. Only the retrievably stored WIPP wastes are excluded from this rubric. The data on these sources were published in 1999, in detailed datasheets containing revised estimates for all wastes containing transuranic radionuclides, except for the retrievably stored wastes.¹¹ These datasheets were summarized in a report that the DOE issued in June 2000.¹² These datasheets include both buried waste and plutonium contaminated soil from hydronuclear testing of devices carried out during the 1958-1961 test moratorium. During 1960 and 1961 a total of 35 such tests were conducted at Los Alamos.¹³ These consisted essentially of sub-critical or very low-yield tests that were done during the U.S.-Soviet testing moratorium.¹⁴

The three main components of the sub-surface plutonium at Los Alamos are as follows:

- Buried waste
- Waste discharged at depths greater than 30 meters (intermediate depth waste)
- Plutonium dispersed due to tests officially described as hydronuclear tests..

There were other smaller sources of waste, such as laundry discharges, that are also detailed below. The largest component of plutonium in subsurface discharges is that present in waste that was dumped in shallow pits and trenches, defined as those of less than 30 meters' depth, mainly in the years prior to 1970, but also to some extent after that. Therefore this item deserves detailed discussion, especially as the manner in which the official data are presented is problematic from the point of view of estimating the amount of weapons plutonium (i.e. the sum of Pu-239 and Pu-240).

Buried waste

The term buried waste in the context of this report (and of the study of plutonium contaminated wastes) refers to wastes buried in trenches and pits at depths of less than 30 meters (about 100 feet). Buried waste is second in quantity of radioactivity only to the retrievably stored waste category. Buried waste at LANL totals about 21,000 curies of alpha-emitting transuranic

¹¹ DOE 1999.

¹² DOE 2000.

¹³ Johnston 2005.

¹⁴ Thorn and Westervelt 1987.

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radionuclides in buried TRU and low-level waste.¹⁵ 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.¹⁶

Isotopic composition of plutonium is critical to its accounting because all weapons plutonium consists of a mixture of isotopes, from plutonium-238 to plutonium-242. The major component by weight is plutonium-239 (usually 93 or 94 percent by weight in weapons plutonium), which has a half-life of over 24,000 years. Plutonium-240 comes next in terms of weight at about 5 to 6 percent. While plutonium-241 is only about 0.5 percent by weight in weapons plutonium, it constitutes most of the radioactivity, since it has a short half-life and hence a very high specific activity. The contribution of plutonium-241 to the weight of weapons plutonium is generally well under one percent but its radioactivity contribution as a fraction of the total depends significantly on the age of the plutonium. Hence when plutonium numbers are specified in units of radioactivity (curies), their interpretation in terms of weight of plutonium becomes uncertain in the absence of data regarding age or isotopic composition. This is the case with the DOE data on buried waste at Los Alamos.

Table 3 shows how the weight of the components of plutonium varies over time

Table 3: Change in weapon-grade plutonium composition with time, by weight

	Fresh Plutonium	After 14 years	After 28 years
Pu-239	93.00%	93.23%	93.42%
Pu-240	6.00%	6.01%	6.01%
Pu-241	0.50%	0.26%	0.07%
Pu-242	0.50%	0.50%	0.50%

Since Pu-241 decays rapidly (half-life 14.4 years) its contribution to the weight goes down, though it never contributes much to the weight of weapons plutonium. By contrast it remains the main component of the radioactivity of weapons plutonium for many decades, as can be seen in Table 4.

Table 4: Radioactivity proportions in weapons plutonium as a function of time

	Fresh Plutonium	After 14 years	After 28 years
Pu-239	10.24%	17.90%	42.25%
Pu-240	2.41%	4.21%	9.92%
Pu-241	87.35%	77.89%	47.81%
Pu-242	0.003%	0.006%	0.014%

Hence if one only has data on the total radioactivity of plutonium, the error in the estimate of plutonium can be large if one does not know the age of the plutonium. Strangely, DOE 1999

¹⁵ DOE 2000, Table 5.

¹⁶ 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 m³ and the radioactivity context is reported as being the “initial (emplaced) values.”

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states that all of the radioactivity can be considered as plutonium-239 because “no [isotopic] inventory data are available.”¹⁷ This is undoubtedly an incorrect assumption. As noted above, Pu-241 accounts for only a small portion of the weight of weapon-grade plutonium, however, it generally accounts for a significant portion of the radioactivity. As the Pu-241 activity declines, the activity of americium-241 builds up, since the former decays into the latter, which has a half-life of 432 years.

Table 5 shows how much difference the decay-correction makes for buried waste amounting to 21,000 curies of plutonium. If it were fresh weapon grade-plutonium, the estimate of the weight of plutonium would be about 36.3 kilograms; the estimate would be 63.5 kilograms if one assumes plutonium that has decayed for 14 years (just under one half life of Pu-241); it would be 149.9 kilograms if one assumes that it has decayed for 28 years has occurred.

Table 5: Estimated Weights of plutonium for an initial 21,000 curies of weapons plutonium mix as a function of time at which the radioactivity is specified

	Fresh weapons plutonium	After 14 years	After 28 years
Pu-239	34.12	59.66	140.85
Pu-240	2.20	3.84	9.06
Pu-241	0.18	0.16	0.10
Pu-242	0.18	0.32	0.76
Total Pu-239 and Pu- 240	36.32	63.50	149.90

Table 5 shows that the estimate of weight if only the radioactivity of the plutonium is known depends greatly on knowledge of the time after production that the radioactivity was measured. If the time is unknown, the uncertainty is considerable due to the short half-life of plutonium-241 relative to the other isotopes of plutonium.

The data on buried wastes indicate that the estimate of 21,000 curies is a non-decay corrected estimate – that is it is the amount of radioactivity that was initially buried in the waste pits and trenches. This would not have been fresh weapons plutonium, since weapons plutonium typically consisted of mixes of old and fresh plutonium and plutonium returns likely occurred on a 20 to 25 year time frame given the rate of replacement of old weapon designs with new ones. Hence an assumption of plutonium being somewhere between fresh plutonium and 10 to 15 year old plutonium on average at the time of disposal is a reasonable one. This means that a reasonable estimate or “best” estimate of the amount of weapons plutonium buried in shallow land burial at Los Alamos is about 50 kilograms. This is about the same as the value of 51.6 kilograms in the 1996 DOE memorandum authored by Guimond and Beckner.¹⁸ It also corresponds approximately to the total for plutonium in waste in the NMMSS data until the end of the 1970s (see below).

¹⁷ DOE 1999, LANL Section, p. 43.

¹⁸ Guimond and Beckner 1996, Attachment C.

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We can get a rough high estimate of the amount of weapons plutonium in Los Alamos buried waste by assuming it had the same isotopic composition as the WIPP waste, the values of which are decay-corrected to 2001. This procedure yields an estimate of about 87 kilograms of plutonium in Los Alamos buried waste.

There are a variety of other sources of plutonium in the underground environment at Los Alamos. The main one other than buried waste is the plutonium dispersed underground during hydronuclear testing in the 1958 to 1961 test moratorium period. We have not found any data for the use of weapons plutonium in subsequent sub-critical or hydronuclear tests at Los Alamos. The tests conducted at the Nevada Test Site would, of course, not contribute to sub-surface plutonium at Los Alamos.

Table 6 shows the various sources and estimates of subsurface waste at Los Alamos.

Table 6: Plutonium in the subsurface environment in Los Alamos – High estimate

	Pu-239/240 (kilograms)	Comments
TA-21 Material Disposal Area A	0.24	
TA-21 Material Disposal Area B	0.10	Uses WIPP Isotopic Ratios
TA-50 Material Disposal Area C – Pits	0.39	
TA-54 Material Disposal Area G – Pits	86.99	Uses WIPP Isotopic Ratios
TA-50 Material Disposal Area C - Shafts	0.24	Uses WIPP Isotopic Ratios
TA-54 Material Disposal Area G - Shafts	15.15	Uses WIPP Isotopic Ratios
TA-21 Material Disposal Area T - Shafts	1.27	
TA-49 Material Disposal Area AB - Hydronuclear Test Shafts	39.19	
TA-21 Material Disposal Area T - Adsorption Beds	0.04	Uses WIPP Isotopic Ratios
TA-21 Material Disposal Area V - Laundry Adsorption Beds	0.0004	Uses WIPP Isotopic Ratios
Total (high estimate)	143.60	

Except for hydronuclear tests, Table 6 gives a high estimate of plutonium in waste, since the WIPP isotopic ratios are assumed for most components. A better estimate of the total plutonium in the Los Alamos subsurface environment, taking into consideration the available information about the time of emplacement of the various components of waste, is about 100 kilograms (of which 50 kilograms is buried waste, 39 is subsurface plutonium dispersed due to hydronuclear tests, and the rest consists of the relatively small categories in the Los Alamos subsurface environment). We will use this value in our analysis unless otherwise specified.

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Section Three: Los Alamos Plutonium-in-Waste Account Balance

As discussed above, the Nuclear Material Management Safeguard System account, which is the master account of plutonium that is maintained to ensure that no significant quantities of plutonium are missing or unaccounted for (other than those attributable to measurement errors) is 610 kilograms. The 50 Years Report states that this value is for plutonium-239 alone:

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 [Integrated Database] does not differentiate between waste that requires nuclear materials safeguards and, therefore is still recorded as part of the inventory, and waste that has actually been removed from the inventory and physically sent to a waste burial site.¹⁹

However, this explanation was a DOE attempt to explain why the waste accounts contained a larger value for plutonium in waste than the NMMSS account. The situation was later reversed when the estimated for stored waste was reduced from over 1,300 kilograms to only about 200 kilograms in the WIPP documentation (see above).

Other parts of the 50 Years Report indicate that it is a total for weapon-grade plutonium. For instance, the report notes that Hanford produced 54.5 metric tons of “weapon-grade plutonium.”²⁰ This indicates that the totals may be for all isotopes or for plutonium-239 and plutonium-240, which is one common way in which to report weapon-grade material. Our analysis has interpreted the 610 kilogram number in the NMMSS for Los Alamos as plutonium-239 plus plutonium-240. We have considered the impact of assuming that it is only plutonium-239, for purposes of completeness as discussed below. The impact of considering the NMMSS value as including all other isotopes is small (except for decay correction issues discussed above) and well within the uncertainties in the present analysis. Table 7 and Figure 2 show our estimates of plutonium in waste and the discrepancies between the waste management accounts and the NMMSS account.

Table 7: Plutonium-239/240 discrepancies between Los Alamos Waste Accounts and the NMMSS Account Waste Declaration (610 kilograms).

All figures have been rounded to the nearest 10 kilograms.

	Subsurface total	WIPP	Total waste accounts	Discrepancy
Total Buried and WIPP Bound Wastes (High estimate)	140	200	340	270 (low estimate)
Total Buried and WIPP Bound Wastes (More Realistic)	100	200	300	310 (more realistic)

¹⁹ DOE 1996, p. 79.

²⁰ DOE 1996, p. 26.

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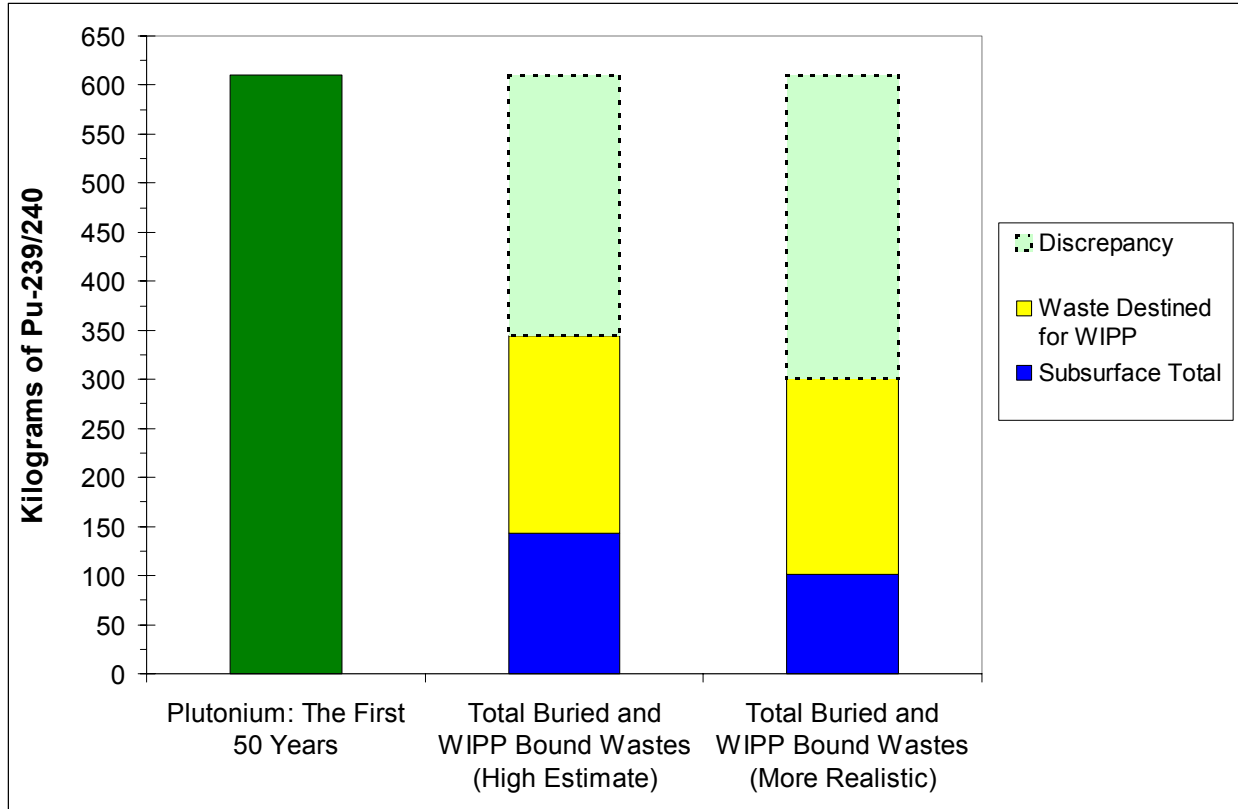


Figure 2: Plutonium-239/240 discrepancies between Los Alamos Waste accounts and the NMMSS account waste declaration from the Plutonium 50 Years Report.

If we round the numbers to the nearest 10 kilograms, the discrepancy in Los Alamos plutonium accounts is at least 270 kilograms and more likely about 310 kilograms. This assumes that the total in the NMMSS account of 610 kilograms includes plutonium-240. If it does not, then the figure for plutonium-239 plus plutonium-240 in the NMMSS account would be about 650 kilograms, and the discrepancies above would be greater by about 40 kilograms – that is, they would range from about 310 kilograms to about 350 kilograms (rounded to the nearest ten kilograms).

Analysis of plutonium discrepancies

Table 8 and Figure 3 show the annual discharges of plutonium to waste in the NMMSS account as presented in the 50 Years Plutonium report. The total cumulative plutonium in waste through the end of 1968 is reported as only 4.3 kilograms. It is clear, therefore, that the NMMSS account indicates, among other things, that

- There was very little waste of plutonium in the first twenty years or so of Los Alamos operation.
- Plutonium used in devices made for hydronuclear testing is not included in the NMMSS waste data, since the former amounts to about 40 kilograms in the period 1958 to 1961 alone and the cumulative value of the latter up to 1968 is only 4.3 kilograms. Note that

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we have included the 40 kilograms of hydronuclear testing plutonium in our estimate of about 100 kilograms of plutonium in subsurface Los Alamos discharges.

Table 8: Normal operating losses of plutonium (in kilograms) at Los Alamos National Laboratory as reported in the Plutonium 50 Years Report.²¹

Year	Annual Losses	Cumulative Losses
through 1968	4.3	4.3
1969	1.3	5.6
1970	0.3	5.9
1971	0.2	6.1
1972	0.4	6.5
1973	0.7	7.2
1974	5.3	12.5
1975	5.0	17.5
1976	4.6	22.1
1977	4.2	26.3
1978	8.2	34.5
1979	13.1	47.6
1980	20.0	67.6
1981	22.1	89.7
1982	55.1	144.8
1983	69.7	214.5
1984	78.9	293.4
1985	92.4	385.8
1986	84.8	470.6
1987	24.7	495.3
1988	26.9	522.2
1989	28.8	551.0
1990	18.9	569.9
1991	2.0	571.9
1992	4.6	576.5
1993	24.9	601.4
1994	8.6	610.0

²¹ DOE 1996, p. 57 (Table 9)

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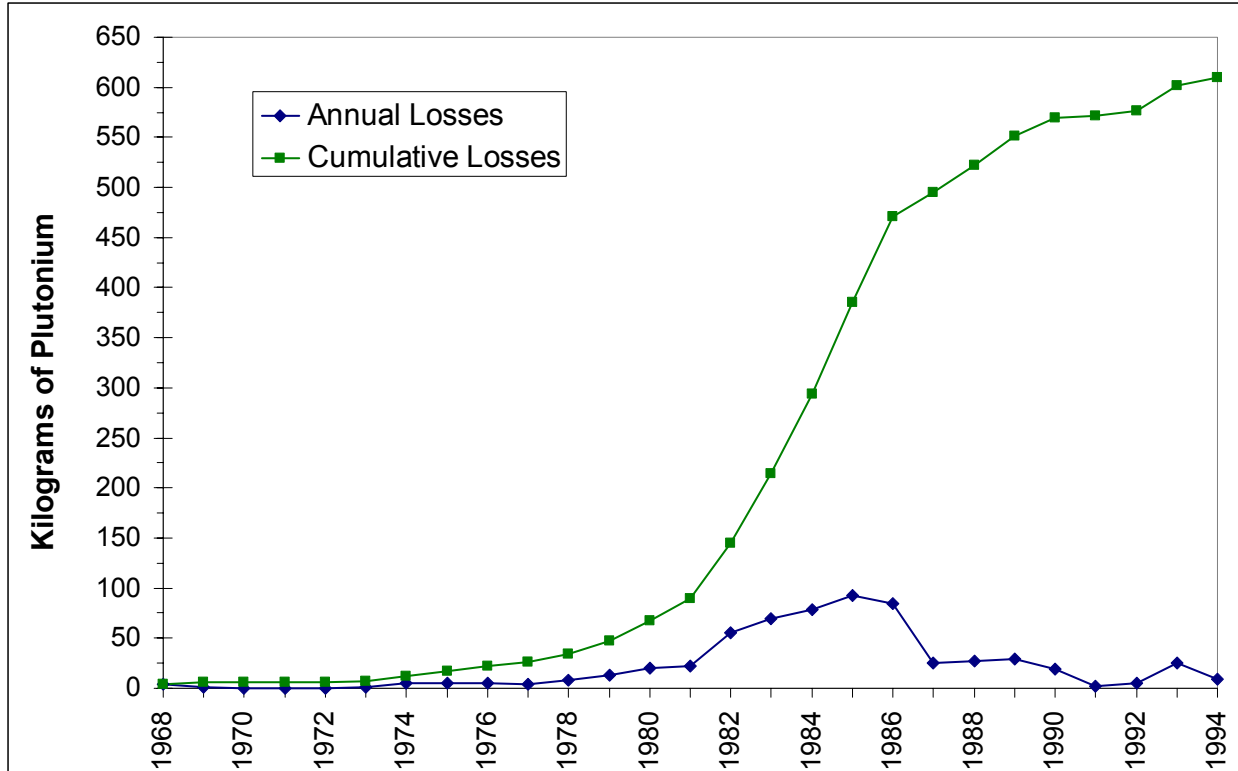


Figure 3. Normal operating losses at Los Alamos National Laboratory as reported in the Plutonium 50 Years Report, DOE 1996, Table 9, p. 57.

If the rapid rise of plutonium in waste in the 1980s reported by the NMMSS account is taken as accurate, then the large annual losses would have been discharged essentially in their entirety to retrievably stored waste. But the WIPP account indicates only about 20 kilograms of plutonium in the waste (decay correction does not make a material difference to the weight quantities). Therefore the clear implication of putting together the data in the 50 Years Report and the WIPP waste data is that if the NMMSS account is correct and if the waste discharge pattern was as described in the 50 Years Report, then the WIPP data are wrong by a large amount. In other words, the wastes designated to be sent to WIPP could contain about 300 kilograms more plutonium than now certified by the DOE. This would put the total of WIPP waste plutonium at about almost 500 kilograms, or about 150 percent larger than the present official estimate of 200 kilograms (total of waste in retrievable storage and disposed of at WIPP).

It is possible of course that there is more plutonium in the buried waste at Los Alamos. But the total amount of plutonium logged as buried waste at Los Alamos in the NMMSS account is less than 50 kilograms until the end of the 1970s, when burial of waste containing significant quantities of plutonium was stopped in favor of retrievable storage. This corresponds approximately to the estimate of buried waste we arrived at above and the estimate in the Integrated Database as well. If far more waste was buried at Los Alamos until 1979, it would mean that the amount of plutonium logged in the NMMSS account for that period is wrong by several-fold, and that all other estimates of buried waste plutonium are wrong as well. It would also mean that the rest of the NMMSS annual account of plutonium waste is wrong because the

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disposal estimates would have to be shifted from the 1980s to the earlier period. This appears to be implausible, but not impossible.

One of the following conclusions, or some combination thereof, appears to be a possible explanation for the discrepancy:

- The present estimate of plutonium in WIPP waste is wrong. We note that the earlier estimate in the Integrated Database, cited by Guimond and Beckner, was much larger. This would mean the plutonium processing and conversion to weapons and other devices at Los Alamos in the 1980s was extremely wasteful.
- The NMMSS account is wrong in its temporal distribution of waste amounts and there was much more waste in the earlier period, which was buried on site. This would lead to questions about the integrity of the safeguards system accounting because the grand total is just the sum of the annual amounts, which could no longer be regarded as sound.
- There were classified activities at Los Alamos, especially in the 1980s, for which the plutonium was logged as waste.
- There was diversion of some plutonium that was logged as waste.

We do not have enough information to make a more definitive analysis of which of these possibilities is more likely. However, we note that if more plutonium was buried at Los Alamos, then the NMMSS plutonium account is wrong in its allocation of waste to various periods. This would make the cumulative value in that account suspect as well.

Comparison with other sites

Some perspective can be thrown on the above result (that approximately 300 kilograms of plutonium appears to be unaccounted for at LANL) by examining the waste that one might expect per plutonium pit or device. LANL was not routinely a mass manufacturing site for plutonium pits. That role was played in the nuclear weapons complex by Rocky Flats. Table 9 shows the plutonium in waste at Rocky Flats, Idaho and Los Alamos. The total of plutonium in waste at Rocky Flats and Idaho represents approximately the plutonium in waste created by the production of about 70,000 plutonium pits at Rocky Flats.²² Only about 600 pits were produced at Los Alamos and about 57 experimental devices.²³

²² Ackland 1999.

²³ Mann and McDonald 2001; Johnston 2005b, Johnston 2005c, Johnston 2005d.

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Table 9: Total amounts of weapons plutonium (i.e. Pu-239/240) in waste at INL, Rocky Flats, and LANL (including wastes already disposed of at WIPP)

	Idaho and Rocky Flats	Idaho and Rocky Flats	LANL, waste data	LANL, waste data	LANL NMMSS data
	Curies	kg	Curies	kg	kg
Total	400,380	5,573	23,150	300	610

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

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 m³ of soil contaminated to 10 nanocuries per gram.

As noted above, Los Alamos did hydronuclear testing involving about 40 kilograms of plutonium. However, this does not appear to be part of the 610 kilograms of waste reported in the NMMSS waste account, in which only 4.3 kilograms of cumulative plutonium in waste are logged until 1968. Rather, the plutonium in the devices that were tested at Los Alamos appears to have been logged as part of the production data. This is reasonable, since these devices were not waste but part of LANL's output of materials at the time they left the production areas.

According to the NMMSS account, large increases in the plutonium discharged to waste in Los Alamos occurred mainly in the 1979 to 1990 period, from the time of the Islamic Iranian Revolution to the end of the Cold War. The amounts discharged increased from less than 10 kilograms per year before 1979 to more 13 kilograms in 1979 and much more in the 1980s, when they ranged from a low of 20 kilograms in 1980 to over 92 kilograms in 1985. It is unclear why plutonium discharged to waste took a sudden leap in 1979 and continued a climb to the mid-1980s, after which there was again a sudden drop (but still more than the pre-1979 values, generally). The year 1979 marked the beginning of new weapons programs, major security crises, including the Iranian revolution and the U.S.-Soviet hostilities in Afghanistan (by Islamic fundamentalist proxy for the U.S.), and U.S. decisions to deploy new nuclear weapons in Europe, etc.

It is possible that a large scale waste of plutonium occurred in the 1979-1990 period in those years, due to haste in designing new weapons and fabricating prototypes for testing. Further, there may also have been other plutonium processing activities that are not encompassed. However, the waste generated from such activities and recorded as such in the NMMSS account should show up in the data for WIPP. But it does not. Since dumping of buried transuranic waste had stopped by 1979 (DOE 1999) and since waste buried as low-level waste is estimated to contain very small amounts of plutonium, the discrepancy between the waste data as indicated by the NMMSS account and that indicated by the WIPP account are stark.

Los Alamos produced about 600 pits in five decades of operation.²⁴ In addition, 57 other devices of Los Alamos design were used for hydronuclear and other safety tests. The 35 hydronuclear tests at Los Alamos contained 39 kilograms of plutonium, or about 1.1 kilograms per device.

²⁴ Mann and McDonald 2001

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Hence if all the Los Alamos safety test devices were made there, the total of plutonium in these devices would be roughly 60 to 70 kilograms and in any case most likely under 100 kilograms.

As regards the amount of plutonium per pit one estimate can be derived from the public record regarding plutonium consumed in the 1030 nuclear tests done by the United States. According to the 50 Years Report this total was 3.4 metric tons,²⁵ or about 3.3 kilograms per weapon. Of course, some test weapons may not have had any plutonium, but been fabricated using only highly enriched uranium. And it is possible that the devices made at Los Alamos had somewhat more, possibly ~4 kilograms, per pit. The total amount of plutonium processed into pits at Los Alamos can therefore be estimated at somewhere between about 2,000 and 2,400 kilograms. Adding 100 kilograms for the safety test devices, we get a total of about 2,500 kilograms as a high estimate. Taking into account that there are other minor uses of plutonium at Los Alamos, we place the estimate of plutonium actually processed in the sense of chemical processing, machining, casting, and the like at about 3,000 kilograms or less.²⁶

For the 70,000 pits produced at Rocky Flats a reasonable range for plutonium processed (including that from returned devices) would be 230,000 to 280,000 kilograms.

If the 3,000-kilogram figure for plutonium processed into devices at Los Alamos at Los Alamos is taken as being near the correct figure then 610 kilograms of plutonium in the waste would mean that, on average, about 20 percent of the amount of plutonium processed at Los Alamos wound up in waste. Given the distribution of waste over the decades, the figure in the 1980s was likely to have been considerably higher. The comparable figure for Rocky Flats would be about 2 percent to 2.4 percent – about an order of magnitude lower than for Los Alamos.

As noted above, it is possible that there were activities that occurred at Los Alamos in the 1980s that involved processing of large amounts of plutonium that were not captured in the 3,000-kilogram estimate described above. However, if the waste generation was comparable in percentage to Rocky Flats, the total amount of plutonium processed in the 1980s would be in the range of about 20,000 to 25,000 kilograms. While this is possible, it seems rather unlikely. It seems more likely that the huge amounts logged as discharged to waste have some other explanation, such as larger discharges to WIPP, larger discharges to buried waste in the pre-1980 era, possible diversion, or some combination of these explanations.²⁷ If the NMSS account is correct, hundreds of millions of dollars of plutonium were sent to waste in the 1980s at rates of wastage per unit of production that were likely to have been much larger than Rocky Flats. If

²⁵ DOE 1996, pp. 49-50.

²⁶ Note that this report does not cover plutonium-242 tests, which contain relatively pure plutonium-242, since this analysis only covers weapon plutonium. Data for plutonium-242 have been separated out of the analysis of plutonium discrepancies.

²⁷ Some of the unaccounted for plutonium may also have been discharged to the air and into waste water, above the amounts logged in those accounts. However, typically, solid wastes contain far more of the radioactive materials in waste than air or water. Further, the largest waste amounts are in the 1980s and 1990s (over 90 percent in all). The vigilance regarding water and air emissions in these years was far greater than in the pre-1970 period. Hence, air and waste water accounts are not analyzed in this report as a major explanation for the plutonium discrepancy. However, it is an aspect that needs investigation, since additional discharges into air and/or water above those reported may have implications for health, environment, clear-up, and compliance with regulations.

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pits, hydro-nuclear, sub-critical, and safety devices were the main activities for plutonium processing, then Los Alamos discarded plutonium to waste streams at a rate about an order of magnitude greater than Rocky Flats. WIPP accounts appear likely to be incorrect in that case.

WIPP data accuracy

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 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.*²⁸

²⁸ Franke and Zerriffi 1998, pp. 10-11, emphasis added.

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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 WIPP 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.

Section Four: Environmental Implications of more Plutonium in Buried Waste

As discussed above, one possible explanation for the discrepancies is that the unaccounted for plutonium is in some combination of retrievable and buried waste. The possibility that it may all be in the buried waste 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, the then-Assistant Secretary of Energy characterized the revised data stated:

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*.²⁹

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). As we have noted, this would mean that the NMMSS annual totals of plutonium in waste for Los Alamos are also wrong. In any case, we decided to examine the environmental implications of 300 kilograms of plutonium in buried waste by performing a RESRAD analysis 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).³⁰ 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.

²⁹ Huntoon 2000, emphasis added.

³⁰ See memorandum by James Carr and other analysis in Makhijani and Smith 2005.

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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. The dose calculations indicate that it should not be left in the soil. The average concentration of plutonium-239 could be approximately 23 nanocuries per gram. Hot spots might run far higher; some may even fall into the category of transuranic waste (more than 100 nanocuries per gram or alpha-emitting, long-lived transuranic radionuclides).

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 (approximately 300 kilograms) may not be in the waste. This is a very distinct possibility, since the comparison waste per unit of plutonium processed and per pit 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 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 unaccounted for plutonium is enough to make one nuclear bomb.

In 2004, when LANL was shut down for a security reasons, three organizations³¹ 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 and that has rightly been the object of immense concern to the United States and other

³¹ IEER, Concerned Citizens for Nuclear Safety, and Nuclear Watch of New Mexico.

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countries as well as the International Atomic Energy Agency.³² 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.

³² 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

memorandum

DATE: JAN 30 1998

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 Crescent, 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.

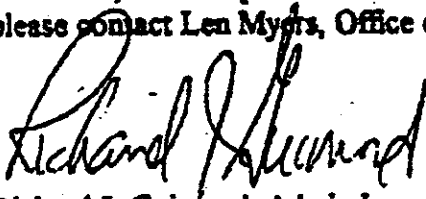
(2) "Waste" Estimates in the NMMSS System Compared to Other "Waste" Inventories.

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 Zenkovich,

Office of Waste Management (EM-35) at (301) 903-7176; 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 reactor 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	"99 Years" Report	IDB/other EM sources	Why difference in accounting?
(Z) 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



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](mailto:arjun[at]ieer.org). You can reach Jay Coghlan 505-989-7342 or [jay\[at\]nukewatch.org](mailto:jay[at]nukewatch.org) and Joni Arends at (505) 986-1973 or [jarends\[at\]nuclearactive.org](mailto: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

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](mailto:ieer[at]ieer.org)
Takoma Park, Maryland, USA

Posted August 11, 2004

Radio commentary added August 12, 2004

Appendix C

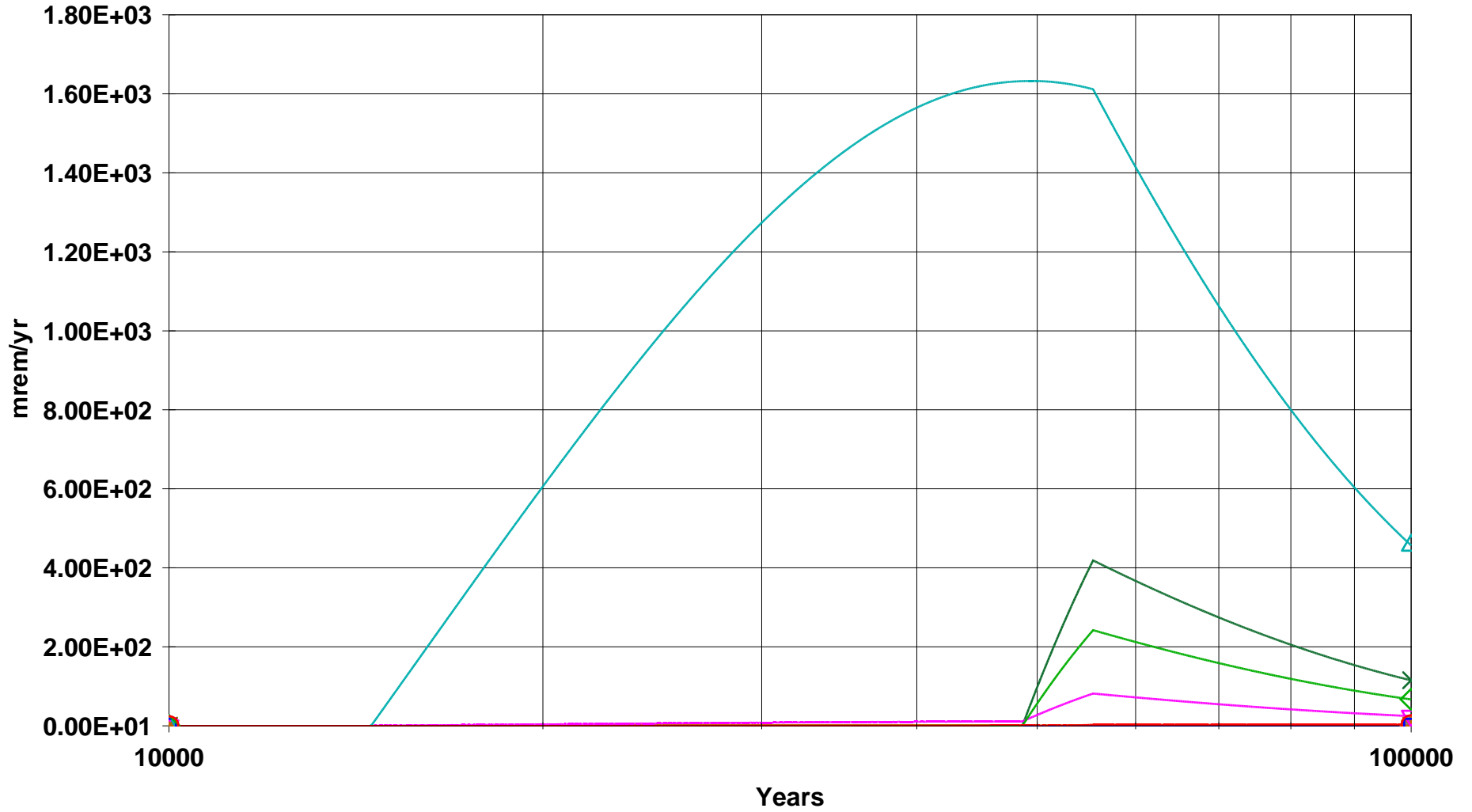
RESRAD Calculations for Disposal of Plutonium and Americium in Area G

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 = $4.68 \times 10^5 \text{ m}^3$ (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 = $4.68 \times 10^5 \text{ m}^3$ (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 = $4.68 \times 10^5 \text{ m}^3$ (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



- External
- Plant (Water Independent)
- Soil Ingest
- Radon (Water Dependent)
- Milk (Water Dependent)
- Inhalation
- Meat (Water Independent)
- Drinking Water
- Plant (Water Dependent)
- Radon (Water Independent)
- Milk (Water Independent)
- Fish
- Meat (Water Dependent)

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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	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	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	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	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)

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-34				
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)
 File: FGR 13 MORBIDITY

Menu	Parameter	Current Value	Base Case*	Parameter Name
D-5	Ra-228D , fish	5.000E+01	5.000E+01	BIOFAC (8,1)
D-5	Ra-228D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC (8,2)
D-5				
D-5	Th-228D , fish	1.000E+02	1.000E+02	BIOFAC (9,1)
D-5	Th-228D , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC (9,2)
D-5				
D-5	Th-229D , fish	1.000E+02	1.000E+02	BIOFAC (10,1)
D-5	Th-229D , 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-235D , fish	1.000E+01	1.000E+01	BIOFAC (13,1)
D-5	U-235D , 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	Unsat. 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	Unsat. 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	Unsat. 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	Unsat. 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	Unsat. 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	Unsat. 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 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 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- 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	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- 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	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- 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	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- 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	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- 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	1.562E+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- 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	2.004E+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	ΣDSR(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	ΣDSR(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	ΣDSR(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	ΣDOSE(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	ΣS(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.

RESRAD.EXE execution time = 7.70 seconds