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A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1952–1983

Volume 1

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Idaho National Engineering Laboratory
Lockheed Idaho Technologies Company
Idaho Falls, Idaho 83415

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PREFACE

This report, *A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1952–1983*, is comprised of five volumes. Volume 1 consists of the main body of the report and Appendices A, C, D, E, F, and G. Appendix B, the complete printout of the inventory database, is provided in Volumes 2 through 5. Because of its size, distribution of Appendix B has been limited. A copy of the volumes containing Appendix B can be provided on request.

ABSTRACT

This report presents a comprehensive inventory of the radiological and nonradiological contaminants in waste buried from 1952 through 1983 at the Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering Laboratory. The project to compile the inventory is referred to as the historical data task. The inventory was compiled primarily for use in a baseline risk assessment under the Comprehensive Environmental Response, Compensation, and Liability Act. The compiled information may also be useful for environmental remediation activities that might be necessary at the RWMC. The information that was compiled has been entered into the Contaminant Inventory Database for Risk Assessment (CIDRA).

The inventory information was organized according to waste generator and divided into waste streams for each generator. Waste information available in facility operating records, technical and programmatic reports, shipping records, and databases was included in the inventory. Additional information was obtained by reviewing the plant operations that originally generated the waste, interviewing personnel formerly employed as operators, and performing nuclear physics and engineering calculations. In addition to contaminant inventories, information was compiled on the physical and chemical characteristics and the packaging of the 234 waste streams.

The contaminant inventories were developed in the form of best estimates. Upper and lower bounds were also formulated by evaluating the methods by which contaminant quantities were estimated.

The completeness of the contaminant inventories was confirmed by comparing them against inventories in previous reports and in other databases, and against the list of contaminants detected in environmental monitoring performed at the RWMC.

A companion report to this report, *A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1984–2003*, INEL-95/0135, Lockheed Idaho Technologies Company, August 1995, covers waste buried or projected to be buried at the Subsurface Disposal Area during the years 1984 through 2003. The methodologies used in the two reports are essentially identical. Taken together, the two reports encompass the waste buried or projected to be buried in the Subsurface Disposal Area from 1952 through 2003.

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Program Management		Calixte O. Doucette Douglass J. Kuhns Douglas K. Jorgensen Steven M. Tom
Technical Lead		Thomas H. Smith
Data Gatherers	TAN	Henry K. Peterson Eric H. Ottewitte John R. Cunningham
	TRA	Yale D. Harker Ernest B. Nieschmidt Cecilia R. Amaro
	ICPP	Donald W. Rhodes
	NRF	Patrick R. Leonard
	ANL-W	Roy P. Grant, ANL-W Michael J. Holzemer, ANL-W Morley T. Wallace, ANL-W Donald W. Rhodes
	RFP	Donald E. Kudera Christine M. Hiaring John R. Cunningham
	Other	Douglas K. Jorgensen Terry B. Arrington Gregory D. Gerber
Uncertainty Analysis		Jeffrey J. Einerson
Database and Application Development		Cathy J. Barnard Melinda J. Schlafman Michael R. Groh Connee D. White
Risk Assessment Coordination		Cynthia A. Loehr

Environmental Monitoring Comparisons	Tiffany A. Bensen Nancy L. Hampton Cynthia E. Klassy
Contaminant Profile Data Sheets	V. Jan Bills
Comparisons Against Other Documents and Databases	Donald E. Kudera Patrick R. Leonard Donald W. Rhodes Thomas H. Smith
Source Documents	Christine M. Hiaring

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EXECUTIVE SUMMARY

Introduction and Background

This report documents the compilation of a comprehensive inventory of radiological and nonradiological contaminants in waste buried in the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering Laboratory (INEL). The inventory was compiled primarily for use in a baseline risk assessment (BRA) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The project to compile the inventory is referred to as the historical data task (HDT).

The RWMC, located in the southwest portion of the INEL, is a solid radioactive waste disposal site. It consists of the 38.85-ha (96-acre) SDA, the 22.7-ha (56-acre) Transuranic Storage Area, and the Administrative Area.

The inventory covers the waste buried from the opening of the SDA in 1952 through 1983. The SDA disposal units covered in this report include the transuranic (TRU) contaminated pits and trenches, non-TRU contaminated pits and trenches, Acid Pit, Pad A, and soil vault rows open during the period of interest. For completeness, the inventory also includes the waste disposed of in Pit 9. This disposal unit may be addressed separately under CERCLA; therefore, the Pit 9 inventory may be subtracted later from the total inventory.

Waste in the Transuranic Storage Area is not included in this inventory because it is stored aboveground. Waste disposed of in the SDA after 1983 is excluded because it is currently considered part of active disposal operations and is covered in a companion report (*A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried or Projected to be Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1984–2003*).

The inventory addresses radioactive waste, hazardous substances per CERCLA (which encompass hazardous waste per the Resource Conservation and Recovery Act), and mixed waste.

This task built upon the inventories in previous reports and databases by adding several types of additional information that are needed for the BRA:

- A more comprehensive inventory of nonradiological contaminants
- Identification of specific radionuclides previously listed under generic names [e.g., mixed fission products (MFP) or mixed activation products (MAP)]
- Physical and chemical forms of the contaminants and of the host waste streams
- Uncertainties in the contaminant quantities.

This inventory was compiled pursuant to regulations and agreements related to CERCLA. A Federal Facility Agreement and Consent Order (FFA/CO) for the INEL was signed by the U.S. Department of Energy, U.S. Environmental Protection Agency, and State of Idaho Department of

Health and Welfare to protect human health and the environment. One of the INEL waste area groups (WAGs) defined under the FFA/CO is WAG-7, the RWMC.

Under the CERCLA implementing regulations of 40 Code of Federal Regulations (CFR) 300.430 (d)(2), the lead agency is required to "characterize the nature of and threat posed by the hazardous substances and hazardous materials and gather data necessary to assess the extent to which the release poses a threat to human health or the environment . . ." The information collected is to cover ". . . the general characteristics of the waste, including quantities, state, concentration, toxicity, propensity to bioaccumulate, persistence, and mobility" and "the extent to which the source can be adequately identified and characterized."

Per guidance in the National Contingency Plan under CERCLA, a human health BRA will be performed for the SDA. The inventory developed here and in the companion report will be used to help determine the source term for the BRA.

In addition to helping determine the BRA source term, the inventory information compiled here has other potential uses. Examples are evaluating remedial alternatives (should remediation be required), assessing health and safety hazards to workers, and identifying potential operational problems.

Methodology for Data Collection and Compilation

The Challenge

The approach for compiling the inventory information had to reflect the complex nature of waste disposal at the SDA. When disposal at the SDA began 43 years ago, requirements and practices did not include the current requirements for waste characterization, so complete information about the waste was not obtained when it was generated and disposed of.

The disposal area is large and the waste is varied; therefore, drilling and sampling and analysis of the samples to determine the contaminant inventory is not feasible. Even a massive drilling and sampling campaign would not result in an inventory in which high confidence could be placed because of the heterogeneity of the waste.

Information and inventories of the waste buried in the SDA have been compiled in previous efforts for various uses. Some of the compilations have been entered into databases, such as the Radioactive Waste Management Information System (RWMIS). The previous compilations contain useful information, but they have limitations. For example, RWMIS problems include the following. For waste shipments before 1960, RWMIS has shipping record entries for only the Rocky Flats Plant (RFP) waste, and those entries generally provide no quantitative information concerning the contaminants. Some textual descriptions are generic (e.g., plant waste) and do not provide insight into the actual contents of the waste. RWMIS contains very little information concerning nonradiological contaminants in the waste. The radionuclide listings in RWMIS have problems, such as (a) entries with only one radionuclide identified (e.g., Pu-239) although knowledge of the waste-generating process indicates that other radionuclides must also be present, (b) entries with only the element specified (e.g., uranium) with no designation of a particular radionuclide, (c) entries with only generic radioactivity terms MAP and/or MFP identified, with no designation of particular

radionuclides, and (d) entries with only one fission product identified (e.g., Cs-137) although others must also be present.

Most previous compilations were derived solely from shipping records. Many addressed only the radiological contaminants in the waste. It was concluded that the existing compilations, though very useful, were not adequate to support the BRA.

The Approach

A different approach to compile the inventory information was devised. The approach emphasizes the use of information about the processes that generated the waste, supplemented by information from reports, shipping records, databases, and nuclear physics calculations. First, the facilities that generated the SDA waste were divided into seven groups, as follows: Test Area North (TAN), Test Reactor Area (TRA), Idaho Chemical Processing Plant (ICPP), Naval Reactors Facility (NRF), Argonne National Laboratory—West (ANL-W), RFP, and "other" generators (this designation includes all other onsite facilities, all other offsite facilities, and decontamination and decommissioning programs). Seven lead data gatherers were then appointed to direct the compilation of information on the waste from the seven generators. In nearly every case, the lead data gatherers had worked at the waste generator location where they collected data, and they were familiar with the operational activities that generated the waste.

Figure S-1 depicts the flow of information in this approach. The rectangles represent items of information, and the ovals represent technical activities performed with the information. Several sources of information were used by the data gatherers: process knowledge and plant operating records, inventory and other technical reports, engineering and nuclear physics calculations, shipping and disposal records (and databases of the records), interviews with plant employees (including retired employees), and other records. For each of the waste generators, varying uses were made of these sources, depending on the availability of the information and the nature of the waste.

The waste from a generator was subdivided into several waste streams. Basically, a waste stream was defined so as to reduce the nonhomogeneity within the stream. For example, one stream consisted of all of the beryllium reflectors from TRA.

A standardized, five-page data form was used to record the information for each of the 234 identified waste streams. The form requested the following information: the waste generator, building, and assigned number of the waste stream from that building; the volume, physical and chemical form, and containment of the waste stream; the quantities (including uncertainties) and the physical and chemical form of the nonradiological and radiological contaminants in the waste stream; the source(s) and reliability of the information; and the assumptions made in dealing with the waste stream.

After the information was entered onto data forms, it was subjected to qualification as shown in Figure S-1 and entered into the new Contaminant Inventory Database for Risk Assessment (CIDRA).

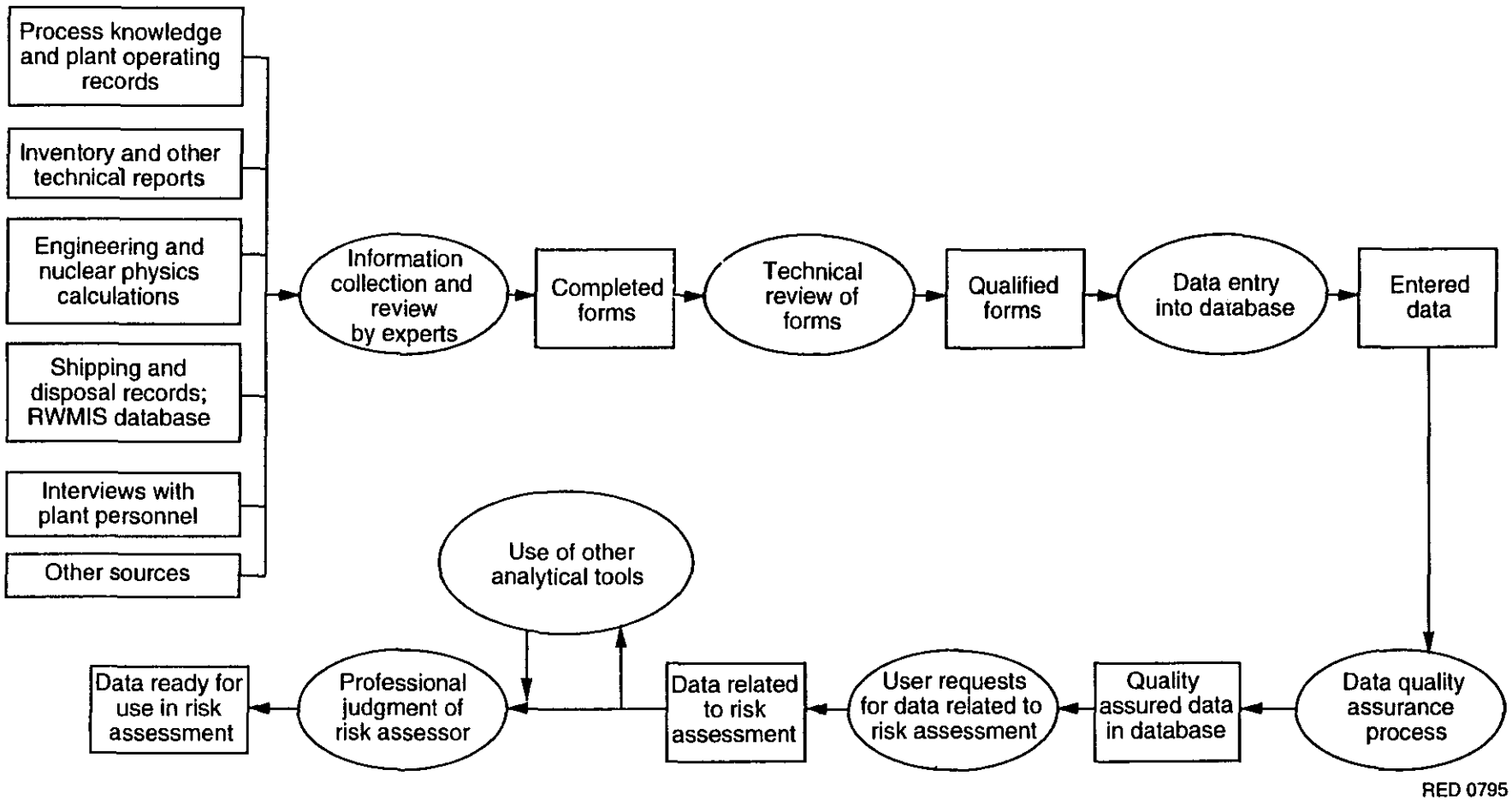

Figure S-1. Approach for information flow in developing the inventory.

Results

Appendix B to this report, in four separate volumes, contains a complete printout of the information in the CIDRA database.

Tables S-1 and S-2 list the total best-estimate quantities of each contaminant, covering all waste streams from all generators. Upper and lower bounds are also given. Table S-1 lists the nonradiological contaminants, in terms of grams. Table S-2 lists the radiological contaminants, in terms of curies at the time of disposal. Similar tables are presented in this report for each waste generator.

All inventories in this report are given to only two significant digits. Specifying more significant digits would give an erroneous impression of the accuracy inherent in the inventories.

The uncertainties in the contaminant inventory were evaluated as follows. Best estimates of the annual quantities of each contaminant for each waste stream were made by the data gatherers. Upper and lower bounds, analogous to 95% confidence limits, accompany the best estimates. When possible, the bounds are based on actual measurements and on the experience and knowledge of the data gatherers. When not possible, generic error bounds were constructed by propagating known biases and expected uncertainties. Using standard statistical techniques, the errors in annual quantities for individual waste streams were propagated to obtain upper and lower bounds on the total quantity for each contaminant. This error-propagation procedure is programmed into CIDRA.

A major bias in many of the waste records is due to the use of the Geiger-Müller (G-M) counter survey method to estimate the quantities of radiological contaminants in the waste containers. Radioactivity data believed to have been obtained by this method were corrected in the CIDRA inventory. The correction was based on extensive study of the results of previous evaluations on the accuracy of that method, using laboratory mockups and actual waste containers. The correction is a downward revision by a factor of two for the affected contaminants and waste streams.

A major source of uncertainty is due to the use of scaling factors for estimating radionuclide distributions. A scaling factor is a fraction or percentage representing the activity of one radionuclide relative to the activity of another radionuclide or to the total activity of a group of radionuclides. Scaling factor uncertainties were estimated empirically using a large data set containing the activities of several radionuclides for several waste streams.

Several nonradiological contaminants were identified for which no defendable estimates of the quantities were possible. For these contaminants, rough, upper-limit estimates were developed where feasible. The results of such evaluations are reported separately and do not appear in Table S-1.

Table S-1. Inventory of nonradiological contaminants (listed alphabetically) from all generators.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
71-55-6	1,1,1-trichloroethane	1.1E+08	9.5E+07	1.2E+08
76131	1,1,2-trichloro-1,2,2-trifluoroethane	9.1E+06	8.5E+06	9.8E+06
1806-34-4	1,4-bis(5-phenyloxazol-2-YL)benzene	Unknown	NA[b]	NA
78-93-3	2-butanone	3.2E+04	2.5E+04	4.0E+04
56-49-5	3-methylcholanthrene	Unknown	NA	NA
67-64-1	Acetone	1.1E+05	9.8E+04	1.3E+05
—	Alcohols	Unknown	NA	NA
7784-27-2	Aluminum nitrate nonahydrate	1.9E+08	1.5E+08	2.4E+08
7664417	Ammonia	7.8E+05	2.7E+05	1.8E+06
120-12-7	Anthracene	2.0E+02	7.0E+01	4.6E+02
7440-36-0	Antimony	4.5E+02	1.6E+02	1.0E+03
—	Aqua regia	3.1E+01	3.0E+01	3.2E+01
1332-21-4	Asbestos	1.2E+06	4.7E+05	2.6E+06
71-43-2	Benzene	Unknown	NA	NA
8032-32-4	Benzine	4.0E+03	3.3E+03	4.8E+03
7440-41-7	Beryllium	1.5E+07	1.4E+07	1.6E+07
1304-56-9	Beryllium oxide	Unknown	NA	NA
71363	Butyl alcohol	9.9E+04	9.0E+04	1.1E+05
7440-43-9	Cadmium	1.6E+06	9.2E+05	2.5E+06
56-23-5	Carbon tetrachloride	1.2E+08	1.1E+08	1.4E+08
7790-86-5	Cerium chloride	5.1E+05	4.2E+05	6.2E+05
67-66-3	Chloroform	3.7E+01	3.6E+01	3.7E+01
7440-47-3	Chromium	1.0E+03	6.8E+02	1.5E+03
7440-50-8	Copper	Unknown	NA	NA
3251-23-8	Copper nitrate	3.3E+02	2.6E+02	4.1E+02
—	Cyanide	Unknown	NA	NA
—	Dibutylethylcarbutol	Unknown	NA	NA
55914	Diisopropylfluorophosphate	Unknown	NA	NA

Table S-1. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
60-29-7	Ether	Unknown	NA	NA
64175	Ethyl alcohol	2.2E+04	1.8E+04	2.8E+04
50-00-0	Formaldehyde	1.4E+05	1.3E+05	1.5E+05
302012	Hydrazine	1.8E+03	1.3E+03	2.3E+03
7664393	Hydrofluoric acid	7.6E+06	6.0E+06	9.6E+06
7439-92-1	Lead	5.8E+08	4.9E+08	6.8E+08
7580-67-8	Lithium hydride	Unknown	NA	NA
12057-24-8	Lithium oxide	Unknown	NA	NA
7439-95-4	Magnesium	9.0E+06	7.4E+06	1.1E+07
7783-40-6	Magnesium fluoride	1.4E+05	1.3E+05	1.4E+05
1309-48-4	Magnesium oxide	Unknown	NA	NA
7439-96-5	Manganese	Unknown	NA	NA
7439-97-6	Mercury	Unknown	NA	NA
7783-34-8	Mercury nitrate monohydrate	8.1E+05	6.3E+05	1.0E+06
67-56-1	Methyl alcohol	2.2E+05	2.0E+05	2.5E+05
108-10-1	Methyl isobutyl ketone	8.9E+06	7.0E+06	1.1E+07
75-09-2	Methylene chloride	1.4E+07	1.4E+07	1.5E+07
7440-02-0	Nickel	2.2E+03	1.0E+03	4.1E+03
7697-37-2	Nitric acid	5.0E+07	3.9E+07	6.2E+07
4165-60-0	Nitrobenzene	Unknown	NA	NA
—	Nitrocellulose	Unknown	NA	NA
—	Organic acids	Unknown	NA	NA
—	Organophosphates	Unknown	NA	NA
1336363	PCB	Unknown	NA	NA
7447-40-7	Potassium chloride	8.0E+07	5.9E+07	1.1E+08
7778-50-9	Potassium dichromate	2.3E+06	1.7E+06	3.0E+06
7757-79-1	Potassium nitrate	1.8E+09	1.3E+09	2.4E+09

Table S-1. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7778-77-0	Potassium phosphate	4.0E+07	3.0E+07	5.4E+07
7778-80-5	Potassium sulfate	8.0E+07	5.9E+07	1.1E+08
7440-22-4	Silver	5.9E+03	4.7E+03	7.3E+03
7440-23-5	Sodium	6.8E+04	6.1E+04	7.5E+04
7647-14-5	Sodium chloride	1.6E+08	1.2E+08	2.1E+08
143-33-9	Sodium cyanide	9.4E+02	3.2E+02	2.2E+03
10588-01-9	Sodium dichromate	4.1E+06	3.0E+06	5.4E+06
1310-73-2	Sodium hydroxide	1.5E+02	5.1E+01	3.4E+02
7631-99-4	Sodium nitrate	1.2E+09	8.4E+08	1.6E+09
10101-89-0	Sodium phosphate	8.0E+07	5.9E+07	1.1E+08
11135-81-2	Sodium potassium	1.7E+06	1.2E+06	2.4E+06
7757-82-6	Sodium sulfate	1.6E+08	1.2E+08	2.1E+08
7664-93-9	Sulfuric acid	1.2E+05	9.9E+04	1.5E+05
26140-60-3	Terphenyl	4.5E+05	1.6E+05	1.0E+06
127-18-4	Tetrachloroethylene	2.7E+07	2.3E+07	3.1E+07
108-88-3	Toluene	1.9E+05	1.3E+05	2.6E+05
126-73-8	Tributyl phosphate	1.0E+06	7.8E+05	1.3E+06
79-01-6	Trichloroethylene	1.0E+08	9.1E+07	1.2E+08
15625-89-5	Trimethylolpropane-triester	1.2E+06	8.4E+05	1.6E+06
10102064	Uranyl nitrate	2.2E+05	1.7E+05	2.8E+05
—	Versenes	Unknown	NA	NA
1330-20-7	Xylene	8.5E+05	7.2E+05	1.0E+06
7440-67-7	Zirconium	1.9E+07	1.6E+07	2.3E+07
—	Zirconium alloys	5.9E+06	4.7E+06	7.3E+06

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table S-2. Inventory of radiological contaminants (listed alphabetically) from all generators (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ag-110	8.4E-01	<0.05	4.6E-03	6.1E+00
Am-241	1.5E+05	1.3	1.1E+05	2.0E+05
Am-242	7.6E-03	<0.05	4.0E-05	5.5E-02
Am-243	2.3E-01	<0.05	2.4E-03	1.6E+00
Ba-133	5.4E-04	<0.05	2.8E-06	3.9E-03
Ba-137m	3.4E+00	<0.05	1.6E-02	2.4E+01
Ba-140	6.6E+02	<0.05	2.8E+01	3.6E+03
Be-10	4.3E+01	<0.05	2.9E-01	3.1E+02
Be-7	3.5E-01	<0.05	7.1E-03	2.2E+00
C-14	1.6E+04	0.1	7.8E+02	8.5E+04
Ca-45	6.7E-04	<0.05	3.2E-06	4.8E-03
Cd-104	1.5E-07	<0.05	3.0E-09	9.5E-07
Cd-109	4.1E-01	<0.05	1.1E-02	2.5E+00
Ce-141	7.6E+02	<0.05	3.7E+01	4.0E+03
Ce-144	1.5E+05	1.3	2.6E+04	5.2E+05
Cf-252	1.0E-02	<0.05	9.8E-05	6.9E-02
Cl-36	3.1E-01	<0.05	3.1E-03	2.2E+00
Cm-242	9.1E+01	<0.05	1.2E+01	3.4E+02
Cm-244	8.0E+01	<0.05	4.9E+00	4.0E+02
Co-57	4.8E+00	<0.05	9.6E-02	3.0E+01
Co-58	1.6E+05	1.3	4.7E+04	4.0E+05
Co-60	2.8E+06	23.8	2.2E+06	3.7E+06
Cr-51	7.3E+05	6.1	1.6E+04	4.5E+06
Cs-134	2.2E+03	<0.05	3.7E+02	7.4E+03
Cs-136	7.7E-01	<0.05	2.6E-02	4.4E+00
Cs-137	7.0E+05	5.8	4.9E+05	9.5E+05
Er-169	7.6E-03	<0.05	7.4E-05	5.3E-02

Table S-2. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Eu-152	2.4E+02	<0.05	2.1E+02	2.6E+02
Eu-154	3.0E+03	<0.05	8.8E+01	1.7E+04
Eu-155	1.5E+04	0.1	7.9E+02	7.6E+04
Fe-55	3.8E+06	31.5	2.2E+06	6.0E+06
Fe-59	9.1E+04	0.8	2.0E+03	5.6E+05
H-3	1.2E+06	9.8	7.5E+05	1.8E+06
Hf-181	3.6E-01	<0.05	3.0E-03	2.6E+00
Hg-203	1.2E-02	<0.05	5.8E-05	8.7E-02
I-125	2.9E-02	<0.05	5.9E-04	1.8E-01
I-129	9.9E-02	<0.05	6.2E-03	4.8E-01
I-131	1.5E+00	<0.05	8.2E-03	1.1E+01
I-133	5.0E-02	<0.05	2.5E-04	3.6E-01
Ir-192	5.4E+01	<0.05	1.4E+00	3.2E+02
Kr-85	1.3E+00	<0.05	6.2E-03	9.5E+00
La-140	7.7E+02	<0.05	3.2E+01	4.2E+03
Mn-53	1.0E-03	<0.05	2.0E-05	6.3E-03
Mn-54	1.8E+05	1.5	3.7E+04	5.4E+05
Mn-56	2.7E+01	<0.05	1.6E-01	2.0E+02
Mo-99	1.0E+00	<0.05	1.5E-02	6.6E+00
Na-22	3.0E-01	<0.05	5.4E-03	2.0E+00
Nb-94	4.9E+01	<0.05	2.5E+01	8.8E+01
Nb-95	2.4E+03	<0.05	1.4E+03	3.9E+03
Ni-59	5.1E+03	<0.05	2.4E+02	2.7E+04
Ni-63	7.4E+05	6.2	4.7E+05	1.1E+06
Np-237	2.4E+00	<0.05	1.7E-01	1.1E+01
P-32	9.2E-02	<0.05	1.4E-03	6.1E-01
Pb-210	9.1E-06	<0.05	1.8E-07	5.7E-05

Table S-2. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Pb-212	2.0E-05	<0.05	4.0E-07	1.3E-04
Pm-147	8.1E+01	<0.05	9.6E-01	5.5E+02
Po-210	7.5E+01	<0.05	1.4E+00	4.8E+02
Pr-143	6.2E+02	<0.05	2.1E+01	3.6E+03
Pr-144	4.2E+04	0.4	3.2E+03	1.9E+05
Pu-238	2.5E+03	<0.05	4.3E+02	8.6E+03
Pu-239	6.6E+04	0.5	4.7E+04	8.9E+04
Pu-240	1.5E+04	0.1	1.0E+04	2.2E+04
Pu-241	4.0E+05	3.3	2.9E+05	5.4E+05
Pu-242	9.9E-01	<0.05	7.3E-01	1.3E+00
Ra-225	2.0E-06	<0.05	1.5E-06	2.5E-06
Ra-226	5.9E+01	<0.05	4.4E+01	7.6E+01
Rb-86	7.1E+00	<0.05	1.1E-01	4.6E+01
Rh-103m	2.7E+02	<0.05	9.2E+00	1.5E+03
Rh-106	6.8E+03	<0.05	5.0E+03	9.0E+03
Rn-222	1.0E-06	<0.05	2.0E-08	6.3E-06
Ru-103	3.6E+02	<0.05	1.5E+01	1.9E+03
Ru-106	6.8E+03	<0.05	5.0E+03	9.0E+03
S-35	8.8E-02	<0.05	1.6E-03	5.6E-01
Sb-124	1.8E+03	<0.05	1.0E+01	1.3E+04
Sb-125	1.3E+05	1.1	1.1E+05	1.4E+05
Sc-44	2.5E-02	<0.05	5.0E-04	1.6E-01
Sc-46	5.3E+01	<0.05	2.9E-01	3.8E+02
Sn-119m	2.7E+04	0.2	2.5E+04	3.0E+04
Sr-85	2.9E-02	<0.05	1.5E-04	2.1E-01
Sr-89	4.7E+02	<0.05	2.0E+01	2.6E+03
Sr-90	4.5E+05	3.8	1.0E+05	1.3E+06

Table S-2. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ta-182	8.5E+00	<0.05	3.5E-01	4.6E+01
Tc-99	2.6E+02	<0.05	1.2E+01	1.4E+03
Th-230	1.8E-02	<0.05	1.4E-02	2.2E-02
Th-232	1.3E+00	<0.05	1.1E+00	1.6E+00
Tl-204	6.7E-04	<0.05	3.2E-06	4.8E-03
Tm-170	3.4E+00	<0.05	1.6E-02	2.4E+01
U-232	8.4E+00	<0.05	6.8E+00	1.0E+01
U-233	1.1E+00	<0.05	7.8E-01	1.6E+00
U-234	6.4E+01	<0.05	5.0E+01	8.2E+01
U-235	5.1E+00	<0.05	4.2E+00	6.0E+00
U-236	2.5E+00	<0.05	1.9E+00	3.3E+00
U-238	1.1E+02	<0.05	7.0E+01	1.8E+02
Y-88	2.5E-02	<0.05	5.0E-04	1.6E-01
Y-90	1.9E+04	0.2	1.8E+03	8.2E+04
Y-91	5.3E+02	<0.05	2.2E+01	2.9E+03
Yb-164	7.6E-03	<0.05	7.4E-05	5.3E-02
Zn-65	3.6E+02	<0.05	3.8E+00	2.5E+03
Zr-93	4.0E+00	<0.05	2.4E+00	6.4E+00
Zr-95	7.6E+04	0.6	7.0E+04	8.2E+04
Total	1.2E+07	99.8[a]		

a. Total in table does not equal 100.0% due to rounding.

Observations and Conclusions

Based on the above results and on knowledge gained in compiling the inventory, the following observations and conclusions are presented:

- The combined use of many types of information sources—process knowledge, operating records, technical calculations, reports, interviews, shipping records, the RWMIS database, and others—was essential to achieve the present degree of completeness of the inventory.

- For radiological contaminants, the inventory information that could be located and that is compiled in the new CIDRA database is believed to be substantially complete.

- For nonradiological contaminants, the inventory information that could be located and that is compiled in CIDRA is also believed to be substantially complete. During the time period of interest, strong emphasis was not placed on documenting the nonradiological hazards in the waste because the current requirements for reporting hazardous chemicals did not exist. However, process information gathered from a multitude of sources has resulted in closing most of the gaps in the shipping records.

- A substantial effort was devoted to breaking down the generic radioactivity terms MAP, MFP, unidentified alpha-emitters, and unidentified beta/gamma-emitters for each generator so that a specific distribution of radionuclides would be available for the risk assessment.

- The predominant (by mass) nonradiological contaminants identified in the waste were as follows: metals—lead, zirconium and its alloys, beryllium, magnesium, sodium-potassium, cadmium, and mercury compounds; organics—carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, and methylene chloride; acids; nitrates and other salts; and asbestos.

- The predominant (by radioactivity at the time of disposal) radiological contaminants identified in the waste were Fe-55, Co-60, H-3, Ni-63, Cr-51, Cs-137, Sr-90, Pu-241, Mn-54, Co-58, Ce-144, and Am-241.

- To confirm its completeness, the compiled inventory of radiological contaminants was compared against the corresponding inventory in the RWMIS database. For the principal radionuclides, the agreement with RWMIS was generally within the total random error of the usual activity-measurement method except for two instances in which the present task developed major new information:

  - The estimated H-3 activity is approximately 20 times larger than the RWMIS value, due primarily to the identification of a major TRA waste stream with approximately 1 million Ci of H-3 entrapped in beryllium.

  - The estimated activities of plutonium and americium radionuclides increased typically by a factor of 10 over the RWMIS values. This result stemmed from an extensive

effort to obtain new information on the RFP waste, based on a plant-wide inventory balance at the RFP.

- As an additional confirmation of its completeness, the compiled inventory of radiological and nonradiological contaminants was compared against the inventories in previous reports. The list of contaminants in the new inventory is considerably longer than those in previous inventories. For nearly all contaminants, the new inventory values are similar to or larger than those in previous inventories. Possible exceptions are asbestos, sodium hydroxide, and zirconium, but the methods of estimating quantities of the contaminants vary from study to study.

- As a final confirmation of its completeness, the present inventory of contaminants was compared against the list of contaminants detected in environmental monitoring at the RWMC. No radiological contaminants were reliably detected in the monitoring that had not been identified in the inventory. The only nonradiological contaminants detected more than rarely in the environmental monitoring and not identified in the inventory were three organic compounds: 1,1-dichloroethylene, 1,1-dichloroethane, and dichlorodifluoromethane. These three contaminants may be degradation products or impurities associated with closely related contaminants that were identified in the inventory. Detected contaminants also could have originated from sources other than the subject waste, e.g., in effluents from other INEL facilities or from other waste at the RWMC.

- A large quantity of information was assembled and entered into CIDRA on the physical and chemical forms of the waste streams and of the contaminants, as well as on the packaging of the waste streams.

- Even though the information now residing in CIDRA has been through multiple checks and reviews, the possibility exists for oversights and discrepancies. As new information is discovered, the database will be revised as necessary.

ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ALE	Argonne National Laboratory–East
ANL-E	Argonne National Laboratory–East
ANL-W	Argonne National Laboratory–West
ANP	Aircraft Nuclear Propulsion (Program)
ARA	Auxiliary Reactor Area
ARMF	Advanced Reactivity Measurement Facility
ATR	Advanced Test Reactor
ATRC	Advanced Test Reactor Critical
BAD	Best Available Data (database)
BNL	Battelle Northwest Laboratories
BORAX	Boiling Water Reactor Experiment
BRA	baseline risk assessment
BWS	buried waste stream
CAS	Chemical Abstract Services
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFA	Central Facilities Area
CFR	Code of Federal Regulations
CIDRA	Contaminant Inventory Database for Risk Assessment
CWS	Chemical Warfare Service
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EBR	Experimental Breeder Reactor

ECF	Expended Core Facility
EFL	Experimental Fuels Laboratory
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ETR	Engineering Test Reactor
ETRC	Engineering Test Reactor Critical
FCF	Fuel Cycle Facility
FFA/CO	Federal Facility Agreement and Consent Order
FMF	Fuel Manufacturing Facility
G-M	Geiger-Müller
GCRE	Gas-Cooled Reactor Experiment
HDT	historical data task
HEPA	high-efficiency particulate air
HFEF	Hot Fuel Examination Facility
HTRE	Heat Transfer Reactor Experiment
ICPP	Idaho Chemical Processing Plant
IET	Initial Engine Test (Facility)
IFR	Integral Fast Reactor
INEL	Idaho National Engineering Laboratory
L&O	Laboratory and Office (Building)
LLW	low-level waste
LOF	Loss-of-Fluid (Test Reactor)
LOFT	Loss-of-Fluid Test (Reactor)
MAP	mixed activation products

MFP	mixed fission products
ML-1	Mobile Low-Power Reactor No. 1
MTR	Materials Test Reactor
NA	not applicable
NCP	National Contingency Plan
ND	not detected
NOS	not otherwise specified
NR	not reported
NRC	U.S. Nuclear Regulatory Commission
NRF	Naval Reactors Facility
NRP	Naval Reactors Program
NRTS	National Reactor Testing Station
OFF	offsite waste generators not otherwise specified
PBF	Power Burst Facility
PCB	polychlorinated biphenyl
PER	Power Excursion Reactor
PM	Portable Medium Nuclear Power Plant
PQL	practical quantitation limit
RCRA	Resource Conservation and Recovery Act
RESL	Radiological and Environmental Sciences Laboratory
RFP	Rocky Flats Plant
RI/FS	remedial investigation/feasibility study
RLWTF	Radioactive Liquid Waste Treatment Facility
RMF	Reactivity Measurements Facility
RML	Radiation Measurements Laboratory

RPDT	recent and projected data task
RPSSA	Radioactive Parts Security Storage Area
RSD	relative standard deviation
RSWF	Radioactive Scrap and Waste Facility
RWMC	Radioactive Waste Management Complex
RWMIS	Radioactive Waste Management Information System
SCMS	Sodium Components Maintenance Shop
SDA	Subsurface Disposal Area
SL-1	Stationary Low-Power Reactor No. 1
SLSF	Sodium Loop Safety Facility
SNAP	Systems for Nuclear Auxiliary Power
SNAPTRAN	Systems for Nuclear Auxiliary Power Transient
SPERT	Special Power Excursion Reactor Test
SPF	Sodium Process Facility
SRE	Sodium Reactor Experiment
TAN	Test Area North
TMI	Three-Mile Island
TRA	Test Reactor Area
TREAT	Transient Reactor Test Facility
TRU	transuranic
TSA	Transuranic Storage Area
TSF	Technical Support Facility
UCL	upper confidence limit
USGS	U.S. Geological Survey
VOC	volatile organic compound

WAG	waste area group
WMC	Waste Management Complex
WRRTF	Water Reactor Research Test Facility
ZPPR	Zero Power Physics Reactor

REGULATORY SOURCES CITED

DOE Orders

DOE Order 5820.2A, "Radioactive Waste Management," September 26, 1988

Codes of Federal Regulation

Code of Federal Regulations, 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Wastes"

Code of Federal Regulations, 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan"

Statutes

Atomic Energy Act

Clean Air Act

Clean Water Act

Comprehensive Environmental Response, Compensation, and Reliability Act

Federal Water Pollution Control Act

National Environmental Policy Act

Resource Conservation and Recovery Act

Safe Drinking Water Act

Solid Waste Disposal Act

Toxic Substances Control Act

Agreements

Federal Facility Agreement and Consent Order for the Idaho National Engineering Laboratory, signed December 9, 1991

A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1952–1983

1. INTRODUCTION AND BACKGROUND

1.1 Objective and Overview

This report documents the compilation of a comprehensive inventory of radiological and nonradiological contaminants in waste buried in the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering Laboratory (INEL) from the opening of the SDA in 1952, through 1983.[a] (This time period is referred to here as the "time period of interest.") The inventory was compiled primarily for performing a future baseline risk assessment (BRA) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The project to compile the inventory is referred to as the historical data task (HDT).

A companion report (LITCO 1995) to this report documents the recent and projected data task (RPDT) project. The RPDT project covers waste buried or projected to be buried at the SDA during the years 1984 through 2003. The methodologies used in the two reports are essentially identical. Taken together, the two reports encompass the waste buried or projected to be buried in the SDA from 1952 through 2003.

In terms of disposal location, nearly all of the SDA is included in the inventory. As explained in Section 2 of this report, the SDA consists of numerous disposal units. The disposal units in this task include the pits, trenches, and soil vault rows open during the time period of interest. The inventory includes an acid pit used during the time period of interest and Pad A. Both are located in the SDA. For completeness, the inventory also includes the waste disposed of in Pit 9. The remediation of Pit 9 may be addressed separately, so the Pit 9 inventory may be subtracted later from the total inventory, depending on the detailed scope of the risk assessment.

In terms of specific disposal units, the inventory addresses the following:

- All of the trenches (1 through 58)
- The Acid Pit

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a. The year 1983 was selected as the cutoff point for the portion of the inventory that is reported here based on the following rationale. One particular waste stream (filters from the Waste Calcining Facility at the INEL) that might not have complied with current waste acceptance criteria was disposed of at the SDA as late as 1983. With only a few exceptions, which are described in LITCO (1995), waste disposed of after 1983 complied with the acceptance criteria.

- Pits 1 through 14
- Pits 15 and 16, through 1983
- The 1982 and 1983 waste that is in Pit 17
- Soil Vault Rows 1 through 10, and 12
- Soil Vault Rows 11 and 13, through 1983
- Pad A.

These disposal units form a completely complementary set with those addressed in the companion report (LITCO 1995). Together, the disposal units include all waste disposed of in the SDA.

Waste in the Transuranic Storage Area (TSA) is not included in this inventory because it is stored aboveground.

The inventory addresses radioactive waste, hazardous substances per CERCLA [which encompass hazardous waste per the Resource Conservation and Recovery Act (RCRA) and other hazardous substances], and mixed waste buried in the time period of interest.

Figure 1-1 presents an overview logic flowchart of the activities conducted to develop the inventory.

Several sources of information were used to compile the inventory, including process knowledge, operating logs, previous inventory-related documents, shipping records, information databases, engineering and nuclear physics calculations, and interviews with personnel having knowledge of the facility operations that produced the waste streams.

This task built upon the inventories in previous reports and databases by compiling several types of additional information that are needed for the BRA:

- A more comprehensive inventory of nonradiological contaminants
- Specific radionuclides previously listed under generic names [e.g., mixed fission products (MFP) or mixed activation products (MAP)]
- Physical and chemical forms of the contaminants and of the host waste streams
- Uncertainties in the contaminant quantities.

To confirm its completeness, the inventory was compared with those in other reports and databases, and the reasons for any differences were explored. The list of contaminants was also compared with the list of contaminants detected in environmental monitoring conducted at the SDA.

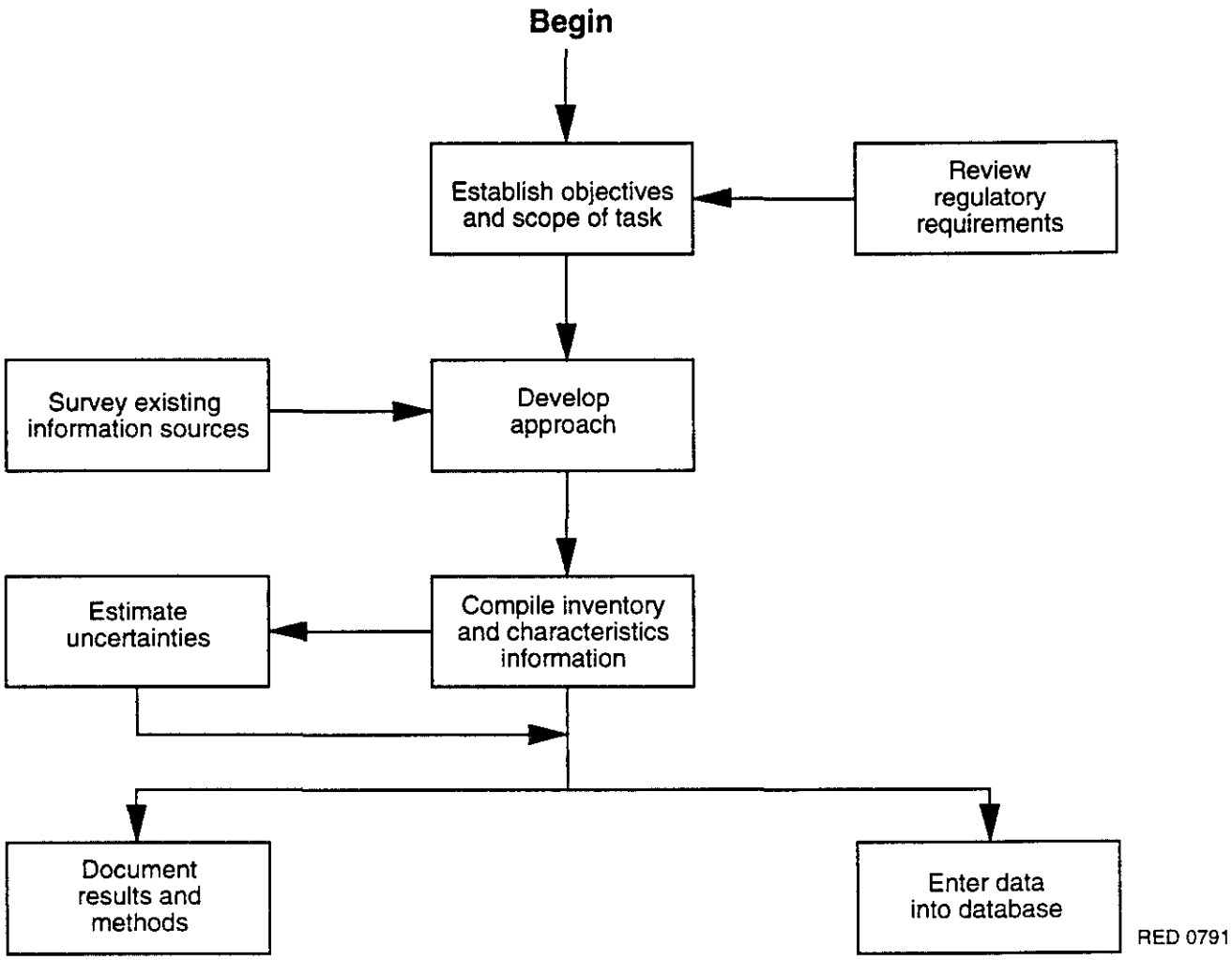

Figure 1-1. Overview logic flowchart for the task.

This report is organized as follows. The remainder of this section provides a brief history and description of the SDA, discusses the regulations and regulatory agreements that create the need for the inventory information, and addresses the potential use of the inventory in other applications. The methods used to collect and compile the information are described in Section 2. For the major waste streams from each generator, the specific assumptions and evaluations that were used are also discussed. Section 3 presents the resulting inventory for instances in which the contaminant quantities are known. Section 4 discusses and attempts estimates for instances in which the contaminant quantities are not known. Section 5 discusses the sources of data uncertainty, the methods used to estimate it, and the development of the upper and lower bounds. The completeness of the compiled inventory is confirmed in Section 6 by comparing it with inventories in existing reports and waste information databases and with the environmental monitoring results.

1.2 Brief History and Description of the Subsurface Disposal Area[b]

The RWMC, located in the southwest portion of the INEL, is a solid radioactive waste disposal site. The RWMC consists of the 38.85-ha (96-acre) SDA, the 22.7-ha (56-acre) TSA, and the Administrative Area (see Figure 1-2). Because the waste inventoried in this report was disposed of only in the SDA, the other two areas are mentioned only in passing.

The SDA consists primarily of three types of disposal units: pits, trenches, and soil vaults. For regulatory purposes, these disposal units are divided into various operable units, as shown in Figure 1-2.

Development of the SDA began in 1952 on a 5.3-ha (13-acre) tract of the original 40.5-ha (100-acre) site that had been identified for waste management purposes. The first shipment of radioactive waste from the INEL, which at that time was called the National Reactor Testing Station (NRTS), was buried in Trench 1 in the SDA that same year. Today, there is a total of 58 trenches; the last trench was closed in 1982.

Pits were also excavated, starting in 1957, because of the large sizes of some waste items and the increased space efficiency of pit disposal. There is a total of 20 pits in the SDA.

Containers of transuranic (TRU)-contaminated waste from the Rocky Flats Plant (RFP) in Colorado were buried at the SDA beginning in 1954 and ending in 1970. The RFP waste was interspersed with the INEL waste in pits and trenches for several years.

By 1957, the original 5.3-ha (13-acre) SDA was nearly filled. The SDA was then expanded eastward and southward to its present size. The expansion also enclosed the Acid Pit, which had been used since 1954 for the disposal of laboratory acids, some of which contained very low levels of radioactivity. The Acid Pit was officially closed in 1961, although records indicate that it possibly was used once in 1967 and once in 1970.

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b. This section was abridged primarily from the detailed RWMC history presented in *A History of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory* (EG&G Idaho 1985).

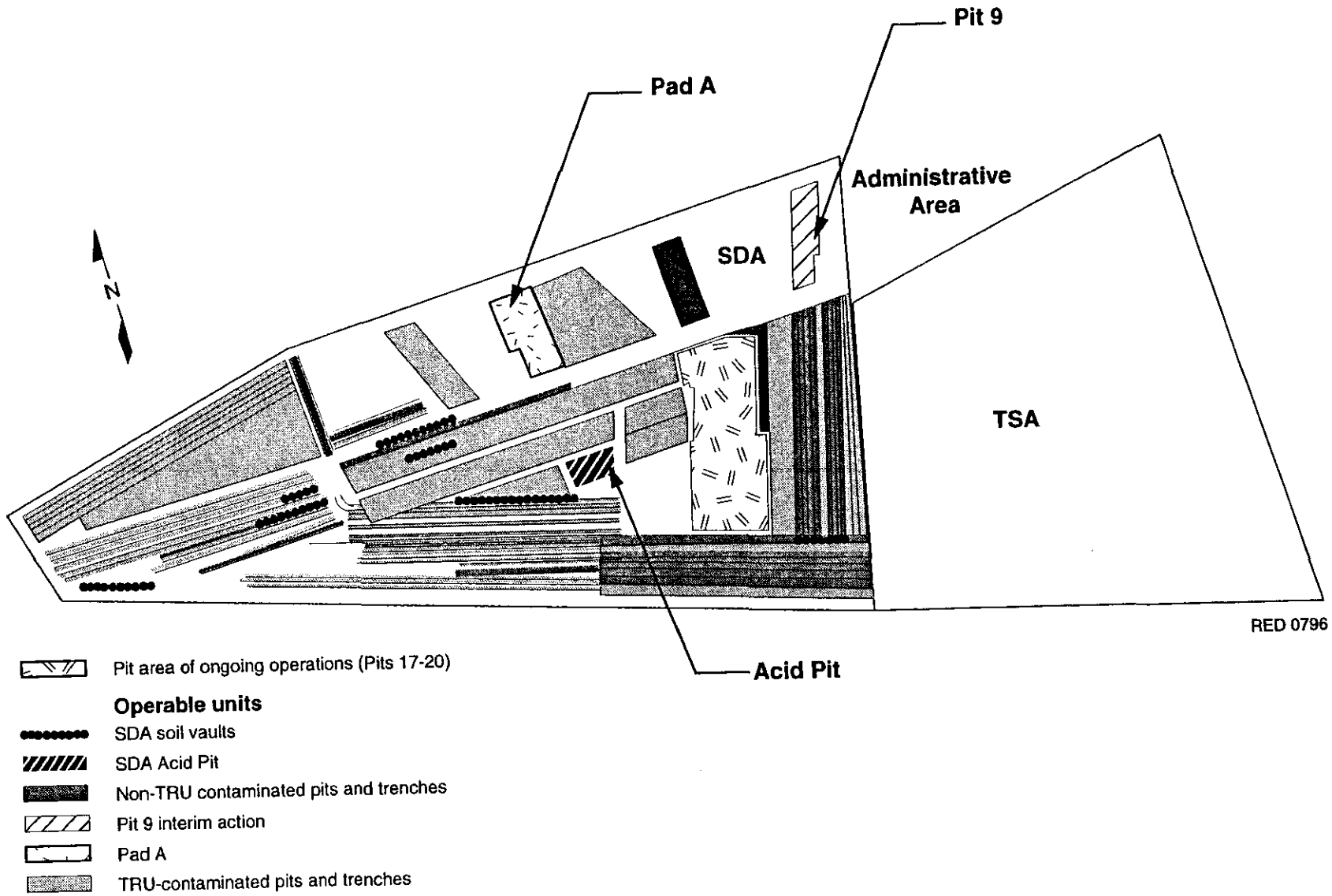

Figure 1-2. Overview layout of the Radioactive Waste Management Complex, including the Subsurface Disposal Area, Transuranic Storage Area, and Administrative Area.

Between 1960 and 1963, the SDA also served as an interim burial ground for waste generated by licensees of the U.S. Atomic Energy Commission (AEC) [a predecessor agency to the U.S. Department of Energy (DOE)]. Waste from a number of offsite generators across the country was buried at the SDA during this period. Two additional shipments of non-RFP offsite waste were buried in 1967 and 1969.

Numerous changes in SDA waste management practices took place from 1952 to 1970. The general trend was toward more rigorous disposal practices. Soil-covering frequency, cover thickness, backfill over bedrock before emplacing waste, container designs, and container-stacking practices, as well as waste recordkeeping, evolved and improved over time.

Several flood control and diking projects were completed, beginning in 1958 and continuing into the 1980s. Most of these projects were in response to flooding of the SDA by local runoff from snowmelt in 1962, 1969, and 1982.

In 1970, the AEC issued a policy requiring the segregation of waste contaminated with TRU radionuclides and the storage of that waste in a mode permitting later retrieval of contamination-free containers. A decision was made at the RWMC to store and cover future receipts of TRU waste[c] (and suspected TRU waste) aboveground. Accordingly, burial of such waste at the SDA ceased in 1970. Burial of non-TRU waste [low-level waste (LLW)] continues. The 22.7-ha (56-acre) TSA was established at the RWMC in 1970 for aboveground storage of newly received TRU waste, thereby expanding the RWMC to its present size.

In 1972, Pad A was established in the SDA for aboveground disposal of waste suspected of containing TRU radionuclides but in concentrations less than 10 nCi/g. Pad A was closed in 1978.

Two programs demonstrated experimental retrieval of part of the waste buried in the SDA. The Initial Drum Retrieval Program (1974 through 1978) and the Early Waste Retrieval Program (1976 through 1978) retrieved approximately 4,248 m^3 (150,000 ft^3) of waste, which was placed on the

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c. The current definitions of TRU waste and LLW are as follows, as stated in DOE Order 5820.2A:

> ***Transuranic waste***—Without regard to source or form, waste that is contaminated with alpha-emitting transuranium radionuclides with half-lives greater than 20 years and concentrations greater than 100 nCi/g at the time of assay.
>
> ***Low-level waste***—Waste that contains radioactivity and is not classified as high-level waste, transuranic waste, or spent nuclear fuel or 11e(2) byproduct material . . . Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may be classified as low-level waste, provided that the concentration of transuranics is less than 100 nCi/g.

Before 1984, the lower limit of transuranic radionuclide activity for defining TRU waste was 10 nCi/g, rather than the currently specified 100 nCi/g.

Much of the LLW and TRU waste disposed of in the SDA during this period is **mixed waste**: waste containing both radioactive and hazardous chemical components as defined by the Atomic Energy Act and RCRA, respectively.

TSA-R storage pad in the TSA and on Pad A. The waste retrieved in these programs has not been subtracted from the inventory developed in this report, but it will be subtracted before preparing the BRA.

In 1977, the use of soil vaults for the disposal of high-radiation-level waste began in the SDA. Soil vaults eventually replaced trenches for the disposal of such waste. The vaults are drilled in rows, as shown in Figure 1-2. As of this writing, final preparations are underway to dispose of future high-radiation-level LLW in concrete vaults placed in pits.

In 1980, disposal of LLW from Argonne National Laboratory-East (ANL-E) in Illinois began at the SDA. Disposal of LLW from that generator ceased in 1988.

1.3 Pertinent Regulations and Agreements

This section describes the regulatory framework under which this task was performed.

Under CERCLA (or Superfund) of 1980, as amended, Federal agencies that have facilities included on the U.S. Environmental Protection Agency's (EPA's) National Priorities List are required to enter into agreements with the EPA. These interagency agreements are designed to expedite remedial actions in response to the release (actual or potential) of hazardous substances to the environment at those facilities.

On December 21, 1989, the INEL was added to the EPA's National Priorities List of Superfund sites. On December 9, 1991, a Federal Facility Agreement and Consent Order (FFA/CO) for the INEL was signed and approved by DOE, EPA, and the State of Idaho Department of Health and Welfare. The goal of this agreement is to ensure that INEL releases of hazardous substances are thoroughly investigated in accordance with the National Contingency Plan (NCP) (see 40 CFR 300) and that appropriate response actions are taken as necessary to protect human health and the environment. One of the INEL waste area groups (WAGs) defined under the FFA/CO is WAG-7, the RWMC.

Under 40 CFR 300.430 (d)(2), the NCP requires that

> "The lead agency shall characterize the nature of and threat posed by the hazardous substances and hazardous materials and gather data necessary to assess the extent to which the release poses a threat to human health or the environment . . ."

The HDT and the RPDT (LITCO 1995) focused on the first part of this regulation, i.e., ". . . characterize the nature of . . . the hazardous substances and hazardous materials . . "[d] disposed of in the SDA. The BRA that this task supports will address the second portion of the requirement.

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d. Generally throughout this report, the term "contaminants" is used in place of "hazardous substances and hazardous materials."

More detailed requirements concerning the characterization of hazardous substances are found in 40 CFR 300.430 (d)(2) (iii) and (iv). The information collected is to cover

> ". . . the general characteristics of the waste, including quantities, state, concentration, toxicity, propensity to bioaccumulate, persistence, and mobility" and "the extent to which the source can be adequately identified and characterized."

The HDT and the RPDT (LITCO 1995) addressed most of the above requirement. The remainder of the requirement will be addressed in the BRA.

Guidance on complying with the NCP regulations is provided in, among other sources, the *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part A* (EPA 1989). Section 4 of that manual lists "determination of the nature of the wastes" as one of the primary data-collection components of the remedial investigation/feasibility study (RI/FS) conducted under the NCP. Available site information must be reviewed, including "information on amounts of hazardous substances disposed (e.g., from site records)."

The HDT was planned and conducted with close attention to the above regulations and guidance. The intent was that the resulting inventory of contaminants comply fully with all applicable requirements.

1.4 Other Uses of the Results

In addition to its use for the BRA, the inventory information has other potential uses. Much of the present information may be useful for evaluating remedial alternatives. The information collected on chemical and physical properties of the waste may be helpful in evaluating treatment alternatives, assessing health and safety hazards to workers, and identifying potential operational problems.

Caution: Other applications of this information may be appropriate only if the nature of the application is compatible with the purpose of this study. This information (which was developed for risk assessments under CERCLA) may not be suitable for use in other applications. For example, the degree of conservatism appropriate in inventory information depends on the application. For some applications, best-estimate values are appropriate. For other applications, more conservative values are appropriate. In evaluations such as safety analyses, highly conservative, upper-limit values are generally appropriate.

Although a major effort has been devoted to compiling this inventory, new information may be identified that could require modifying the inventory. Furthermore, some information concerning certain contaminants may never be located because of the lack of records.

References for Section 1

EG&G Idaho (EG&G Idaho, Inc.), 1985, *A History of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory*, WM-F1-81-003, Revision 3, July 1985.

EPA (U.S. Environmental Protection Agency), 1989, *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual*, Part A, interim final, EPA/540/1-89/002, U.S. Environmental Protection Agency, December 1989.

LITCO (Lockheed Idaho Technologies Company), 1995, *A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried or Projected to be Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1984–2003*, INEL-95/0135, Rev. 1, August 1995.

2. METHODOLOGY FOR DATA COLLECTION AND COMPILATION

This section describes the methods by which the waste inventory information was identified, collected, compiled, reviewed, and entered into a database.

2.1 Overview

The first step in a risk assessment is to identify and quantify all radiological and nonradiological contaminants in the waste with the potential to harm humans or the environment.

Waste disposal at the SDA began in 1952. Disposal requirements and practices at that time did not include the current requirements for waste characterization. Certainly, it was not envisioned at that time that the information provided about the waste would be used later to perform a formal risk assessment; therefore, complete information about the waste was not obtained when it was generated and disposed of. However, as discussed later in this section, inventory information that is sufficiently comprehensive and reliable to support a risk assessment can be and has been compiled.

Contaminants are often identified through a sampling and analysis program. Drilling, sampling, and analysis to determine an appropriate SDA inventory is not considered feasible or practical for several reasons: (a) the area is quite large, (b) drilling into disposal units containing radioactive waste is hazardous, and (c) the contaminants are distributed unevenly over the area in concentrated and dilute form. Even a massive drilling and sampling campaign would not result in an inventory in which high confidence could be placed because of the heterogeneity of the waste.

Information and inventories concerning the waste buried at the SDA have been compiled in many previous efforts for various uses. Some of the compilations have been entered into databases. (Sections 2.2 and 2.3 discuss existing documents and databases, respectively, that contain information on the buried waste.) Some of the compilations pertain to the entire SDA; others pertain to only 1 of the 90 disposal units addressed in this report. Most of the compilations were derived from shipping records. (Section 2.3 discusses some of the deficiencies in the shipping records.) Many of the inventory compilation efforts addressed only the radioactive component of the waste. Further, waste information obtained for one purpose often does not provide all of the parameters needed for a different purpose. After investigation, it was concluded that the existing compilations of waste inventory information were very useful, but they were not adequate to support a risk assessment of the SDA under CERCLA.

In view of the limitations of the these approaches, an information gathering approach that emphasized the use of process knowledge was devised.

First, the facilities that generated the SDA waste were divided into seven groups:

1. Test Area North (TAN)
2. Test Reactor Area (TRA)
3. Idaho Chemical Processing Plant (ICPP)

4. Naval Reactors Facility (NRF)

5. Argonne National Laboratory—West (ANL-W)

6. Rocky Flats Plant (RFP)

7. Other generators — This includes all other onsite facilities, all other offsite facilities, and decontamination and decommissioning (D&D) programs.

Figure 2-1 shows the geographic locations of waste generators at the INEL. The RFP is located near Denver, Colorado. See Section 2.4.7 for a complete list of the other offsite generators that are scattered throughout the United States.

Seven lead data gatherers were appointed to compile information on the waste from the seven generators. In nearly every case, the lead data gatherers had worked at the waste generator location where they collected data, and they were familiar with the operational activities that generated the waste. Thus, the approach was *primarily one of evaluating the waste based (where possible) on knowledge of the specific processes that generated it*, as well as on review of pertinent records, databases, and reports, rather than on simply rereviewing the shipping records.

Figure 2-2 depicts the flow of information in this approach. The rectangles represent items of information, and the ovals represent technical activities performed with the information.

The upper left portion of the figure shows the principal sources of information used by the data gatherers. The data gatherers used process knowledge and plant operating records, inventory and other reports, engineering and nuclear physics calculations, shipping and disposal records (and databases of such records), interviews with plant employees (including retired employees), and other records.

The next question was the level at which the waste should be characterized. The goal was to divide a generator's waste, for data-gathering purposes, so that the resulting information could be applied to the risk assessment. Characterizing waste at the generator level would not provide sufficient detail because the waste varied greatly in form, constituents, and characteristics. Characterizing each waste container individually was not feasible. Even if information were available on the contents of each waste container (which it is not), hundreds of thousands of containers were involved.

The approach used was to divide the waste from a given generator into "waste streams." (Dividing the waste into streams was strictly for convenience in organizing the data and did not in any way restrict the data that could be gathered.) Although the definition used in this report for a waste stream is flexible, the term generally refers to a collection of waste containers with similar contents. In some cases, waste streams could be defined that were fairly uniform from one container to another. For example, all of the benelex and plexiglass from the RFP were defined as one waste stream, and all of the beryllium reflectors from TRA were defined as one waste stream. On the other hand, for a minor building that produced a very small amount of assorted waste, all waste from the building was generally grouped together into one, nonuniform stream.

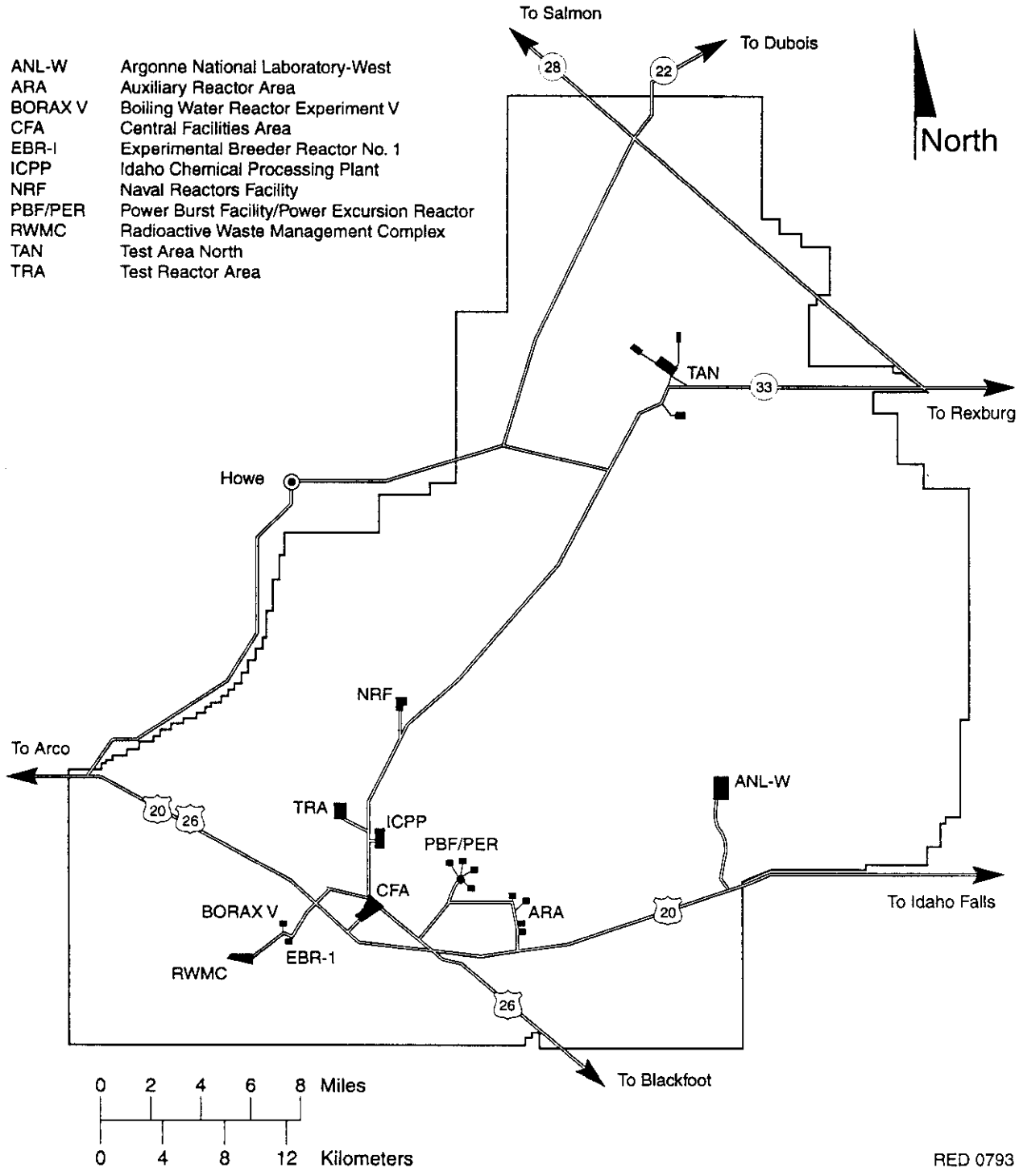

Figure 2-1. Locations of the Idaho National Engineering Laboratory waste generators in 1952 through 1983 and the location of the Radioactive Waste Management Complex.

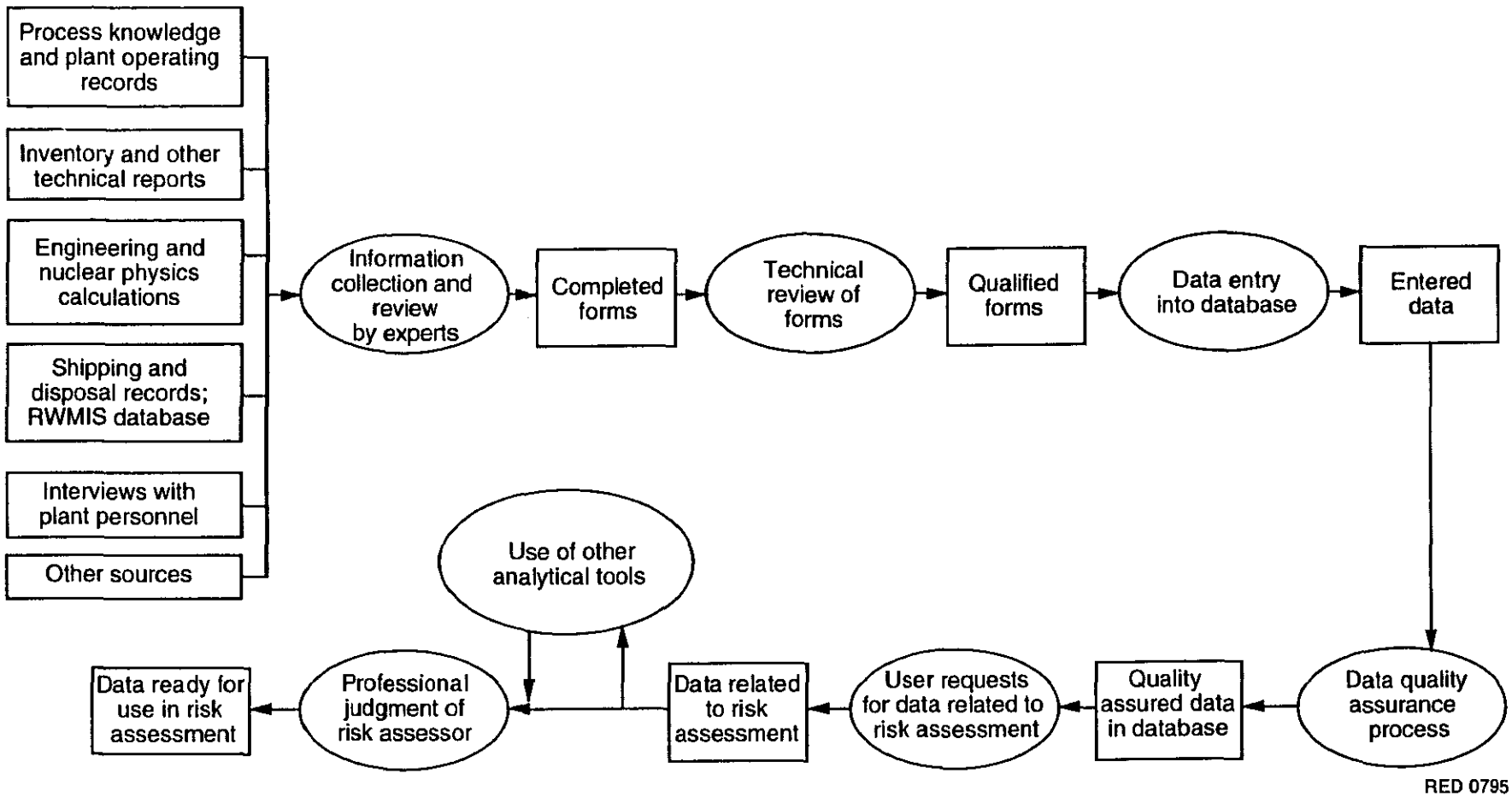

Figure 2-2. Approach for information flow in developing the inventory.

Applying this approach led to dividing the waste from a major generator into anywhere from 8 to 111 waste streams. The total number of waste streams was 234, a manageable number.

A standardized, five-page data form (see Appendix A) was used to record the information collected for each waste stream. The form indicates the generator, building, and assigned number of the waste stream from that building; the volume, physical and chemical form, and containment of the waste stream; the quantities (including uncertainties) and physical and chemical form of the nonradiological and radiological contaminants in the waste stream; the source(s) and reliability of the information; and the assumptions made in dealing with the waste stream. The form (plus continuation pages as needed) was completed for each of the 234 waste streams that were identified.

Many of the information items on the data forms were computer-searchable data fields with prescribed lists of possible answers. However, for flexibility in describing the waste, the forms included several "free" fields where verbal descriptions could be entered to an appropriate level of detail. Although free fields cannot be rolled up using the database, some of the information is invaluable in understanding subtle characteristics of the waste that affect parameters such as the mobility of the contaminants.

Candidate nonradiological and radiological contaminants for Parts C and D of the data forms (see Appendix A) were addressed as follows. All radionuclides identified in the waste streams were included on Part D. Candidate nonradiological contaminants for Part C were addressed by screening against two lists. One list consisted of the hazardous substances designated by the EPA under CERCLA. The list included chemicals designated under the Federal Water Pollution Control Act, Solid Waste Disposal Act, Clean Air Act, Clean Water Act, RCRA, and Toxic Substances Control Act. The second list covered contaminants listed in the National Primary Drinking Water Standards of the Safe Drinking Water Act. If there was any question about whether to include a nonradiological contaminant, it was included. One class of nonradiological contaminants not included on Part C was metals commonly found in alloy form in structural components, i.e., nickel and chromium, which are used in stainless steel. A literature review and analysis (Weidner 1993) indicated that, considering the extremely slow corrosion rate of stainless steel in the RWMC soil and the very limited solubility of nickel and chromium at the pH of interest, the mobility of these chemicals is expected to be extremely limited.

The steps in Figure 2-2 are discussed in more detail in the remainder of Section 2. Section 2.2 discusses the use of source documents. Section 2.3 describes the use of an existing database of shipping and disposal records. Section 2.4 provides a detailed description of how the waste information was obtained for each waste generator.

After the information was collected and entered onto data forms, it was subjected to a qualification process (discussed in Section 2.5) and entered into a contaminant inventory database for risk assessment (described in Section 2.6). Finally, with the use of other analytical tools and the professional judgment of risk assessors, the data are ready for use in risk assessments.

2.2 Use of Source Documents

As indicated in Figure 2-2, technical reports and other documents containing inventory and related information about the waste buried in the SDA were one of the primary sources of information

collected in this study. This section discusses the types of reports available and describes how the reports were used.

A large number of documents contain useful information about the waste buried in the SDA. The documents range from brief letters to comprehensive technical reports. The scope of the documents ranges from narrow (addressing only one waste stream from one generator) to comprehensive (fairly complete inventories), although none of the documents covers the full scope required for the BRA. Some of the documents are devoted solely to discussions of inventory, while others address inventory only briefly as part of another topic, such as the characteristics of waste to be processed in a proposed treatment facility. Many of the documents contain data extracted from previous documents. The dates of the documents range from the 1950s to the present. Some of the documents offer crucial information, while others are of limited value.

Because the existing documents were of considerable value to the current study, as many as possible were identified and evaluated for their applicability. Data gatherers reviewed the documents related to their assigned generator and incorporated the appropriate information into the data-gathering effort.

For each waste stream, the data gatherer specified the sources of information in Part E of the data form (see Appendix A). If a document was the source of an item of information, the box titled "reports" was marked on the data form, and the title, author, report number, and date were entered. On many data forms, the data gatherers also compared the inventory specified in a reference report against sometimes-conflicting data from other sources of information, made a judgment as to which data were considered more credible, and indicated the basis for the judgment.

More than 190 specific reports and letters are discussed and referenced in later parts of Section 2.

2.3 Use of the Radioactive Waste Management Information System

In addition to process knowledge, technical reports, calculations, shipping records, and interviews, existing databases were searched to obtain information. The principal databases accessed in the current task were the Radioactive Waste Management Information System (RWMIS) and the accompanying Qualifier Flag/Additional Contents database.

2.3.1 Description of RWMIS

RWMIS (Litteer 1988) is a mainframe electronic database developed in 1971, which resides on an IBM 3083 computer. Information reported in RWMIS includes all airborne (onsite effluent), liquid, and solid radioactive waste shipped to or generated at the INEL. RWMIS provides an inventory of radioactive waste stored or disposed of at the RWMC and radioactive effluents generated at the INEL.

The data in RWMIS originated from shipping and disposal forms[a] that accompanied the waste when it was shipped for storage or disposal.

The database consists of *summary* waste shipping and disposal records for the years 1954 to 1970 (nothing from 1952 to 1954), *waste shipment* records for 1971 to 1986, and *container-by-container* records from 1986 to the present. Shipment-specific waste information data before 1971 are not included in the user-accessible database. These pre-1971 records are referred to as the Best Available Data (BAD) database. Records in RWMIS for 1971 to 1983 and 1984 to the present are referred to as the historical database and the current database, respectively.

RWMIS is a hierarchical database consisting of a parent-master (shipment information) and two children: a nuclide information child and a container information child. The parent-master has a one-to-many relationship with the nuclide and container information children.

Table 2-1 lists and describes the primary fields in RWMIS.

2.3.2 Verification of RWMIS; the Qualifier Flag/Additional Contents Database

RWMIS data were verified in 1992 by comparing the original shipping manifests that accompanied the waste shipments with the corresponding fields on printouts of the RWMIS database. RWMIS data for waste disposed of in the following pits and trenches at the RWMC were verified:

- Pits 2–16
- Trenches 17–58

Data for the following locations were not verified:

- Soil vault rows
- Pits 1 and 17–20
- Trenches 1–16.

During the verification process, an additional database (the Qualifier Flag/Additional Contents database) was created to capture information not included in RWMIS. The database contains an inventory of the specific discrepancies between the RWMIS printout and the shipping manifest. It also documents the additions or deletions to the RWMIS content code required to reflect the contents of the waste specified on the shipping manifest. This information was captured using a prespecified set of codes.

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a. For simplicity, shipping and disposal forms are generally referred to as "shipping records."

Table 2-1. Primary information fields in the RWMIS database.

Primary RWMIS fields	Description
Waste origin	The site (area and building/location) at which the waste was generated.
Waste type	The physical phase of the waste (i.e., liquid or solid).
Radioactive	A flag that specifies if the shipment is radioactive.
Report date	The date generally identifies the date the shipment form was completed. It usually appears on the form as the date of approval for shipping the waste.
Waste description	A generic description of the shipment. In most cases, this field also includes radiation readings taken at contact and at 1 m (3 ft) from the shipment.
Gross volume	The gross volume of the waste shipment in cubic meters.
Gross weight	The gross weight of the waste shipment in grams.
Gross curies	The gross curies in the waste shipment.
Disposal date	The date of waste disposal or storage.
Container type	The type of waste container.
Container number	The number of waste containers in the waste shipment.
Container volume	The volume of each type of waste container in the waste shipment.
Volume unit	The unit of volume for each waste type container.
Waste description	The content code that provides a generic description of the waste in the container (e.g., Code 003 implies paper, metal, and wood).
Disposal location	The disposal or storage location of the waste.
Nuclide	The isotopic nuclide designation.
Nuclide weight in grams	The gram quantity of each nuclide in the waste shipment.
Nuclide quantity	The curie quantity of each nuclide in the waste shipment.

2.3.3 RWMIS Download for the Current Task

The RWMIS, BAD, historical, and current mainframe electronic databases were downloaded from NOMAD to an IBM personal computer dBASE environment to support the HDT. The download was performed for Pits 1 through 16, Pit 17 for the years 1982 and 1983, Trenches 1 through 58, Pad A, and Soil Vault Rows 1 through 13. RWMIS contains no data for the Acid Pit.

To use RWMIS in the dBASE environment, the data were downloaded into three relational databases. These databases consisted of the master (as stored in RWMIS), a nuclide information database (with key information from the master), and a container information database (with key information from the master). A verification procedure was written and implemented to maintain the integrity of the RWMIS databases during the download. In the RWMIS mainframe environment, a count was made of the number of records, and all numerical fields were summed. The same checks were made on the download (dBASE) version of the database. All inconsistencies were resolved before the data were used.

The download version of RWMIS was used as one source of information to support the current task. As shown in Figure 2-2, RWMIS and the accompanying Qualifier Flag/Additional Contents database were useful sources of information collected by the data gatherers.

2.3.4 RWMIS Limitations

Section 2.1 indicates that existing reports and databases of SDA waste inventory information were very useful, but they are not adequate to support risk assessments conducted under the FFA/CO. This section provides more detail on why the RWMIS database could not serve as the sole source of inventory information.

For shipments before 1960, RWMIS has entries for only RFP waste (none of which are available for Trenches 11 through 15), and those entries generally provide no quantitative information concerning the contaminants. Essentially no records for onsite waste were available when RWMIS was created.

Another limitation of RWMIS is that it does not contain content codes (well-defined physical and chemical descriptions) for waste disposed of between 1971 and 1983. Textual descriptions are used to describe the contents of the waste. Some of the textual descriptions are generic (e.g., plant waste) and do not identify the actual contents of the waste. Also, many of the textual descriptions refer to more than one waste form. This makes providing summaries by waste form extremely difficult, if not impossible. Finally, several different textual descriptions may be used to identify the same waste form.

Another limitation of RWMIS is that it contains very little information concerning nonradiological contaminants in the waste.

Before 1986, RWMIS stored data only on a shipment basis. The curies (or grams) identified with each isotope were specified for the entire shipment and not for individual containers. For example, this limitation makes it difficult to determine if the contents of an individual container should be classified as TRU waste or LLW.

From a risk assessment perspective, there are several other deficiencies in the RWMIS database. These deficiencies reflect a lack of either detail or completeness. Some of these deficiencies include entries with

- Only one radionuclide identified, e.g., Pu-239, whereas knowledge of the waste-generating process indicates that other radionuclides must also be present
- Only the element specified, e.g., uranium, with no designation of a particular radionuclide
- Only MAP and/or MFP identified, with no designation of particular radionuclides
- Equal amounts of MAP and MFP identified, suggesting that no rigorous estimate of radionuclide breakdown was performed
- Only one fission product identified, e.g., Cs-137, whereas knowledge of the waste-generating process indicates that others must also be present
- Only one activation product identified, e.g., Co-60, whereas others must also be present
- Unidentified radionuclides, e.g., unidentified beta-gamma, unidentified alpha
- No chemical form specified
- No physical form specified.

2.4 Data Collection Methods

This section discusses the methods used to collect waste information for the seven waste generators. Because the waste and the available information differed among generators and waste streams, the data-collection methods also differed.

The discussion of the methods is presented in three ways. First, Sections 2.4.1 through 2.4.7 generally describe the waste generator of interest, the processes by which the waste was generated, the availability of waste information from the generator, and the data-collection approach selected.

Second, these sections also describe in detail the "most important" waste streams, by generator. Most important waste streams are defined as

> Those streams that collectively contain at least 90% (typically 98%) of the estimated total quantity of all radiological and nonradiological contaminants, based on the results of risk-based screening calculations using a draft version of the inventory.

Approximately 60 waste streams were designated as the most important streams under this definition. A few additional streams that were considered to be of interest by the data gatherers are also described in detail.

For each of these streams, the following information is provided: how the stream was generated, the principal contaminants in the stream (not necessarily in order of quantity), the sources of information about the stream, and the assumptions and analysis used in estimating the quantities of

contaminants. *If the stream helped to contribute to the 90% quantity of any radiological contaminants, then the principal radiological contaminants in the stream are listed. Similarly, if the stream helped to contribute to the 90% quantity of any nonradiological contaminants, then those contaminants are listed. If both cases apply, then both types of contaminants in the stream are listed.*

Third, information on the assumptions and the sources of information for every waste stream is available on the data forms for the various waste streams. As discussed in Section 2.6, the data forms have been entered into a database. A printout of the entire contents of the database is provided in Appendix B, Volumes 2 through 5 of this report.

The database uses an alphanumeric designator to uniquely identify each waste stream. The first part of the designator generally is a three-letter code representing the name of the major generator. The second part generally is a three-digit code representing the building number where all or most of the waste stream originated. The third part of the designator is a number representing the sequence of the waste stream identified from the given building. A suffix is added to the end of the waste stream number to indicate if the stream is historical (H), recent (R), projected (P), or Pad A (A). Only the historical streams and Pad A are within the scope of this document; recent and projected streams are addressed in a companion document LITCO (1995). Thus, the designator TRA-603-21H represents the 21st waste stream identified and characterized from Building 603 at the Test Reactor Area during the historical period.

2.4.1 Test Area North

The Generator. TAN lies at the north end of the INEL, about 43 km (27 mi) northeast of the Central Facilities Area (CFA) (see Figure 2-1). TAN was designed and constructed in the early 1950s to support the General Electric Aircraft Nuclear Propulsion (ANP) Program, the mission of which was to test the concept of the nuclear-powered airplane. For a 9-year period, until the program was canceled by the U.S. Congress in 1961, the program tested three versions of a full-scale, nuclear-powered aircraft engine (Wilks 1962). The program support facilities consisted of the Technical Support Facility (TSF), where technical support facility personnel had offices; the Initial Engine Test (IET) Facility; the Hot Shop, a large hot cell into which the engines could be moved for repair, assembly, and disassembly; and some smaller hot cells, built for the examination of individual irradiated fuel pieces or other irradiated specimens. The IET and Hot Shop were connected by a double set of rail tracks that allowed the engines to be moved back and forth.

Testing of the three Heat Transfer Reactor Experiment (HTRE) engines involved passing preheated air through the 93.4% enriched uranium core and jet engine components and releasing it to a 46-m (150-ft)-high stack (Devens et al. 1958). Each test sequence conducted in the ANP Program was designated with an IET number. The HTRE-1 engine, in which IET #3, #4, and #6 tests were conducted as a proof of principle, consisted of a reactor core of 37 fuel assemblies clad with nichrome (80% nickel and 20% chromium) (Thornton et al. 1962).

The HTRE-2 core was used for the remaining 20 IET tests except #13, #16, #18, and #25, and lasted from February 1957 to March 1961. A central test location was used to test various fuel/ceramic configurations (Flagella 1962). All but one of these tests involved a fuel/ceramic configuration of beryllium oxide (BeO). The remaining nonceramic test, IET #15, was an endurance testing sequence involving a Cr-UO_2-Ti (metallic), concentric-ring, fueled insert (Evans 1959).

The HTRE-3 engine, designed for the actual airplane, was used to confirm operational parameters and endurance characteristics for the core (Linn et al. 1962). This core was used for conducting the IET #13, #16, #18, and #25 experiments.

After the ANP Program, the TAN Hot Shop and hot cells were used on an ad hoc basis for projects that required heavy shielding.

In 1961, near the end of the ANP Program, a Stationary Low-Power Reactor No. 1 (SL-1) accident occurred at the NRTS, the former name of the INEL. The SL-1 reactor vessel was disassembled for examination at the TAN Hot Shop.

From July 1962 until the 1970s, the TAN Hot Shop and hot cells were, with four exceptions, devoted principally to the Loss-of-Fluid Test (LOFT) and miscellaneous minor examinations and tests for TRA and the Power Burst Facility (PBF). The four exceptions involved examining the two reactor cores included in the Systems for Nuclear Auxiliary Power Transient (SNAPTRAN) tests that were conducted in 1964 (Fletcher 1964; Kessler et al. 1965) and 1966 (Cordes et al. 1967; Kessler et al. 1967), the final disassembly and examination of the Mobile Low-Power Reactor No. 1 (ML-1) reactor core (Murphy et al. 1966), and the testing and examination of the Portable Medium Nuclear Power Plant (PM)-2A reactor vessel (Mousseau et al. 1967). The disassembly and examination of each of the two reactor/reactor vessel components required the disposal of radioactive material that was roughly equivalent in radioactivity to that for the SL-1 examination and disassembly. To more accurately account for the radioactive and hazardous waste that was sent to the RWMC by these projects, the TAN Hot Shop and hot cell logs were reviewed.

The SNAPTRAN tests were criticality-destruct type tests that purposely destroyed the nuclear core. The first test, in 1964, simulated a water immersion accident during launch of the power plant. The fuel-moderator was an alloy of zirconium hydride and 10 wt% of 93% enriched uranium. The small core contained U-235 in 37 fuel rods and 464 gram-moles of H_2. The core was reflected by beryllium inserts. The interstitial space among the fuel rods contained NaK.

The second SNAPTRAN test, in 1966, destroyed the core in air with the same type of destructive criticality event as in the 1964 test. This test configuration contained significantly more beryllium than the first test, but no NaK (Dietz 1966). The internal beryllium reflector in both tests amounted to about 5,500 g, and the external beryllium reflector of the second test added an additional 11,000 g of beryllium.

Beginning in 1980, the TAN Hot Shop and hot cells supported research and development of material from the Three-Mile Island (TMI)-2 reactor as a result of the 1979 accident. During the mid-1980s, the final tests for the LOFT program were supported by the Hot Shop.

Generation of the Waste. Most of the waste produced at TAN was a result of the specific test and evaluation programs discussed. The decontamination, disassembly, evaluation, and discarding of the components of the tests generated a wide variety of waste as discussed below.

From December 1955, when nuclear testing of the HTRE-1 engine commenced, until after 1983, the majority of activity in the waste generated at TAN was shipped from the TAN Hot Shop or hot cells to the RWMC. The experiments and test assemblies were disassembled and examined at these facilities.

During the IET #3 and #4 tests in HTRE-1, because of the rigorous test requirements and the uncertainties with respect to fuel and fuel-clad design, problems developed that led to the melting of the fuel cladding and fuel. The radioactivity produced in the cladding and the fuel contaminated the duct to the stack and the engine internals. These tests were the near-sole source of radioactive waste sent from TAN to the RWMC from December 1955 to February 1957, when testing with the HTRE-2 commenced (Thornton et al. 1962).

During testing of the HTRE-2 inserts, insignificant fuel and fuel-clad melting occurred in the driver core, but fuel, BeO, and fission products were released from the insert configuration to contaminate the reactor and jet engine internals and the duct. This contamination and the discarded insert materials were the sources for the primary waste streams from TAN from March 1957 until the end of the ANP Program in 1961.

Later in the ANP Program, during testing of the HTRE-2 inserts, the hot cells became the dominant source of waste from TAN. During this testing period, the HTRE was brought back to the Hot Shop; the insert was removed from the reactor and taken to the hot cells for examination. After the examination had been completed, the samples and specimens were discarded.

Information about the disposal of the insert material is uncertain based on discussions with personnel previously employed with the ANP Program. A check with personnel at ICPP indicated that no ICPP records existed to show that ceramic fuels had been received or were being stored at ICPP. In addition, the only fuel to be processed at ICPP, other than metallic fuel, was the graphite ROVER (nuclear rocket propulsion program) fuel. To date, no ceramic fuel has been processed at ICPP.

From May 1961 until July 1962, the TAN Hot Shop examined the SL-1 core and reactor vessel (Kunze 1962; GE 1962a). Discarded reactor parts and reactor structural material constituted the majority of the TAN Hot Shop waste stream from May 1961 until August 1962.

Following the first SNAPTRAN test, essentially all of the material (i.e., the environmental tank, the reactor vessel, the internal beryllium reflector), including about 1% of the core fuel, was sent to the RWMC for disposal.

Again, following the second SNAPTRAN test, all of the core structural material, the beryllium reflector, the tank, and a maximum of about 4% of the fuel were eventually sent to the RWMC for disposal. The reclaimed fuel for both tests was sent to ICPP for reprocessing.

During and between the time of the two SNAPTRAN tests, the ML-1 and PM-2A reactor vessel examinations were performed at TAN facilities. These examinations resulted in many metallurgical samples and scrap materials being discarded from the Radiation Measurements Laboratory (RML) and hot cell facilities. Reactor skids, shielding, fixtures, and other parts associated with these systems, not discarded from the RML and hot cells, were discarded from the Hot Shop.

The TAN hot cells generated waste when examining the fuel and other materials received from TMI-2 and LOFT.

Routine operations and maintenance at TAN generated waste such as combustibles used for decontamination and contaminated tools.

General Availability of Information. The waste generated at TAN came from a broad range of sources and was at a peak relatively early (in the early 1960s), when waste recordkeeping was in its early stages. Several programmatic reports provide insights to the activities that generated the waste. These reports furnish supplementary information to the shipping records and RWMIS, which are sketchy during that time period.

In 1958, the AEC Health and Safety Division at the NRTS began to publish an annual report that summarized programmatic activities, including waste disposal at the RWMC. (See the AEC reports provided in the reference list. See also Osloond 1965, 1966, 1967, 1968, 1970, and an undated report.) Data from these reports and associated waste shipping records are considered the best available data for the early years, the time for which there is most question as to the volume of the waste and the contaminants in the waste.

Much information on the characterization of early waste shipments had to be obtained by interviewing personnel who had been involved in packaging the waste.

Reports that allude to waste items considered for disposal were another valuable source of information. Although the reports may not have addressed the waste, they described programs and designs in detail, allowing a defendable identification of the waste items that would have been produced. Because the early waste is most uncertain, many early reports that described the ANP Program were reviewed for the types of material that were used in the IET. These tests were conducted by the U.S. Air Force and were under the purview of an AEC operations office other than the Idaho Operations Office. Therefore, the primary repository for the reports was not at the INEL. Many of the reports that described these tests were not available at the INEL Technical Library until after the INEL Historical Dose Evaluation Study (DOE 1991) had been completed in 1991.

Data-Collection Approach. The general data-collection approach used for TAN was to review programmatic and AEC Health and Safety Division annual reports; conduct interviews with personnel who had worked at TAN during the ANP project, the SL-1 core examination, and the SNAPTRAN tests; review the shipping records; and search the RWMIS database.

The shipping records and RWMIS do not reflect INEL-generated waste before 1960. (Only waste from the RFP is available, and that information is incomplete.) Fortunately, annual totals of radioactivity in INEL-generated waste are available elsewhere (see the AEC reports in the reference list). The activities estimated for 1956, 1957, and 1958 are based on the IET experiments conducted and the amount of fuel damage that occurred during these tests, and they are judged against estimates documented for similar operations that occurred during 1959 and 1960. The IET #3 and #4 tests experienced relatively severe fuel damage, and both of these tests occurred in 1956. The IET #6 through #26 tests were relatively mild with respect to IET #3 and #4 tests fuel damage, but the schedule for the later tests was vigorous with one test closely following another.

As the preceding and following discussions imply, radionuclide distributions were developed from process knowledge and engineering and nuclear physics calculations for each stream. Therefore, no single uniform assumption was made concerning the breakdown of generic radioactivity terms such as MAP and MFP in shipping records.

In an attempt to more accurately characterize these generic radioactivity terms for TAN waste streams, the RSAC-5 computer code (Wenzel 1993) and activation calculations were used as described in this section for 8 of the 10 major waste streams, i.e., TAN-607-1H through TAN-607-4H and

TAN-633-1H through TAN-633-4H. These calculations were based on reactor operating parameters, report information, and discussions with personnel involved with the examinations or operations. The calculations reflect, as accurately as possible, the radionuclides in the respective waste streams. For the minor waste streams and, with one exception, the two remaining major waste streams, TAN-607-5H and TAN-633-5H, the information in Table 2-2 was used for the waste stream characterization. The table was developed based on Plansky and Hoiland (1992), 5-year average radionuclide distributions of all waste shipped in 1987 through 1991 to the RWMC, and consideration of the radionuclides listed in the 10 Code of Federal Regulations (CFR) 61 regulations of the U.S. Nuclear Regulatory Commission (NRC) that apply to commercial disposal facilities for LLW. One exception is that all tritium has been eliminated from the major waste streams because of the high temperature of the early tests, the high volatility of tritium, and the escape directly to the atmosphere. Also, the examination work that generated the waste was conducted principally on structural material that had been out of the reactor for a substantial time; thus, tritium would not have been present in or on structural material.

Description of Waste Streams. The waste generated at TAN was divided into 28 waste streams (see Table 2-3).

The 10 most important waste streams from TAN are discussed in the following paragraphs. For each of these streams, the discussion tells how the stream was generated, the principal contaminants in the stream, the specific information sources reviewed and used, and the assumptions and analysis used to estimate the quantities of contaminants.

TAN-607-1H (HTRE-1 waste)

- **Generation of the waste stream.** This waste stream was generated by the decontamination of the duct to the stack, the reactor, and the jet engine internals and by discard of contaminated and damaged Thermoflex insulating liners after the IET #4 test in HTRE-1.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Cr-51, La-140, Ce-141, Ba-140, Zr-95, Y-91, and Sr-89.

- **Information sources reviewed and used.** The information used to evaluate this waste was taken primarily from Thornton et al. (1962) and from interviews with former ANP Program employees.

Table 2-2. Distributions used for mixed activation products, mixed fission products, unidentified beta-gamma, and unidentified alpha in certain Test Area North waste streams.

	Radionuclides											
Descriptor	C-14	Cm-242	Co-60	Cs-137	H-3	I-129	Pu-241	Sr-90	Tc-99	U-235	U-234	U-238
Unidentified beta-gamma	—	3.2E-11	9.6E-2	0.63	—	7.8E-14	2.8E-5	0.27	1.7E-8	—	—	—
Unidentified alpha	—	5.1E-9	—	—	—	—	4.5E-5	—	—	0.030	0.969	0.001
MAP	2.2E-7	—	1.0	—	—	—	—	—	—	—	—	—
MFP	—	—	—	0.36	0.48	1.2E-13	—	0.16	2.5E-8	—	—	—

Table 2-3. Waste streams originating at Test Area North.

Waste stream number	Description of waste
TAN-603-1H	Backup steam condensate from the TAN Hot Shop into TAN-603 boilers
TAN-606-1H	Unidentified minor waste from the TAN Manufacturing Building during the LOFT era
TAN-607-1H	Decontamination and disposed contaminated parts from the ANP HTRE-1 IET #3, #4 and #6 tests
TAN-607-2H	Contamination and contaminated parts from the ANP HTRE-2 testing (IET #8 through #26 tests)
TAN-607-3H	Activated SL-1 reactor parts contaminated during the SL-1 reactor accident of January 3, 1961, and activated experiment and fuel elements associated with stainless steel
TAN-607-4H	Reactor and auxiliary components from ML-1, PM-2A, and two SNAPTRAN systems
TAN-607-5H	Myriad manufacturing, assembly, health physics, and Hot Shop activities associated with TAN programs
TAN-607-6H	Minor unidentified radioactive waste from the TSF area
TAN-615-1H	U-235-contaminated structures removed during refurbishment of the fuel assembly area of TAN-615
TAN-616-1H	Waste generated in the cleanup of the Liquid Waste Treatment Plant and associated PM-2A secondary evaporator
TAN-620-1H	Minor radioactive waste from the IET Control and Equipment Building
TAN-623-1H	Minor radioactive waste from the sewage pumphouse
TAN-629-1H	Minor radioactive waste from the airplane hanger building during the LOFT and LOFT cleanup eras
TAN-630-1H	Minor unidentified LOFT area waste from TAN-630
TAN-633-1H	RML and hot cell samples and specimens of fuel assemblies from the HTRE-1 IET #3, #4, and #6 tests

Table 2-3. (continued).

Waste stream number	Description of waste
TAN-633-2H	Metallurgical samples and specimens from the HTRE-2 insert tests
TAN-633-3H	Metallurgical samples and specimens examined and discarded from the RML and hot cells resulting from the SL-1 accident of January 3, 1961
TAN-633-4H	Metallurgical samples and specimens from examination of ML-1, PM-2A, and two SNAPTRAN systems
TAN-633-5H	Waste from hot cells abutting TAN-607, with remote-handling equipment for examining radioactive-contaminated material
TAN-636-1H	Minor radioactive waste from the Carpenter and Paint Shop
TAN-640-1H	Rags, plastic, and one radium-beryllium neutron source from the Water Reactor Research Test Facility (WRRTF) Test Building
TAN-641-1H	Minor radioactive waste attributed to the WRRTF Control Building
TAN-645-1H	Minor radioactive waste from the Semiscale Control Building
TAN-647-1H	Low-level radioactive component of the split table reactor from the Radioactive Parts Security Storage Area (RPSSA) Contaminated Storage Building
TAN-650-1H	Minor radioactive waste from the LOFT Containment and Service Building
TAN-711-1H	Minor radioactive waste from the TAN Sewage Treatment Plant
TAN-ANP-3H	Waste from the Low-Power Test Facility
TAN-UNK-1H	Miscellaneous waste from an undetermined building at TAN

- **Assumptions and analysis.** The analysis was based on 30-day-old nichrome-clad activation products, U-235 fuel, and associated fission products generated by the core operated at 10.6 MW for 194 hours (2,065 MW-h), which was the burnup during the IET #4 test. The total assumed radioactivity (from Table 2-4) is 3,000 Ci and applies only to 1956. The distribution of the activity is based on the release of 704 g of fuel and associated fission and clad activation products that would remain after being heated to 1,093°C (2,000°F). The fission product inventory was calculated with the RSAC-5 computer code. The clad activation products were calculated by the methodology provided in Brice and Heath (1960). The fuel release assumed is as documented in DOE (1991) mainly for the IET #3 and #4 tests, and, to a lesser extent the IET #6 test.

TAN-607-2H (HTRE-2 waste)

- **Generation of the waste stream.** This waste stream was generated by the decontamination of the duct to the stack, the reactor, and the jet engine internals and by discard of contaminated and damaged insulation liners and insert shrouds resulting from the testing of the HTRE-2 IET tests.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are La-140, Pr-143, Ce-141, Ba-140, Zr-95, and Sr-89.

- **Information sources reviewed and used.** The following references were reviewed and used as appropriate: Baker (1961); Baker et al. (1959); Blumberg (1960); Evans (1957a, 1957b, 1958a, 1958b, 1959, 1960a, 1960b); Field (1961); Flagella (1962); Foster et al. (1958, 1960); Highberg et al. (1960, 1961); Holtslag (1956); Miller et al. (1960); Pincock (1959, 1960a, 1960b, 1960c, 1960d, 1960e); and Showalter (1959). Interviews were also conducted with former ANP Program employees.

- **Assumptions and analysis.** This waste stream applies to the time period 1957 through 1961. The activity estimates of Table 2-4 are assumed to be valid. The quantities of fuel and associated fission products that leached from the BeO insert matrix at high temperature were estimated as follows. During the HTRE-2 tests, 190 g of U-235 is conservatively estimated to have been released from the reactor core (DOE 1991). The activity for fission products is based on the amount of 30-day decayed fission products that would have been released with 190 g of fuel after being heated to 1,093°C (2,000°F). The fission products were calculated with the RSAC-5 computer code, assuming that the reactor operated at a power level of 14 MW for 100 hours and that the insert generated 7.4% of the total reactor power. Ten percent of the released fuel and associated fission products are ascribed to this waste stream.

TAN-607-3H (Waste from the SL-1 core/vessel examination period)

- **Generation of the waste stream.** This waste stream was generated by the disposal of contaminated materials, such as reactor internals and samples, following the metallurgical, chemical, and radiological examination of the SL-1 accident-generated material. Decontamination of selected materials was also responsible for a small fraction of the waste (Kunze 1962). This waste stream existed only for 1962 and 1963.

Table 2-4. Test Area North contributions to radioactivity in early waste disposed of at the Radioactive Waste Management Complex.

Year	Total onsite radioactivity shipped to the RWMC (Ci)	Percent of radioactivity from TAN (%)	Radioactivity from TAN (Ci)
1952	70	Negligible	Negligible
1953	800	Negligible	Negligible
1954	1,500	Negligible	Negligible
1955	1,500	Negligible	Negligible
1956	10,000	30[a]	3,000
1957	15,000	13[a]	2,000
1958	10,000	20[a]	2,000
1959	23,704	8.3[b]	1,915
1960	9,246	19.4[b]	1,710
1961	155,039	1.36[b]	2,110[c]
1962	118,177	14.3[b]	16,000
1963	253,565	Negligible	<0.1
1964	145,485	Negligible	Negligible

a. Assumed value. The percentage of total onsite radioactivity in the waste from TAN was assumed to be as shown for 1956 through 1958 based on general knowledge of the extent of contamination produced in the TAN projects for that time period.

b. Percentage of onsite radioactivity from TAN was calculated based on known activity from TAN.

c. Based on the sum of curie values disposed of from TAN on the shipping records.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Ce-144, Pm-147, Cs-137, Sr-90, Co-60, and Ru-106.

- **Information sources reviewed and used.** The following sources were reviewed and used as appropriate: Kunze (1962); General Electric Company (1961a, 1961b, 1961c, 1961d, 1962a, and 1962b); RWMIS; waste shipping records; interviews with former ANP Program employees; and TAN Hot Shop, RML, and fuel transfer logs.

- **Assumptions and analysis.** The principal contaminants were activation products produced in the vessel internal structural materials and fission products produced by a 931 MW-d operation, followed by a shutdown of 7 days and a subsequent criticality event of 133 MW-s. All of the activity before shipment was assumed to be decayed by an average of 450 days post-criticality. (The reactor vessel was moved to TAN on November 30, 1961, about 332 days following the accident.)

  The fission product inventory of the core was calculated with the RSAC-5 computer code for the documented steady-state operation in the 93% enriched core, the 7-day decay, and the 133 MW-s criticality event. Activation product activities are based on sample analysis results provided in Kunze (1962) and GE (1961b, 1961c, 1961d, 1962a, and 1962b). For the activated hardware that comprised the majority of the waste activity, type 304 stainless steel with high burnup and 1-year decay was assumed to determine the radionuclide distribution.

TAN-607-4H (Waste from reactor and auxiliary components of ML-1, PM-2A, and the two SNAPTRAN systems)

- **Generation of the waste stream.** This waste stream includes the reactor components generated during the ML-1 and PM-2A reactor vessel examinations and during the two SNAPTRAN tests that were conducted at TAN during the period 1964 through 1966.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Ce-144, Pm-147, Cs-137, Sr-90, Co-60, Ru-106, Ba-140, and La-140.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this stream are beryllium and lead.

- **Information sources reviewed and used.** The following sources were reviewed and used as appropriate: Cordes et al. (1965, 1967); Fletcher (1964, 1965); Mousseau et al. (1967); Murphy et al. (1966); radioactive waste manifests; and interviews with personnel involved with the SNAPTRAN tests and the ML-1 and PM-2A reactor vessel examinations.

- **Assumptions and analysis.** A review of the radioactive waste manifests shows the majority of the waste from the Hot Shop to be routine hot waste and that activities were aimed at preparing the facility for the ML-1 and PM-2A examinations. The radionuclide distribution is assumed to be from decayed SL-1 fission products, calculated by the RSAC-5 computer code, and decayed to the appropriate time for shipment to the RWMC.

The mass of the beryllium contained in the SNAPTRAN reactor internal and external reflectors was calculated based on drawings because the quantity is not provided in the reports cited. The total radioactive waste for the 3-year period for this waste stream amounted to only 12.75 Ci; the majority of radioactive waste from TAN for this period is attributed to a companion waste stream, TAN-633-4H.

TAN-607-6H (Miscellaneous Hot Shop waste)

- **Generation of the waste stream.** This waste stream, which consisted of miscellaneous LLW generated from 1967 to 1983 not included in the other five TAN-607 streams, resulted from contaminated and activated pieces of stainless steel and decontamination materials from operations in the TAN Hot Shop.

- **Principal radiological contaminants.** The principal radiological contaminants in this stream are Co-60, Cs-137, and Sr-90.

- **Information sources reviewed and used.** Information concerning this stream was taken from RWMIS.

- **Assumptions and analysis.** The activities of the radiological contaminants in this stream were taken from RWMIS.

TAN-633-1H (HTRE-1 metallurgical samples and hot cell waste)

- **Generation of the waste stream.** This waste was generated by the need to dispose of metallurgical samples and other materials associated with the HTRE-1 IET #3, #4, and #6 tests.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Cr-51, La-140, Ce-141, Ba-140, Zr-95, Y-91, and Sr-89.

- **Information sources reviewed and used.** The information used to evaluate this waste was taken primarily from Thornton et al. (1962).

- **Assumptions and analysis.** The analysis of the metallurgical samples was based on the same assumptions used for the test hardware from which the samples were fabricated. These assumptions were described for waste stream TAN-607-1H.

TAN-633-2H (Waste from the HTRE-2 IET tests)

- **Generation of the waste stream.** This waste stream was generated by the need to dispose of metallurgical samples and other materials associated with the HTRE-2 IET tests.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are La-140, Pr-143, Ce-141, Ba-140, Zr-95, and Sr-89.

- **Information sources reviewed and used.** The following references were reviewed and used as appropriate: Baker (1961); Baker et al. (1959); Blumberg (1960); Evans (1957a, 1957b, 1958a, 1958b, 1959, 1960a, 1960b); Field (1961); Flagella (1962); Foster et al. (1958, 1960); Highberg et al. (1960, 1961); Holtslag (1956); Miller et al. (1960); Pincock (1959, 1960a, 1960b, 1960c, 1960d, 1960e); and Showalter (1959).

- **Assumptions and analysis.** This waste stream of metallurgical samples applies to the time period 1957 through 1961 and assumes that the activity estimates of Table 2-4 are valid. The quantities of fuel and associated fission products that leached from the BeO insert matrix at high temperature were estimated as described for waste stream TAN-607-2H.

TAN-633-3H (Waste from the SL-1 core/vessel examination period; 90% of the released fuel and associated fission products are ascribed to this waste stream)

- **Generation of the waste stream.** This waste stream was generated by the need to dispose of metallurgical samples and other materials associated with the SL-1 core and vessel examination, and it includes the years 1962 and 1963.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Ce-144, Pm-147, Cs-137, Sr-90, Co-60, and Ru-106.

- **Information sources reviewed and used.** The following sources were reviewed and used as appropriate: Kunze (1962); GE (1961a, 1961b, 1961c, 1961d, 1962a, and 1962b); RWMIS; and waste shipping records.

- **Assumptions and analysis.** The metallurgical samples and resulting scrap were assumed to be contaminated with activation products produced in the vessel internal structural materials and fission products produced by the reactor operation as described for waste stream TAN-607-3H.

TAN-633-4H (Waste from the SNAPTRAN tests and ML-1 and PM-2A vessel examinations)

- **Generation of the waste stream.** This waste stream was generated by the need to dispose of waste and metallurgical samples from the ML-1 and PM-2A vessel examinations and the SNAPTRAN tests. Because available documentation does not separate these operations in time, this stream includes the years 1964 through 1966.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Ce-144, Pm-147, Cs-137, Sr-90, Co-60, Ru-106, Ba-140, and La-140.

- **Information sources reviewed and used.** The following sources were reviewed and used as appropriate: Cordes et al. (1965, 1967); Fletcher (1964, 1965); Mousseau et al. (1967); Murphy et al. (1966); radioactive waste manifests; and interviews with personnel involved with the SNAPTRAN tests and the ML-1 and PM-2A reactor vessel examinations.

- **Assumptions and analysis.** An analysis of the waste described on the radioactive waste manifest forms showed the percentage waste attributed to ICPP Waste Calcining Facility off-gas filters and hot cell filters, to the amount of fuel materials disposed of, and to the amount of activated stainless steel disposed of. The assumptions for radionuclide loading on the filters, based on information from ICPP personnel, were that (a) there are equal percentages of Cs-137 and Sr-90 and (b) 1% of the total gamma activity is Pu-238. Therefore, to use the year 1964, for example, when 304 Ci was attributed to the disposal of these filters, the associated activity would be 304 Ci of Cs-137, 304 Ci of Sr-90, and 3 Ci of Pu-238 because neither the curies of Sr-90 nor Pu-238 would have registered on the gamma activity reading made by the TAN health physics technician for disposal purposes. The U-235 fuel material documented for disposal was assumed to be 93% enriched, the normal enrichment for this time period. The activity of the irradiated stainless steel was assumed to be for stainless steel type 304 with high burnup conditions and a 1-year decay, as described in DOE (1992).

TAN-633-5H (Miscellaneous hot cell waste)

- **Generation of the waste stream.** This waste stream, which consists of miscellaneous LLW generated from 1967 to 1983 not included in the other five TAN-633 streams, resulted from contaminated and activated pieces of stainless steel and decontamination materials from operations in the TAN Hot Shop.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Co-60, Cs-137, and Sr-90.

- **Information sources reviewed and used.** Information concerning this stream was taken from RWMIS.

- **Assumptions and analysis.** The activities of the radiological contaminants in this stream were taken from RWMIS.

2.4.2 Test Reactor Area

The Generator. TRA is located approximately 8 km (5 mi) north of CFA and approximately 3.2 km (2 mi) west of ICPP at the INEL (see Figure 2-1). The major facilities at TRA are the test reactors: Materials Test Reactor (MTR), operating from 1952 to 1970; Engineering Test Reactor (ETR), operating from 1957 to 1981; and Advanced Test Reactor (ATR), operating from 1969 to the present. In addition to the test reactors and their support facilities, the following facilities and laboratories have been or are currently operating at TRA:

- TRA hot cells (1952 to present)

- Radiation Measurements Laboratory (RML) (1952 to present)

- Nuclear physics laboratories (1953 to present)

- Radiochemistry laboratories (1952 to present)

- Advanced Test Reactor Critical (ATRC) (1968 to present)
- Engineering Test Reactor Critical (ETRC) (1957 through 1980)
- Reactivity Measurements Facility (RMF) (1956 through 1960)
- Advanced Reactivity Measurement Facility (ARMF) (1960 through 1992)
- Gamma facility
- Metallurgical laboratories
- Hydraulics test facility
- Nuclear materials inspection storage facility
- Maintenance shops.

All of the TRA reactors have used highly enriched uranium (i.e., 93% U-235) as their nuclear fuel. The fuel is contained in fuel element assemblies that are composed of multiple fuel plates. The central core of each fuel plate contains a matrix of uranium and aluminum called UAl_x, and the core is covered by an outer layer of pure aluminum. Reactor cores are cooled and neutron-moderated with water. The MTR, ETR, ATR, ETRC, and ATRC have beryllium reflectors surrounding or adjacent to the reactor cores, while the RMF and ARMF have water reflectors surrounding the reactor cores. The beryllium was replaced every 7 to 10 years; therefore, a large quantity of beryllium has been disposed of at the RWMC.

Irradiated fuels from the TRA reactors were stored in canals near the reactors for a cooling period and then shipped to ICPP for processing. The gamma facility and each reactor or critical facility had a canal to store irradiated and unirradiated fuel and irradiated experiment assemblies.

The major role of a test reactor is to test the physical, chemical, and nuclear properties of materials during and after exposure to highly intense neutron/gamma fields. Experiments are placed in the reactor core or in the reflector adjacent to the reactor core. The size of the experiments varies from a small irradiation capsule to a major irradiation loop. The standard loop experiment consists of a pressurized water piping system with its own cleanup system, and it is designed to provide the controlled physical and chemical conditions for the test region. Typical conditions that are monitored and controlled include the temperature, pressure, and pH of the experiment coolant. The major sponsors of the test reactors have been and continue to be the Bettis Atomic Power Laboratory and the Knolls Atomic Power Laboratory, funded by the Naval Reactors Program (NRP) of DOE and its predecessor agencies. Experiments from these users are designed or specified by the sponsor. After completing the irradiation, the test internals are generally transferred to the sponsor's facilities for disassembly and examination or to the TRA hot cells.

The MTR (TRA-603), the first test reactor at TRA, began full-power operation in 1952. The loading of the reactor core contained approximately 5 kg of U-235. It operated for most of its life at a power level of 40 MW (thermal power).

The primary goal of the MTR tests was to support the development of fuels for the nuclear propulsion systems on naval vessels. Much of the testing in the MTR dealt with developing zircaloy-clad fuels for pressurized water reactor systems. In addition to the naval experiments, major experiments were carried out for the ANP Program, the space nuclear reactor project, and the development of advanced aluminum-clad nuclear fuel for research and test reactors. The MTR was also used to produce radioactive isotopes, primarily for nuclear research.

Physics experiments in the MTR were generally devoted to measuring neutron cross-sections and nuclear decay properties of radioactive materials. In the early 1960s, the neutron cross-section measurements were extended to target materials such as the radionuclides of protactinium, plutonium, curium, and promethium. To support these measurements, the alpha wing (TRA-661) of the MTR was constructed. In this wing, samples irradiated in the MTR were radiochemically processed to produce target materials for cross-section measurements.

The MTR operated until 1970, when it was placed on inactive status. Beginning in 1975, the emergency core-cooling working reservoir, an elevated water tank, and primary and secondary coolant systems were dismantled. The reactor fuel and beryllium reflector were removed, and the beryllium was sent to the RWMC. The major loop experiments have all been removed and transferred to either the ATR, ETR, or RWMC. With the exception of the fuel and beryllium, the reactor core internals remain inside the reactor vessel.

To provide higher neutron fluxes and a better ability to control the experimental conditions, the ETR (TRA-642) was constructed; it began full-power operation in 1957. The ETR used the same type of fuel as the MTR. The operating power level was 175 MW, and the core loading was approximately 30 kg of U-235.

The ETR operated as a test reactor until 1973, at which time the naval test loops were transferred to the ATR. The facility was inactive from 1973 to 1975. In 1975, the ETR was reconfigured to support the fast reactor development program under the sponsorship of Argonne National Laboratory. The name given to this experiment was the Sodium Loop Safety Facility (SLSF). For these tests, the ETR operated on a very limited basis. There would be a short period of operation to precondition the fuel in the test section, then the experiment assembly would be subjected to simulated accident scenarios while in the ETR core. After each test, the internal test assemblies would be removed from the ETR and shipped to ANL-W for examination. The containment and outer portions of the SLSF assembly would remain in the ETR core and would be made ready to accept the next experiment assembly from ANL-W. This experiment used liquid sodium; however, after the SLSF test series was completed, all of the sodium was returned to ANL-W. No sodium was sent from TRA to the RWMC. The SLSF experiments were concluded in 1981, and the ETR was placed on inactive status from 1981 to 1982. In 1982, the ETR was decontaminated, the primary and secondary cooling systems were dismantled, and the facility was placed on permanent inactive status.

The ATR (TRA-670) was the last of the three test reactors built at TRA. It began full-power operation in 1969. Unlike the rectangular MTR and ETR cores, the ATR core is in the shape of a four-leaf clover. There are nine major regions for experiments. The power for each region can be tailored to meet the experimenters' requirements. The maximum power level of the ATR is 250 MW; however, it typically operates at a power level of about 125 MW. The core loading for the

ATR is approximately 40 kg of U-235. It was necessary to change the beryllium reflector and core internals every 7 to 10 years.

From 1969 to 1992, the ATR was operated almost exclusively for the NRP. Since 1992, there has been some diversity in the experiments conducted in the ATR; however, the NRP still remains the primary user of the facility. In addition to NRP experiments, isotope production experiments and experiments for the New Production Reactor Program have been conducted.

To support reactor safety assurance and experiment needs, the ETR and ATR had critical assemblies (the ETRC and ATRC, respectively), which were nuclear mockups of the reactors. The major function of these critical assemblies was to measure reactor criticality and the effect that experiments would have on criticality. These reactors operated at low power levels (less than 1 kW). At these power levels, the fuel and core structural parts can be handled without using remote-handling equipment or shielding. In 1981, the ETRC was dismantled; all of the fuel, the core structure, and the beryllium reflector have been disposed of. The ATRC is still operating in support of the ATR.

The RMF and its successor, the ARMF, were designed to be critical assemblies for precisely measuring the neutron cross-sections of materials slated for use in or produced by reactors. The RMF was located in the canal of the MTR and used unirradiated MTR fuel elements. It typically operated at less than 100 W. The ARMF replaced the RMF and was located in a separate building (TRA-660) east of the MTR building. The ARMF contains two critical assemblies, ARMF-I and ARMF-II, which share a common canal. In 1969, ARMF-II was reconfigured to support the fast reactor development program. A block of U-238 was placed in the center of the core. After this conversion, the ARMF-II was renamed the Coupled Fast Reactivity Measurement Facility. In 1992, these reactors were placed on temporary inactive status.

The TRA hot cells have been an integral part of test reactor support operations since the beginning of operations at the MTR. They are used for disassembly and examination of irradiated samples and experiment assemblies from the test reactors. Until the Expended Core Facility (ECF) at NRF was constructed, the TRA hot cells were the primary handling facility for the naval experiment assemblies irradiated in the MTR. Much of the experiment waste sent to the RWMC was generated at the hot cells. After the ECF was operational, almost all irradiated naval reactor experiment assemblies were processed through ECF. However, the TRA hot cells still support the test reactor programs. In the 1970s and early 1980s, the TRA hot cells processed severe damage fuel experiments conducted at PBF and analyzed small fuel samples from the damaged TMI-2 reactor and the H. B. Robinson commercial power plant.

The other operations at TRA will not be described because they are very minor generators of waste sent to the RWMC.

Generation of the Waste. Most of the waste generated at TRA is associated with the operations of the test reactors and the examination of irradiated experiment assemblies in the TRA hot cells. Most of the radioactive waste generated at TRA contains radioactive fission products produced in the nuclear fuel and radionuclides produced by neutron activation. The nuclear fuel-produced radioactivity is typically classified as MFP; however, some activation products are associated with certain fuels. Neutron activation products are typically classified as MAP. The actual distribution of

specific nuclides in either MFP or MAP depends on the reactor fuel and the process that generated the waste.

The irradiated fuel is normally sent as intact assemblies to ICPP for processing; however, in some instances, fuel elements are disassembled in the TRA hot cells. Because most of the reactor fuel is processed at ICPP, the bulk of the fission product activity ends up in ICPP waste. Only a minor component of that activity is left at TRA. This component is the result of fission products leaking through the reactor fuel cladding into the reactor coolant. The fission products then can potentially contaminate all items that come in contact with the coolant. This includes materials inside the reactor vessel and pipes, pumps, and cleanup systems associated with the primary coolant.

In addition to fuel leakage, there can also be leakage of radioactivity from the fueled experiments. This primarily contaminates the experiment coolant and cleanup system, and it secondarily contaminates the main reactor coolant. When these experiments are disassembled in the TRA hot cells, the irradiated components and associated handling equipment and materials are contaminated and become waste.

The filters in the reactor and hot cell ventilation systems also contain some of the fission products produced in the reactor fuel and fueled experiments. Although the reactors are water-cooled, there have been experiments in which the coolant has been gaseous. In those cases, the filters from cleanup systems of those experiments were contaminated and eventually sent to the RWMC. For example, a gaseous coolant experiment was performed for the ANP Program in the MTR during the 1950s.

Activation products are produced when neutrons are captured or otherwise interact to produce radionuclides. Neutron interactions can occur in the reactor fuel, and the radionuclides are carried along with the fission products. Neutrons can also interact with reactor and experiment structural components, resulting in radionuclides becoming fixed contamination in those components and also through corrosion in the reactor or experiment coolant. In the coolant system, the radionuclides can potentially contaminate the same items as the fission products. Therefore, for radioactive waste generated by test reactor operations and support activities, there will be a mixture of fission products and activation products.

In addition to fission products and activation products, TRU radionuclides are produced in a reactor. These radionuclides are produced by multiple neutron capture events, combined with beta and alpha decay. In the early days of the MTR, several experiments were designed to generate these nuclides for research purposes. However, that effort was very small in terms of waste generation and was virtually completed by the mid-1950s. From that point on, the test reactors were used to produce minor amounts of TRU radionuclides, generally in the microcurie range. Most TRU radionuclides not bound in reactor fuel were brought to the INEL from offsite producers.

The hot cells are the second largest generator of waste at TRA. In addition to experiments in the test reactors, the TRA hot cells have been used to process experiments performed outside TRA. These include the severe fuel damage experiments performed at PBF and fuel samples from the damaged TMI-2 reactor. The PBF and TMI fuel contains low-enriched uranium (approximately 4% U-235 by mass). The radionuclide distributions in these fuels are different from those in the test

reactor fuels. In addition, the activation products because of the zircaloy cladding are different from activation products generated by test reactors.

Almost all items removed from the hot cells are considered to be radioactive. If there is no further need for these items, they are classified as radioactive waste.

The critical facilities (i.e., ATRC, ETRC, and ARMF) contribute small amounts of radioactive waste, most of which is carried into the facilities on samples and experiments from the test reactors or from non-TRA facilities. In most cases, the mix between fission products and activation products is about the same as that found for the test reactors.

The radiochemistry and physics laboratories at TRA handle small quantities of radioactive materials as part of their research, typically microcuries to millicuries. The hot cell and the californium cell in the alpha wing (TRA-661) are possible exceptions. Originally, the alpha-wing hot cell was constructed to fabricate radioactive targets for the MTR cross-section measurements program. When that program ceased, the glove boxes and hot cell liners were sent to the RWMC. Since then, the radiochemistry programs have used the alpha-wing hot cell to separate transuranics and other research efforts. The californium cell contains microgram amounts of Cf-252 used to produce nanocurie amounts of fission products for nuclear decay measurements. The alpha-wing solid waste has higher concentrations of alpha-emitters from the decay of TRU nuclides. The remainder of the radiochemistry and physics laboratories generate waste similar in content to reactor plant waste.

The gamma facility was used to expose food items and other materials to high doses of gamma radiation from intact spent fuel elements. The fuel elements were then shipped to ICPP for processing. The gamma facility was operating in the 1950s and early 1960s. During that period, the reports about TRA waste shipped to the RWMC did not specify whether the waste was generated at the gamma facility or some other facility at TRA. Any waste generated at the gamma facility would not differ significantly in radionuclide distribution from normal plant waste or canal waste. Also, the amount of waste (in curies) generated at the gamma facility was minor compared with that generated by the test reactors.

Radioactive liquid waste from TRA was disposed of in the TRA waste retention basins (if low to moderate activity) or sent to ICPP for processing (if moderate to high activity).

The test reactors were the major generators of nonradiological contaminants in TRA waste sent to the RWMC. The primary contaminant is beryllium. This waste is generated when a reactor reflector is replaced.

Cadmium was used frequently as a neutron shield. Some of this material was sent to the RWMC from TRA.

The following are examples of waste streams sent to the RWMC from TRA.

- Ion-exchange resins used in the reactor coolant cleanup systems.

- Irradiated fuel element end boxes that were cut off the fuel plates in the hot cells. The end boxes may contain some fuel, but they generally contain only activation products.

- Core and experiment loop components constructed of aluminum, stainless steel, or zircaloy. They generally contain activation products.

- Contaminated glassware from radiochemistry and physics laboratories. They can contain fission products, activation products, or alpha-emitters.

- Contaminated vermiculite. It was used to clean up liquid spills and can potentially contain fission products, activation products, or alpha-emitters.

- Contaminated air filters. They were used to remove airborne contaminants in fume hoods, glove boxes, and ventilation systems.

- Contaminated rags and floor sweepings.

- Contaminated concrete, bricks, and wood.

- Uranium powder. This may be irradiated or unirradiated. The unirradiated uranium may contain sufficient activity from U-234 to classify it as radioactive.

- Irradiated beryllium from the reactor reflector changeouts.

- Contaminated or activated lead no longer useful for shielding. The major activation products are generated in antimony, which is present in most commercially available lead.

General Availability of Information.

Period 1952 through 1959—For this early period, the data source believed to be most reliable is the letter file of the health physics supervisor, John F. Sommers, during the period 1953 to 1959 (approximately 110 letter reports). Two types of letters appear in this file concerning waste sent to the RWMC: monthly progress reports and radioactive waste disposal reports. The monthly progress reports contain the number of shipments from TRA to the RWMC during the month, but they are of little value. The radioactive waste disposal reports list the radioactivity shipped during the month. However, for most years, there are missing months. For 1952, there are no entries; 1953 has 4 entries; 1954 has 11 entries; 1955 has 12 entries; 1956 has 10 entries; and there are no entries for 1957 or later years.

For the years when monthly records were missing from the letter file of the health physics supervisor, yearly amounts were established by averaging the monthly radioactivity for the months data were available and multiplying by 12. For 1952, no data were available, so the amount in 1952 was estimated as one-half of the 1953 amount. The rationale for this approach is that the amount doubled from 1953 to 1954, and doubled again from 1954 to 1955.

Estimates of the activity in TRA waste for 1957, 1958, and 1959 are from the annual reports of the Health and Safety Division for these years (see AEC reports in the reference list and Cassidy 1982).

Period 1960 through 1969—The data for this time period were obtained from the AEC Health and Safety Division annual reports (see AEC reports in the reference list); Osloond (1965, 1966, 1967, 1968); shipping records; and RWMIS. An assessment of the SDA for the period 1952 through 1970 also produced data (Vigil 1990; Plansky and Hoiland 1992).

Period 1970 through 1979—Information for this time period is available in the Aerojet waste management plans and revisions (Hickman 1972, 1974) and RWMIS. The information, for the most part, is identical in the various sources. An additional source for 1975 is ERDA (1977). The years 1975 and 1978 show discrepancies in the values. In the case of an unresolved discrepancy, the higher value was used.

Period 1980 through 1983—For this period, the RWMIS values and those from other sources [Cassidy (1982) and the radioactive waste management information reports for 1979 through 1982 (see DOE reports in the reference list)] agree reasonably well. Another survey of the inventory was completed in 1991 (Barnard et al. 1991).

Several other information sources were reviewed for the task, but they did not yield definitive information about the waste. The following sources did give insight, however, as to what operational activities were going on and when: Adams (1985); Aerojet Nuclear (1970, 1971, 1972, 1973, 1975a, 1975b, 1976); Akers et al. (1993); Allied Chemical Corporation (1971); Brenton (1956); Bright (1958, 1959a, 1959b); Browder (1985); Chamberlain (1971); Clements (1981); Coates (1982); Commander (1971); EG&G Idaho (1984); Frank (1984); GE (1985); Gruen (1982a, 1982b); Hanson (1952); INC (1969a, 1969b, 1970a, 1970b, 1970c, 1971a, 1971b); Jones and Kern (1958); McMurry (1954); Nelson (1959); Norberg (1959); PPCo (1961a, 1961b, 1966); Price (1958); Simpson et al. (1982); Stroschein (1967); Watanabe (1958); Witt (1957); and the MTR cycle reports for Cycles 16 through 200, from June 1959 through December 1963.

The general trend of the disposed radioactivity follows the initiation and termination of facilities at TRA. After MTR startup, waste disposal increased steadily with time until the startup of the ETR. After startup of the ETR, waste disposal increased again. Waste disposal increased shortly before startup of the ATR, as experiments were removed from the MTR and ETR and transferred to the ATR. After shutdown of the MTR, waste disposal decreased until D&D operations at the MTR were initiated, and then it rose again (Kaiser 1984; Smith 1985). After the cleanup of some of the MTR facilities, the waste amounts decreased because little D&D was performed on the ETR facilities.

Data-Collection Approach. The data sources used for TRA waste were (a) monthly and annual reports and letters, (b) topical reports, (c) shipping records, and (d) RWMIS entries. For simplicity, all of these sources are referred to in this discussion as generic reports. In addition, nuclear physics considerations and calculations were used to obtain the radionuclide distributions in many cases.

Reports and shipping records provide varying degrees of completeness in specifying radionuclide distributions. The following information describes how the available records and reports were

combined with nuclear physics evaluations to project a reasonably complete distribution of radionuclides having the appropriate total amount of radioactivity.

Table 2-5 is the master list of radionuclides considered in calculating the nuclide-by-nuclide activity breakdown of the waste generated at TRA. This list is a composite based on (a) a performance assessment of dose at the RWMC performed in 1993, (b) the reporting requirements imposed by the NRC on waste from operating power reactors (10 CFR 61), and (c) the expected importance of the radionuclide in TRA waste. Based on an activity build-up calculation using the ORIGEN2 computer code (Graff 1980; Schnitzler 1994) for a typical ATR fuel element irradiation history, the activity for any TRU radionuclide with an atomic number or mass greater than that of Cm-244 is too weak to be reportable and is not included.

Radioactive waste generated at TRA has been reported as individual nuclides, MFP, MAP, unidentified beta-gamma, or unidentified alpha. Most waste streams or waste generation processes at TRA contain all types of activity; however, the relative mix differs. Because there are different mixes, it was decided that the waste should be categorized according to the generator mode or generic content, rather than by activity. Based on a review of commercial power plant waste reports (e.g., EPRI 1987) and other sources, six general categories of waste were identified by analogy for TRA:

1. Unirradiated fuel
2. Irradiated fuel
3. Dry radioactive waste not otherwise specified
4. Reactor coolant resins
5. Sludge
6. Unidentified alpha.

Tables 2-6 through 2-11 list the radionuclides and the activity scaling factors for each waste category. Scaling factors are fractions or percentages representing the activity of one radionuclide relative to the activity of another radionuclide or to the total activity of a group of radionuclides. (Section 5 provides a detailed discussion of radioactivity distributions and scaling factors.) INEL data for the scaling factors of difficult-to-measure radionuclides in TRA waste are limited. Therefore, many of the scaling factors for these radionuclides were taken from data gathered on commercial nuclear power reactors (EPRI 1987). There are limitations in applying those data to waste from INEL test reactors, but these data are the most applicable available data.

The scaling factors are based on fractional activities consistent with the assumption that measuring total activity using the G-M method would include only gamma activity. (Section 5 discusses the detailed G-M method and its limitations.) The approach followed to generate tables that used more than one data source is described in Harker and Akers (1994) and in Harker (1995a).

Use of Standard Waste Categories for Various Situations—For the years 1952 to 1960, the information is given in monthly and annual reports in terms of total radioactivity, and it

Table 2-5. Master list of radionuclides evaluated for waste from the Test Reactor Area.

Nuclide	Half-life[a] (years)	Decay mode[b]	Fission product	Activation product
Am-241	433	α	—	X
C-14	5.7×10^3	β	—	X
Ce-144	0.78	$\beta+\gamma$	X	—
Co-60	5.3	$\beta+\gamma$	—	X
Cm-242	0.45	α	—	X
Cm-244	18.1	α	—	X
Cs-137	30.2	$\beta+\gamma$	X	—
Fe-55	2.73	β	—	X
Eu-152	13.5	$\beta+\gamma$	X	—
Eu-154	8.6	$\beta+\gamma$	X	—
Eu-155	4.7	$\beta+\gamma$	X	—
H-3	12.3	β	X	X
I-129	1.6×10^7	$\beta+\gamma$	X	—
Nb-94	2.0×10^4	β	—	X
Ni-59	7.6×10^4	β	—	X
Ni-63	100	β	—	X
Np-237	2.1×10^6	α	—	X
Pu-238	87.7	α	—	X
Pu-239	2.4×10^4	α	—	X
Pu-240	6.6×10^3	α, sf	—	X

Table 2-5. (continued).

Nuclide	Half-life[a] (years)	Decay mode[b]	Fission product	Activation product
Pu-241	14.4	β	—	X
Ra-226	1.6×10^3	α	—	—
Sb-125	2.8	$\beta+\gamma$	X	X
Sr-90	29	β	X	—
Tc-99	2.1×10^5	β	X	—
U-232	70	α	—	—
U-233	1.6×10^5	α	—	—
U-234	2.5×10^5	α	—	—
U-235	7.0×10^8	α	—	—
U-236	2.3×10^7	α	—	—
U-238	4.5×10^9	α	—	—

a. Half-lives taken from GE (1989).

b. α = Decays by alpha emission
β = Decays by beta emission
$\beta+\gamma$ = Decays by beta emission plus gamma transitions
α, sf = Decays by alpha emission and spontaneous fission.

Table 2-6. Nuclides and activity scaling factors for highly enriched uranium unirradiated fuels from the Test Reactor Area.[a]

Nuclide	Activity scaling factor[b]
U-234	0.95
U-235	0.05
U-238	0.00

a. Applies to MTR, ETR, and ATR fuels.

b. Scaling factors are based on highly enriched uranium (93% U-235 by mass).

Table 2-7. Nuclides and activity scaling factors for irradiated fuels from the Test Reactor Area.[a]

Nuclide	Activity scaling factor[b]
H-3	1.9×10^{-3}
Sr-90	4.3×10^{-1}
Tc-99	5.5×10^{-5}
Sb-125	2.5×10^{-2}
I-129	1.0×10^{-7}
Cs-137	4.5×10^{-1}
Eu-152	1.6×10^{-6}
Eu-154	3.4×10^{-2}
Eu-155	2.1×10^{-2}
U-234	4.6×10^{-6}
U-235	1.0×10^{-7}
U-238	1.8×10^{-6}
Np-237	2.8×10^{-6}
Pu-238	1.2×10^{-2}
Pu-239	5.0×10^{-5}
Pu-240	3.1×10^{-5}
Pu-241	2.0×10^{-2}
Pu-242	3.1×10^{-7}
Am-241	3.4×10^{-5}
Am-243	4.0×10^{-6}
Cm-242	2.0×10^{-4}
Cm-244	5.5×10^{-4}

a. Applies to MTR, ETR, and ATR fuel unless otherwise specified on the data source. This applies to all irradiated fuels discarded from the TRA hot cells.

b. Activity scaling factors are based on an ORIGEN2 calculation for one ATR fuel element irradiated for 85 days at 8 MW per element and allowed to decay for 1 year after irradiation (Graff 1980; Schnitzler 1994).

Table 2-8. Nuclides and activity scaling factors for dry radioactive waste from the Test Reactor Area.

Nuclide	Activity scaling factor[a]	Data source
H-3[b]	8.2×10^{-2}	EPRI (1987)[c]
C-14	1.1×10^{-3}	EPRI (1987)[c]
Fe-55	1.9	EPRI (1987)[c]
Co-60	6.7×10^{-1}	EPRI (1987)[c]
Ni-59	5.7×10^{-4}	Evans et al. (1984)[d]
Ni-63	3.2×10^{-1}	EPRI (1987)[c]
Sr-90	9.2×10^{-4}	EPRI (1987)[c]
Tc-99	1.8×10^{-4}	EPRI (1987)[c]
I-129	4.4×10^{-8}	Harker (1995b)[e]
Cs-137	2.0×10^{-1}	EPRI (1987)[c]
Ce-144	4.7×10^{-3}	EPRI (1987)[c]
Eu-154	2.9×10^{-6}	Evans et al. (1984)[d]
Eu-155	9.4×10^{-3}	Graff (1980) and Schnitzler (1994)[f]
U-234	2.1×10^{-6}	Graff (1980) and Schnitzler (1994)[f]
U-235	4.5×10^{-8}	Graff (1980) and Schnitzler (1994)[f]
U-236	8.0×10^{-7}	Graff (1980) and Schnitzler (1994)[f]
Np-237	1.2×10^{-6}	Graff (1980) and Schnitzler (1994)[f]
Pu-238	5.4×10^{-5}	EPRI (1987)[c]
Pu-239	5.4×10^{-5}	EPRI (1987)[c]
Pu-240	5.6×10^{-6}	Graff (1980) and Schnitzler (1994)[f]
Pu-241	5.9×10^{-3}	EPRI (1987)[c]

Table 2-8. (continued).

Nuclide	Activity scaling factor[a]	Data source
Am-241	2.7×10^{-5}	EPRI (1987)[c]
Cm-242	2.7×10^{-5}	EPRI (1987)[c]
Cm-244	2.5×10^{-5}	EPRI (1987)[c]

a. It was assumed that the measured activity was determined by a predominantly gamma-sensitive device (e.g., G-M counter, NaI scintillation detector). As such, only gamma activity was reported. However, there were cases where the gamma activity was increased to account for the beta-emitters. This correction was not universally applied and, in many cases, not even noted. To be conservative, it was assumed that the reported activity (MAP, MFP, and unidentified beta-gama) includes only gamma activity. The scaling factors listed in this table have taken the beta activity into account. Therefore, the sum of the scaling factors is a number greater than unity. The difference between the sum and unity is the relative beta activity. See Harker (1995a) for details on how the scaling factors were derived.

b. There is a question as to whether tritium is present at the fraction indicated in this table for all dry waste. Tritium is present in dry waste that has direct contact with the reactor coolant and, in some cases, where there has been secondary contact. The tritium scaling factor listed in this table represents a history of experience with pressurized water reactors and should give numbers that are valid on the average. However, in those cases where there was evidence that tritium was not present or was present in much lower concentrations, the scaling factor for tritium in the table was not used. A note to this effect was placed with that data entry.

c. Dry active waste generated by all commercial pressurized water reactors in the United States.

d. Activation products in 304 stainless steel.

e. The factor was based on the ratio of I-131 activity to Cs-137 activity in ATR primary coolant water and on ratios of I-129, I-131, and Cs-137 activities calculated with ORIGEN2.

f. ORIGEN2 calculation based on irradiating an ATR fuel element for 85 days at 8 MW per element and allowing it to decay for 1 year.

Table 2-9. Nuclides and activity scaling factors for reactor coolant resin from the Test Reactor Area.

Nuclide	Activity scaling factor[a]	Data source
H-3	5.0×10^{-4}	ATR[b]
C-14	4.3×10^{-3}	EPRI (1987)[c]
Fe-55	2.0×10^{-1}	EPRI (1987)
Ni-59	2.8×10^{-3}	ATR[b]
Ni-63	2.8×10^{-1}	ATR[b]
Co-60	6.8×10^{-1}	ATR[b]
Sr-90	2.8×10^{-1}	ATR[b]
Tc-99	1.5×10^{-5}	ATR[b]
I-129	6.8×10^{-8}	Harker (1995b)[d]
Cs-137	3.1×10^{-1}	ATR[b]
Ce-144	6.7×10^{-3}	ATR[b]
Eu-154	7.3×10^{-3}	ATR[b]
Eu-155	3.1×10^{-3}	ATR[b]
U-234	4.2×10^{-6}	Graff (1980) and Schnitzler (1994)[e]
U-235	9.2×10^{-8}	Graff (1980) and Schnitzler (1994)[e]
U-236	1.6×10^{-6}	Graff (1980) and Schnitzler (1994)[e]
Np-237	2.6×10^{-6}	Graff (1980) and Schnitzler (1994)[e]
Pu-238	1.8×10^{-4}	ATR[b]
Pu-239	4.6×10^{-5}	ATR[b]
Pu-240	2.8×10^{-5}	Graff (1980) and Schnitzler (1994)[e]
Pu-241	1.5×10^{-2}	ATR[b]

Table 2-9. (continued).

Nuclide	Activity scaling factor[a]	Data source
Am-241	4.2×10^{-3}	ATR[b]
Cm-242	2.8×10^{-4}	ATR[b]
Cm-244	1.3×10^{-4}	ATR[b]

a. It was assumed that the measured activity was determined by a predominantly gamma-sensitive device (e.g., G-M counter, NaI scintillation detector). As such, only gamma activity was reported. However, there were cases where the gamma activity was increased to account for the beta-emitters. This correction was not universally applied, and in many cases, not even noted. To be conservative, it was assumed that the reported activity (MAP, MFP, and unidentified beta-gama) includes only gamma activity. The scaling factors listed in this table have taken the beta activity into account. Therefore, the sum of the scaling factors is a number greater than unity. The difference between the sum and unity is the relative beta activity. See Harker (1995a) for details on how the scaling factors were derived.

b. Activities scaled to Cs-137 (for H-3, Sr-90, Tc-99, Eu-154 and Eu-155); to Co-60 (for Ni-59 and Ni-63); or to Pu-239 (for Pu-238, Pu-241, Am-241, Cm-242, and Cm-244) as measured for ATR resin shipment 92026 (see Harker and Akers 1994) are assumed to be representative for all resin shipments.

c. Assumed reactor coolant resin C-14 activity relative to Co-60 as reported for pressurized water reactors is representative of the ATR resin C-14 to Co-60 activity ratio.

d. The factor was based on the ratio of I-131 activity to Cs-137 activity in ATR primary coolant water and on ratios of I-129, I-131, and Cs-137 activities calculated with ORIGEN2.

e. ORIGEN2 calculation based on an ATR fuel element irradiated for 85 days at 8 MW per element and allowed to decay for 1 year. Activity is scaled to Pu-239 activity as measured by gamma spectrometry.

Table 2-10. Nuclides and activity scaling factors for sludge waste from the Test Reactor Area.

Nuclide	Activity scaling factor[a]	Data source
H-3[b]	1.0×10^{-1}	EPRI (1987)[c]
C-14	1.0×10^{-2}	EPRI (1987)[c]
Fe-55	7.7×10^{-1}	EPRI (1987)[c]
Co-60	8.7×10^{-1}	EPRI (1987)[c]
Ni-59	4.0×10^{-3}	Resin[d]
Ni-63	3.2×10^{-1}	EPRI (1987)[c]
Sr-90	6.4×10^{-4}	EPRI (1987)[c]
Tc-99	1.1×10^{-4}	EPRI (1987)[c]
I-129	3.0×10^{-8}	Harker (1995b)[e]
Cs-137	1.3×10^{-1}	EPRI (1987)[c]
Ce-144	4.2×10^{-2}	EPRI (1987)[c]
Eu-154	3.1×10^{-3}	Resin[d]
Eu-155	1.3×10^{-3}	Resin[d]
U-234	2.2×10^{-6}	Resin[d]
U-235	4.8×10^{-8}	Resin[d]
U-236	8.5×10^{-7}	Resin[d]
Np-237	1.3×10^{-6}	Resin[d]
Pu-238	3.3×10^{-5}	EPRI (1987)[c]
Pu-239	3.4×10^{-5}	EPRI (1987)[c]
Pu-240	2.1×10^{-5}	Resin[d]
Pu-241	3.7×10^{-3}	EPRI (1987)[c]
Am-241	1.4×10^{-5}	EPRI (1987)[c]
Cm-242	2.7×10^{-5}	EPRI (1987)[c]

Table 2-10. (continued).

Nuclide	Activity scaling factor[a]	Data source
Cm-244	1.3×10^{-5}	EPRI (1987)[c]
U-238	2.9×10^{-9}	Graff (1980) and Schnitzler (1994)[f]

a. It was assumed that the measured activity was determined by a predominantly gamma-sensitive device (e.g., G-M counter, NaI scintillation detector). As such, only gamma activity was reported. However, there were cases where the gamma activity was increased to account for the beta-emitters. This correction was not universally applied and, in many cases, not even noted. To be conservative, it was assumed that the reported activity (MAP, MFP, and unidentified beta-gama) includes only gamma activity. The scaling factors listed in this table have taken the beta activity into account. Therefore, the sum of the scaling factors is a number greater than unity. The difference between the sum and unity is the relative beta activity. See Harker (1995a) for details on how the scaling factors were derived.

b. There is a question as to whether tritium is present at the fraction indicated in this table for all dry waste. Tritium is present in dry waste that has direct contact with the reactor coolant and, in some cases, where there has been secondary contact. The tritium scaling factor listed in this table represents a history of experience with pressurized water reactors and should give numbers that are valid on the average. However, in those cases where there was evidence that tritium was not present or was present in much lower concentrations, the scaling factor for tritium in the table was not used. A note to this effect was placed with that data entry.

c. Sludge waste generated by all commercial pressurized water reactors in the United States.

d. Activities relative to Co-60 (for Ni-59); to Cs-137 (for Eu-154, Eu-155, U-234, U-235, U-236, and Np-237); or to Pu-239 (for Pu-240) are assumed to be the same as those listed for resins (see Table 2-9).

e. The factor was based on the ratio of I-131 activity to Cs-137 activity in ATR primary coolant water and on ratios of I-129, I-131, and Cs-137 activities calculated with ORIGEN2.

f. ORIGEN2 calculation based on an ATR fuel element irradiated for 85 days at 8 MW per element and allowed to decay for 1 year. Activity is scaled to Pu-239 activity as measured by gamma spectrometry.

Table 2-11. Nuclides and activity scaling factors for unidentified alpha-emitters from the Test Reactor Area.

Nuclide	Activity scaling factor[a]
Np-237	2.2×10^{-4}
Pu-238	9.3×10^{-1}
Pu-239	4.0×10^{-3}
Pu-240	2.4×10^{-3}
Pu-242	2.5×10^{-5}
Am-241	2.8×10^{-3}
Cm-242	1.6×10^{-2}
Cm-244	4.4×10^{-2}

a. From ORIGEN2 calculation based on an ATR fuel element irradiated for 85 days at 8 MW per element and allowed to decay for 1 year (Graff 1980; Schnitzler 1994).

does not differentiate between waste classifications according to nuclide composition or classification according to waste stream. For those years, the data entries were made annually. The radionuclide distributions were based on weighted sums of the six waste categories, with the totals equal to the total curies reported for each year. Scaling factors used were based on composite fractions in each waste category derived from waste reports in the following years where differentiation was identified in the waste reports. The calculated nuclide-by-nuclide distribution was entered into the data file for that year.

For the years 1960 to 1983, there are, as a minimum, data entries in RWMIS. Annual reports, topical reports, and letters also indicate waste-generating activities. The latter data were used where possible to verify or replace the data contained in RWMIS. The following approach was used:

- **Reports containing nuclide-by-nuclide distributions.** The individual activities listed in the report were used. In most cases, if an error was not stated, an assumed measurement error was assigned.

- **Reports containing nuclide-by-nuclide distributions plus MAP, MFP, unidentified beta-gamma, and/or unidentified alpha.** The waste was identified as one of the six waste categories listed above. The MAP, MFP, and beta-gamma activities were summed to get a total activity of overall beta/gamma-emitters. A nuclide-by-nuclide

distribution was calculated based on this total activity and the corresponding activity scaling factors for that waste category. The unidentified alpha activity was distributed into individual nuclide activities based on the activity scaling factors listed in Table 2-11 and the total unidentified alpha activity. The reported nuclide distribution, the calculated waste category nuclide distribution, and the calculated alpha nuclide distribution were all added as separate tables.

- **Reports containing only MAP, MFP, unidentified beta-gamma, and/or unidentified alpha.** The waste was identified as one of the six waste categories listed previously. The MAP and MFP activities were summed to arrive at the total beta-gamma activity. A nuclide-by-nuclide activity distribution was calculated based on the total beta-gamma activity and the corresponding activity scaling factors for that waste category. The unidentified alpha activity was divided according to the activity scaling factors listed in Table 2-11. The calculated waste category radionuclide distribution and the calculated unidentified alpha distribution were submitted as separate tables.

- **Reports containing only total activity.** The waste was identified as one of the six waste categories listed above. A nuclide-by-nuclide activity distribution was calculated based on the reported total activity and the corresponding activity scaling factors. The calculated waste category distribution was submitted.

As the preceding and following discussions imply, radionuclide distributions were developed from process knowledge and nuclear physics calculations for each category of waste stream. Therefore, no single, uniform assumption was used for the distribution of generic radioactivity terms such as MAP and MFP in shipping records.

Two entries for the same radionuclide in the same year appear on the data sheets for some TRA waste streams. In these cases, the bounds differ on the entries because parts of the total activity were determined using different methods. For example, two entries for Cs-137 in a waste stream for a given year were obtained using laboratory measurements and by distributing a MFP term using scaling factors.

Description of Waste Streams. The TRA waste was divided into a total of 40 waste streams (see Table 2-12). The eight most important waste streams from TRA are discussed in detail below. For each of these streams, the discussion tells how the stream was generated, the principal contaminants in the stream, the specific information sources reviewed and used, and the assumptions and analysis used to estimate the quantities of the contaminants.

TRA-603-1H (Resins)

- **Generation of the waste stream.** Resins are used to purify the reactor coolant water. They capture and immobilize activation and fission products. When their useful capacity for ion exchange has been reached, they are removed and become waste.

- **Principal radiological contaminants.** The major radiological contaminants in this waste stream are Co-60, Ni-63, Cs-137, and Sr-90.

Table 2-12. Waste streams originating at the Test Reactor Area.

Waste stream number	Description of waste
TRA-603-1H	Resins
TRA-603-3H	Irradiated end boxes
TRA-603-4H	Core and loop components
TRA-603-5H	Uranium in metal
TRA-603-6H	Sludge
TRA-603-7H	Glass
TRA-603-8H	Radioactive sources
TRA-603-9H	Irradiated fuel
TRA-603-10H	Asbestos
TRA-603-11H	Meat contaminated with botulinus
TRA-603-12H	Vermiculite
TRA-603-13H	Filters
TRA-603-14H	Continuous air monitors
TRA-603-15H	Metal (aluminum, stainless steel, zircaloy, beryllium, and cadmium)
TRA-603-16H	Paper
TRA-603-17H	Dirt
TRA-603-18H	Rags, floor sweepings, and glassware
TRA-603-19H	Concrete, metals, and wood
TRA-603-20H	Wood
TRA-603-21H	Construction materials, concrete, brick, sand, soil, and asphalt

Table 2-12. (continued).

Waste stream number	Description of waste
TRA-603-22H	Rags, floor sweepings, and glassware
TRA-603-23H	Terphenyl (Santo-wax)
TRA-603-24H	Gas bottles
TRA-603-25H	Sodium
TRA-603-26H	Lead
TRA-604-1H	Uranium powder
TRA-614-1H	Capsules of graphite, nickel, and scrap U-235
TRA-614-2H	Continuous air tank
TRA-632-1H	Core structural pieces
TRA-642-1H	Fission chambers with foils
TRA-642-2H	Insulation
TRA-642-3H	Hydrofluoric acid solidified and neutralized as NaF
TRA-642-4H	Rags, paper, and wipes
TRA-642-5H	Irradiated fuel rods
TRA-642-6H	Scrap metal pieces
TRA-642-7H	Various combustible materials
TRA-653-1H	Benzine
TRA-670-1H	Beryllium reflectors from the MTR, ETR, and ATR
TRA-670-2H	Stainless steel and aluminum
TRA-706-1H	Tank

- **Information sources reviewed and used.** Information sources reviewed and used include Abrashoff (1992a, 1992b); Beatty (1992a, 1992b); Brower (1992); Schnitzler (1994); and Vance and Associates (1992).

- **Assumptions and analysis.** The total radioactivity is taken from the sources cited. The distribution of radionuclides is that given in Table 2-9. The distribution was assumed to be the same for the MTR, ETR, and ATR. The analysis assumed that the amount of radioactivity in the resins was proportional to total reactor power.

TRA-603-4H (Core and loop components)

- **Generation of the waste stream.** This waste stream is comprised of material that was in or very near the reactor core. The material has been subjected to extreme neutron and gamma-ray exposures.

- **Principal radiological contaminants.** The large amounts of stainless steel contain Co-60 and Ni-63, and they are also contaminated with fission products because of the proximity to the core. The principal fission products are Sr-90 and Cs-137.

- **Information sources reviewed and used.** Information sources reviewed and used are Osloond (1965), annual reports of the AEC Health and Safety Division, DOE radioactive waste management information reports, and RWMIS.

- **Assumption and analysis.** The total radioactivity is taken from the sources cited. The distribution of radionuclides is that given in Table 2-8.

TRA-603-5H (Uranium in metal)

- **Generation of the waste stream.** This material came mostly from activities performed in the metallurgy and chemistry laboratories at TRA.

- **Principal radiological contaminants.** The principal radiological contaminants include the various nuclides of uranium: U-232, U-233, U-234, U-235, and U-238.

- **Information sources reviewed and used.** Information sources reviewed and used are Osloond (1965), annual reports of the AEC Health and Safety Division, DOE radioactive waste management information reports, and RWMIS.

- **Assumption and analysis.** If an information source indicates depleted uranium, the uranium was assumed to be U-238; natural uranium was not encountered. Entries other than special forms were assumed to be highly enriched uranium. Special forms of U-232 and U-233 were entered only if specifically identified. The majority of the entries are for highly enriched uranium; the nuclide activity distribution was taken from Table 2-6.

TRA-603-15H (Metal)

- **Generation of the waste stream.** This waste stream contains contaminated metals that are not stated to be core or loop components or canal trash. Cadmium, for example, was used as a neutron shield and absorber in loop cubicles. It became contaminated and was disposed of when a cubicle was cleaned.

- **Principal radiological contaminants.** The principal radiological contaminants of this waste stream are the activation products Co-60, Ni-59, and Ni-63 and the fission products Cs-137 and Sr-90.

- **Principal nonradiological contaminants.** Cadmium is the principal nonradiological contaminant in this stream.

- **Information sources reviewed and used.** Information sources reviewed and used are Osloond (1965), annual reports of the AEC Health and Safety Division, DOE radioactive waste management information reports, and RWMIS. An unpublished scoping report on the HDT by an expert committee led by R. L. Nitschke was used to gain information about cadmium. [The report is an attachment to a letter from R. L. Norland to D. W. MacDonald (Norland 1993)].

- **Assumptions and analysis.** The total radioactivity is taken from the sources cited. The nuclide activity distribution is assumed to be that contained in Table 2-8. Information in RWMIS and the expert committee report were used to assess cadmium disposal.

TRA-603-16H (Paper)

- **Generation of the waste stream.** This waste stream category includes blotting paper used during reactor shutdown to prevent the spread of contamination. It was also used to soak up spills of highly contaminated water. Some contaminated wood is included.

- **Principal radiological contaminants.** The principal radiological contaminants of this waste stream are Co-60, Ni-63, Cs-137, and Sr-90.

- **Information sources reviewed and used.** Information sources reviewed and used are Osloond (1965), annual reports of the AEC Health and Safety Division, DOE radioactive waste management information reports, and RWMIS.

- **Assumptions and analysis.** The total radioactivity is taken from the sources cited. The nuclide activity distribution is assumed to be that contained in Table 2-8.

TRA-603-18H (Rags, floor sweepings, etc.)

- **Generation of the waste stream.** This waste stream contains items used to clean up after spills or after a shutdown.

- **Principal radiological contaminants.** The principal radiological contaminants of this waste stream are Co-60, Ni-63, Cs-137, and Sr-90.

- **Information sources reviewed and used.** Information sources reviewed and used are Osloond (1965), annual reports of the Health and Safety Division, radioactive waste management information reports, and RWMIS.

- **Assumption and analysis.** The total radioactivity is taken from the above sources. The nuclide activity distribution is assumed to be that contained in Table 2-8.

TRA-603-20H (Wood)

- **Generation of the waste stream.** A large portion of this waste stream is wood from the MTR and ETR cooling towers. This wood was contaminated because of small primary and secondary breaks over the years.

- **Principal radiological contaminants.** The principal radioactive contaminants of this waste stream are Co-60, Ni-63, Cs-137, and Sr-90.

- **Information sources reviewed and used.** Information for this stream was obtained from White (1975), RWMIS, and interviews with former employees.

- **Assumptions and analysis.** The total radioactivity is taken from the sources cited. The nuclide radioactivity distribution is assumed to be that contained in Table 2-8.

TRA-670-1H (Beryllium reflectors)

- **Generation of the waste stream.** The beryllium reflectors in this waste stream were used around the reactor core to reflect escaping neutrons back into the core. They were subject to very high neutron fluences.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are H-3 and Be-10.

- **Principal nonradiological contaminants.** Beryllium is the principal nonradiological contaminant in this stream.

- **Information sources reviewed and used.** Information sources reviewed and used were a letter from P. K. Nagata to T. H. Smith on December 22, 1993 (Nagata 1993), a letter from T. A. Tomberlin to D. E. Sheldon on December 22, 1986 (Tomberlin 1986), annual reports of the AEC Health and Safety Division, and DOE radioactive waste management information reports. Information from the unpublished expert committee report on the HDT (see attachment in Norland 1993) was also used.

- **Assumptions and analysis.** The mass of beryllium sent to the RWMC was correct on the shipping records, as confirmed by the calculations of Nagata (1993). The radioactivity

was based on results in Nagata (1993). Nagata's method for estimating the tritium activity in the reflectors was based on Tomberlin's calculation of the tritium generation rate per unit volume of beryllium. Although disposal of the reflectors occurred between 1969 and 1977, generation of the tritium in these reflectors was occurring fairly steadily from about 1963 through 1977. The reflectors were in the reactors and in storage canals at the reactor facilities for various periods of time before being shipped for disposal. In the absence of readily available, detailed histories of each reflector, the simplifying assumption was made that the tritium (and other radionuclides) produced in the reflectors was generated at a uniform rate from 1963 through 1977.

During the operating period of the MTR and ETR, carbon tetrachloride was a popular cleaning solvent. Carbon tetrachloride was used on external parts of the reactor. It is not known how much carbon tetrachloride was used to clean contaminated external reactor parts. Most carbon tetrachloride used at TRA probably went to the sanitary landfill as nonradioactive waste. However, a small amount may have gone to the RWMC on contaminated rags, paper, etc. One RWMC worker reported that 500-gal lots of solvent were sent from the TRA metallurgical laboratory to the RWMC in the 1950s and 1960s. The nature of the solvent was not known. A former employee of the TRA metallurgic laboratory was interviewed, however, and no confirmation or refutation of the presence of carbon tetrachloride was obtained. Thus, no reliable data are available concerning this contaminant in TRA waste buried in the SDA.

2.4.3 Idaho Chemical Processing Plant

The Generator. ICPP is located near the center of the INEL between CFA and TRA (see Figure 2-1). The primary purpose of this facility was to recover U-235 from expended military and test reactor fuel.

The facility originally included a storage pool, housed in a separate building, to store the fuel under water until a processing campaign was underway. A process building contained dissolvers to dissolve the fuel assemblies in nitric and hydrofluoric acids and a solvent extraction system that used tributyl phosphate, hexone, and nitric acid to recover the uranium. Laboratory, water treatment, and evaporator facilities were also a part of the complex.

In the early 1960s, a fluidized bed calciner was constructed and operated to convert the highly radioactive waste (resulting from the processing of fuel) to a granular solid. This facility was replaced by the New Waste Calcining Facility in the late 1970s.

In the early 1970s, an improved and larger fuel storage pool facility was constructed and placed into operation. About 1973, a new building was constructed and joined onto the original fuel storage facility to store dry graphite-type fuels, for which no uranium recovery process existed.

In 1992, a decision was made by DOE to discontinue the processing of all fuels at ICPP. Since then, operations at ICPP have been limited to the storage of spent fuel and the calcination and storage of high-level liquid waste.

Generation of the Waste. Most of the radioactive waste produced at ICPP remains in storage at that facility. Raffinates resulting from the dissolution and processing of nuclear fuels, waste

solutions resulting from the decontamination of process cells, and waste solutions produced by concentrating radioactive liquids in the process equipment waste evaporator are stored in underground stainless-steel tanks. This waste is later processed in the fluidized bed calciner at ICPP to convert the liquid to a granular solid. This processing of irradiated fuels produced thousands of gallons of high-level liquid waste containing several million curies of radionuclides. These radionuclides were nearly all retained at ICPP, either as liquid waste stored in underground stainless-steel tanks or as granular solids stored in underground stainless-steel bins.

Several processes at ICPP, however, produced waste that was sent to the RWMC for burial. These processes included

- Removing end pieces from Experimental Breeder Reactor-II (EBR-II) fuel assemblies before processing.
- Removing several years' accumulation of sludge from the CPP-603 fuel storage basin.
- Leaching of Vycor glass, which was contaminated with uranium and radionuclides from the EBR-II pyrometallurgical process.
- Replacing off-gas filters from the off-gas cleaning system of the Waste Calcining Facility after they became loaded with particulate matter.
- Dissolving small quantities of irradiated Navy fuel pieces in the Multicurie Cell to test uranium dissolution flowsheets.
- Operating laboratory and decontamination facilities.
- Using nonregenerable inorganic ion-exchange materials to remove radiological contaminants from fuel storage basin water, which resulted in the ion-exchange material becoming a waste stream.
- Using lead bricks and lead sheets for shielding in areas subject to radiological contamination.
- Conducting "cold testing" of the uranium solvent extraction systems using nonradioactive fuel materials and large quantities of chemical solutions.
- Removing soil and building exterior structural materials contaminated with localized deposits of radioactive particles from inadvertent airborne releases.
- Leaking in underground piping that carried highly radioactive solutions.
- Accumulating zirconium metal scrap for "cold testing" uranium recovery or waste calcination flowsheets. The excess material became a waste stream.

General Availability of Information. For waste produced before 1960, letters, special work permit forms, and the early types of waste shipment forms were found. For liquid waste disposed of

in the Acid Pit, waste disposal records were the only source of information located. For liquid waste in which the concentrations were not recorded, values were assigned based on the process believed to have produced the waste.

For waste produced in the post-1960 years, reports that were used included Batchelder (1984), DOE (1973), Hoech and Rhodes (1979), Jorgensen (1992), Liekhus (1992), Modrow and Lakey (1964), Osloond (1970), PPCo (1963), Plansky and Hoiland (1992), and Rhodes (1981). In addition, RWMIS, individual waste shipment records, and interviews with early waste handlers were used as appropriate.

Where the radiological contaminant was listed as MFP or unidentified beta-gamma, the breakdown into individual radionuclides (unless otherwise indicated) was that given in Plansky and Hoiland (1992). This breakdown is 10% Sr-90, 10% Y-90, 3.1% Zr-95, 3.1% Nb-95, 10% Cs-137, 19.7% Ce-144, 19.7% Pr-144, 4.4% Sb-125, 10% Ru-106, and 10% Rh-106. This breakdown, supplied by ICPP personnel, was reported to be valid for all time periods. It is assumed that this is a valid breakdown because, except for the fuel end pieces, essentially all of the radiological waste originated from solutions produced by the dissolution and solvent extraction or storage of aged fuel elements, which did not differ appreciably in fission product content. The breakdown for MAP in ICPP waste from ANL-W fuel end pieces was supplied by ANL-W personnel as reported in Plansky and Hoiland (1992), which is 50% Co-58 and 50% Mn-54. There were no entries for unidentified alpha radionuclides.

Data-Collection Approach. The general data-collection approach used was to review any documents that might contain process information pertaining to an individual waste stream and compare this information with data obtained from the individual waste shipping records and RWMIS. Where possible, individuals familiar with the process that produced the waste stream were interviewed. In some cases, assumptions were made on the basis of these interviews or from the data gatherer's personal knowledge of the process.

Description of Waste Streams. The ICPP waste was divided into 15 waste streams (see Table 2-13). The nine most important waste streams from ICPP are discussed in detail below. For each of these streams, the discussion tells how the stream was generated, the principal contaminants in the stream, the specific information sources reviewed and used, and the assumptions and analysis used to estimate the quantities of the contaminants.

CPP-601-1H (Leached Vycor glass)

- **Generation of the waste stream.** One of the initial goals of the EBR-II facility was to process the expended fuel from the EBR-II reactor by a pyrometallurgical process. In this process, the uranium was recovered and used to fabricate new fuel elements. One step in this process was to pour the molten uranium into Vycor glass molds to form the new fuel elements. When the uranium solidified, the Vycor glass mold was crushed and the fuel element was removed. Some uranium and a considerable amount of fission products remained attached to the crushed glass. This crushed glass was shipped in a shielded container to ICPP, where it was leached with hot nitric acid to recover the uranium remaining attached to the glass. The uranium was processed through the ICPP uranium recovery systems, and the Vycor glass was shipped to the RWMC for disposal.

Table 2-13. Waste streams originating at the Idaho Chemical Processing Plant.

Waste stream number	Description of waste
CPP-601-1H	Leached Vycor glass
CPP-601-2H	Insulation, pipe, wire, wood, plastic, rags, and concrete
CPP-601-3H	Dissolved fuel specimens
CPP-601-4H	Acidic aqueous liquid
CPP-601-5H	Organic solvents
CPP-601-6H	Pipe, glass, gloves, cans, vessels wire, valves, paper, metal, wood, clothing, filters, plastic bottles, and rubber
CPP-601-7H	Zirconium and zirconium-uranium alloy
CPP-603-1H	Fuel end pieces
CPP-603-2H	Lead
CPP-603-3H	Fuel storage pool sludge
CPP-603-4H	Decontamination chemicals
CPP-603-5H	Zeolite
CPP-603-6H	Contaminated roof materials and top soil
CPP-604-1H	Surface soil
CPP-633-1H	High-efficiency particulate air filters

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Cs-137, Ce-144, Sr-90, and Cs-134.

- **Information sources reviewed and used.** The values for each waste shipment were reported on the individual waste shipping records and in RWMIS. No other source of information for this waste was found. A personal interview with Morse Jacobson, who performed the leaching in the Multicurie (shielded) Cell, indicated that the only information about the contents was probably that on the waste shipment records. The main concern at the time was recovery of the uranium.

- **Assumptions and analysis.** Some of the glass reported on the waste shipment records may not have been from the EBR-II process, but it was not possible to distinguish other glass from the EBR-II glass. Therefore, it was assumed that all of the glass that came from the Multicurie Cell was EBR-II glass. Because the EBR-II leaching process took place over a period of several years, it is likely that the majority of the glass was from EBR-II. The MFP values were believed to have been obtained by converting radiation readings and using other information.

CPP-601-3H (Dissolved Navy fuel specimens)

- **Generation of the waste stream.** In 1969, experiments to develop a dissolution process for Navy fuel that had been irradiated in the ETR were run in the Multicurie Cell at ICPP. It was necessary to use a shielded cell facility because the fuel specimens used were highly radioactive. After the experiments were completed, the total solution produced (including the U-235) was reacted with plaster of Paris in polyethylene bottles to produce a solid, and the resulting solid was transported to the RWMC for disposal. This was a one-time operation, but it produced a significant quantity of radiological contaminants.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Sr-90, Y-90, Zr-95, Nb-95, Cs-137, Ce-144, Pr-144, Sb-125, Ru-106, Rh-106, U-238, U-234, and U-235.

- **Information sources reviewed and used.** Only one waste disposal record was used to identify this waste stream, and only a total curie value was reported. The values for the individual radiological contaminants were obtained by using the radionuclide distribution given in Plansky and Hoiland (1992) for ICPP to break down the total curies for the shipment. Osloond (1970) was used to make a comparison, as described below. Additional information was obtained from a personal interview with L. A. Decker, who performed the experiment.

- **Assumptions and analysis.** L. A. Decker indicated that the reactor history of the fuel specimens was well known. The reactor history and radiation measurements were used to establish the value for the total curies. The uranium value was believed to have been obtained from a radiochemical analysis. Although this was a one-time experiment, it produced about 96% of the total curies from ICPP that were buried in the RWMC in 1969, using the total curie values reported for ICPP in Osloond (1970) for 1969.

CPP-601-4H (Aqueous chemicals)

- **Generation of the waste stream.** In the 1950s, a pit outside the RWMC boundary was used to dispose of chemical solutions used in cold runs for testing chemical processes or originating from laboratory activities. When acid solutions were disposed of, large quantities of lime were added to the pit to neutralize the acid. About 1960, the boundaries of the RWMC were changed and use of the Acid Pit, which was enclosed within the new boundaries, was discontinued. All of the INEL facilities used this pit to some extent. This liquid waste contained very low levels of radioactivity. Some of the waste was generated in the Chemical Engineering Laboratory, which was located at CFA. The facility was operated by ICPP personnel testing ICPP processes; therefore, the waste produced was reported as an ICPP waste stream.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this waste stream are nitric acid, aluminum nitrate nonahydrate, mercuric nitrate monohydrate, uranyl nitrate, sodium nitrate, hydrofluoric acid, sulfuric acid, chromium, beryllium, and copper nitrate.

- **Information sources reviewed and used.** Information for this waste stream was obtained from individual records prepared at the time of waste shipment. These records included special work permits and waste disposal forms of different types. Jorgensen (1992) contained a listing of the waste, but this listing was taken from the individual waste shipment records. A personal interview with M. Young (retired) provided additional information.

- **Assumptions and analysis.** The chemicals and their concentrations were taken from the individual records, where possible. The concentrations frequently were not given; therefore, concentrations were assigned based on the process that was believed to have produced the waste. In at least one case, neither the chemicals nor concentrations were given for several large shipments from ICPP, totaling about 22,100 gal. The contents of these shipments were identified by a personal interview with M. Young, who had signed many of the waste shipment forms. This waste was from a cold, full-scale process run at ICPP, so a chemical composition and concentration values for the chemicals were assigned on that basis (1.0 molar nitric acid and 1.2 molar aluminum nitrate nonahydrate).

CPP-601-7H (Zirconium metal)

- **Generation of the waste stream.** In the early 1960s, a large quantity of zirconium and zirconium alloy metal scrap was shipped to ICPP for full-scale testing of dissolution and solvent extraction flowsheets for zirconium and zirconium alloy reactor fuels. When this testing was completed, the remaining metal was stored outside in wooden boxes and metal drums for several years. In 1967, this material was shipped to the RWMC for burial.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this waste stream are zirconium and zirconium alloy. Some natural uranium was reported to be in the shipment, but it was not stated whether this was alloyed with the zirconium.

- **Information sources reviewed and used.** Two waste shipping forms and RWMIS contained information pertaining to the shipment of zirconium to the RWMC. Liekhus (1992) reported this material was buried in Pit 9, but the information in that document was obtained from RWMIS and waste shipment records. A personal interview with L. O. Zohner at ICPP also provided some information.

- **Assumptions and analysis.** Most of the zirconium was listed on one waste shipment record. This record listed the weight as 30,000 to 40,000 lb. The mean value of 35,000 lb was used for the weight of the zirconium, so the uncertainty would be ±5,000 lb or 14%. Because the weight was probably estimated, the uncertainty was increased to ±20% to account for error in estimating the weight. The second waste shipment record listed 3,400 lb of zirconium and 182 kg of natural uranium. The 3,400 lb was added to the 35,000 lb to bring the total to 38,400 lb. Liekhus (1992) listed the zirconium content as 15,000 kg (33,000 lb). In estimating the weight of the metals for his report, Liekhus subtracted the weight of the containers, which may account for the lower value.

CPP-603-1H (Fuel end pieces)

- **Generation of the waste stream.** To process the EBR-II stainless-steel-clad fuel, the end pieces, which did not contain uranium, were cut off in the fuel storage basin. Thus, when the fuel was processed, this excess stainless steel did not have to be dissolved. The end pieces were collected and stored in containers on the floor of the fuel storage basin. At the end of the two EBR-II fuel processing campaigns in 1973 and 1982, the end pieces were loaded into a shielded cask and disposed of at the RWMC.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are activation products produced by the reaction of neutrons with the components of the stainless steel. These radionuclides were identified as Co-60, Co-58, Cr-51, Fe-59, and Mn-54 on the waste disposal records. Technetium-99, C-14, Nb-94, Ni-63, Ni-59, and Zr-93 were later shown to be present in this type of waste. These latter radionuclides were not identified earlier because they were either present in very low concentrations or were weak beta-emitters, or both. They were not important for determining the shielding required to transport the waste, but they may be important for a risk assessment because of their long half-lives. The concentrations of these latter radionuclides were calculated as described below.

- **Information sources reviewed and used.** The information sources used to obtain the values for the preceding radionuclides included Batchelder (1984), DOE (1973), the individual waste shipping records, RWMIS, calculations, and a personal interview with L. W. Madsen, the operator who handled the equipment used to cut and ship the end pieces. The documents showed large values of radioactivity from ICPP in 1973 and 1982, the years the fuel end pieces were disposed of. The values for Co-60 and Co-58 reported in DOE (1973) agreed with the total values reported on the individual waste records. However, the document did not break down the radioactivity into individual waste streams. The most detailed information was obtained from RWMIS and the individual shipping records. The concentrations of some of the radionuclides (Ni-63, Tc-99, C-14, Nb-94,

Ni-59, and Zr-93) were obtained from calculations made by using the ratio of Co-60 to Ni-63 to calculate the activity of Ni-63 and then using the ratio of Ni-63 to the nuclide in question to calculate the activity for that nuclide. These ratios were calculated by using DOE (1992) to estimate the quantities of these neutron activation products in the stainless-steel structural materials.

- **Assumptions and analysis.** Although no analytical records were found, the breakdown of radionuclides reported on the waste records probably came from a laboratory analysis of a dissolver product sample. The dissolver product solution had to be sampled to track the U-235 inventory. Thus, it would have been a simple matter to use this sample also for a total radionuclide inventory, which was required at this time for waste shipments transported to the RWMC. This analysis probably would have been accurate to within 10%, but the weight of the end pieces was estimated, and it was assumed that this value could have been off by as much as 50%. This reasoning was used to determine the maximum and minimum values. In addition, the 23,075 Ci of MAP was distributed among the principal radionuclides in the waste according to the distribution suggested by EBR-II personnel in Plansky and Hoiland (1992). The suggested breakdown was 50% Co-58 and 50% Mn-54.

CPP-603-2H (Lead)

- **Generation of the waste stream.** Lead bricks and lead sheets were commonly used at the INEL to provide shielding from radiation arising from experiments or operational activities. In addition, lead is used as shielding in containers for transporting radioactive samples or fuel materials. When the lead became sufficiently contaminated with radionuclides to create a potential contamination or radiation problem, it was sometimes decontaminated for reuse; however, frequently it was transported to the RWMC for burial.

- **Principal nonradiological contaminants.** The principal nonradiological contaminant in this waste stream is lead.

- **Information sources reviewed and used.** Osloond (1970) includes a summary of the solid waste disposed of at the RWMC during the time period 1952 through 1969. Batchelder (1984) provides similar information for the time period 1952 through 1983. The lead bricks were disposed of in 1978, and the lead sheets and other materials were disposed of from 1960 through 1977. However, Osloond (1970) and Batchelder (1984) provide only summary tables of radioactivity and volumes, and they do not specify what materials made up these values. The principal source of information for the disposal of the lead was the individual waste shipment records and RWMIS.

- **Assumptions and analysis.** The lead bricks were of uniform size and weight, so it was assumed that the total number of bricks multiplied by the weight of one brick would give a weight within 10%. The lead sheets would have been more difficult to assign a weight to, but it was assumed that this value would be within 25%. The weight of the lead was obtained from the individual waste shipment records.

CPP-603-3H (Sludge from the fuel storage basin)

- **Generation of the waste stream.** The CPP-603 fuel storage basin consists of three concrete basins interconnected by a transfer canal, all housed in the CPP-603 building. The basin contained water to a depth of about 6 m (20 ft) to provide shielding for the radioactive fuel. The building consists of a steel frame covered with transite panels. There was no seal where the roof and the walls intersected and large rollup doors were opened frequently; therefore, windblown dust entered the building and settled to the floor of the basin.

  Two of the basins were covered with a steel grating that corroded and dropped iron oxide particles into the water. Additionally, galvanized yokes and hangers extended from an overhead monorail to a point just above the floor of the basin. Galvanized steel buckets were attached to these yokes and contained the irradiated fuel elements. The galvanized steel also corroded and released particulate matter into the water.

  Over a period of about 26 years, a 5- to 10-cm (2- to 4-in.) layer of sludge accumulated on the floor of the basin. This sludge had ion-exchange properties, which caused it to sorb radionuclides released into the water from leaking fuel materials. The sludge made the water cloudy when fuel was moved, making it difficult to handle the fuel safely. It also contaminated shipping casks, which posed a radiation hazard to personnel when the casks were removed from the water for decontamination before shipping.

  The sludge was removed from the basin using an underwater vacuum system. The sludge was then transported through a flexible line to a hydroclone, where it was separated into (a) a concentrated sludge, which was placed in temporary storage in a large stainless-steel tank, and (b) water containing finely divided solids, which was returned to the inlet of the multimedia filters. Later, the sludge was pumped from the sludge storage tank into concrete steel-lined vaults, where it was dewatered and solidified, then buried at the RWMC.

- **Principal radiological contaminants.** The radiological contaminants in this waste stream are Ce-141, Ce-144, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Zr-95, Ru-106, Sb-125, Sr-90, U-234, U-235, U-236, U-238, Y-90, Nb-95, Pr-144, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, and Rh-106.

- **Information sources reviewed and used.** The information sources used include Hoech and Rhodes (1979), RWMIS, and individual waste shipment records. A personal interview with L. W. Madsen provided information on the process that was used. Batchelder (1984) was reviewed, but it did not contain a breakdown of the ICPP waste by streams, so it was not used.

- **Assumptions and analysis.** Hoech and Rhodes (1979) reported that the sludge was sampled on the basin floor before vacuuming and in the storage tank that collected the concentrate from the hydroclone during the vacuuming process. It was assumed that the concentrations of the radionuclides reported on the waste shipping records and from RWMIS came from laboratory analyses of these samples. Because the analyses were likely

done in the ICPP analytical laboratory and the sludge was thoroughly mixed during the vacuuming process, it was assumed that the results were accurate within 20%.

CPP-604-1H (Contaminated soil)

- **Generation of the waste stream.** In 1974, during the course of drilling in the ICPP tank farm to install cathodic protection electrodes, a high concentration of radiological contamination was encountered at a point approximately 2 m (7 ft) below grade. Approximately 43 m^3 (56 yd^3) of contaminated soil containing about 3,000 Ci of radiological contamination was excavated, packaged, and transported from the tank farm to the RWMC. Subsequent examination revealed that the contamination came from a first-cycle waste stream that leaked through a small hole in piping that transported waste from the process building to the high-level waste tanks.

  Soil from several other contamination incidents of lesser magnitude was included as part of this waste stream.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Ce-144, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Mn-54, Pr-144, Pu-238, Pu-239, Ru-106, Rh-106, Sb-125, Sr-90, Y-90, Zr-95, and Nb-95.

- **Information sources reviewed and used.** The principal source of information was a report entitled *ICPP Tank Farm Contaminated Soil Incident*, dated October 1, 1974. This report does not have a document number, but it is attached to a letter from F. H. Anderson to R. Glenn Bradley (Anderson 1975). RWMIS was used to obtain values for the radiological contaminants for the smaller soil incidents. Plansky and Hoiland (1992) was used to distribute the MFP among the various radionuclides. Batchelder (1984) was reviewed. It covered the time period of interest but did not list individual waste streams, so it was not used.

- **Assumptions and analysis.** A laboratory analysis of the soil for the radiological contaminants (as reported in the tank farm document) was used to identify the contaminants. It was assumed that the total amounts could be estimated by multiplying the known volume of spilled liquid by the concentration of the contaminants in the liquid. RWMIS was used to obtain values for the radiological contaminants for the smaller soil contamination incidents. Because of the lack of detailed information on the smaller incidents, the uncertainty for the radiological contaminants was considered to be $\pm 50\%$.

CPP-633-1H (Filters from the Waste Calcining Facility)

- **Generation of the waste stream.** Filters were used in the Waste Calcining Facility off-gas system as a final barrier to prevent the atmospheric release of any particulate matter (calcine) in the off-gas. When the pressure drop across the filters became excessive, the filters were replaced and the old filters were disposed of at the RWMC.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Ce-144, Cs-137, Nb-95, Pr-144, Rh-106, Ru-106, Sb-125, Sr-90, Y-90, and Zr-95.

- **Information sources reviewed and used.** Sources of information reviewed were Modrow and Lakey (1964), Phillips Petroleum Company (1963), individual waste shipment records, and RWMIS. Information was also obtained from a personal interview with Barry O'Brien at ICPP.

- **Assumptions and analysis.** The radiological contaminants and their concentrations were listed on the individual waste shipment records and in RWMIS. Modrow and Lakey (1964) indicated that a small side stream of the off-gas was pulled through a Millipore filter, and this sample was analyzed in the laboratory.

2.4.4 Naval Reactors Facility

The Generator. NRF is located in the western part of the INEL, about 23 km (14 mi) north-northeast of the RWMC (see Figure 2-1).

NRF was established in 1950 when construction began on the prototype power plant for the U.S. Navy's first nuclear-powered submarine, the USS Nautilus. This prototype, later named S1W, was developed to test the propulsion plant design and to train Navy personnel to operate reactors in preparation for duty on nuclear-powered submarines and ships in the fleet. Two additional naval reactor prototypes were subsequently built at NRF: A1W in 1957 and S5G in 1965. The basic mission of these other prototypes was the same as for the original prototype—to test propulsion plant designs and to train Navy personnel. The S1W plant was shut down in October 1989, A1W was shut down in January 1994, and the S5G plant was shut down in May 1995.

The ECF, built at NRF in 1958, was designed to receive irradiated naval reactor fuel, perform examinations on the fuel elements, remove excess structural material from the fuel elements, and transfer the fuel elements to ICPP. The ECF has also received and examined naval fuel test specimens that have been irradiated in other reactors, such as the ATR. The fuels are remotely handled under water in the ECF water pits. The water serves as a transparent shielding medium in which a number of procedures can be carried out, including disassembling, cutting, sawing, milling, and visually examining various parts of the fuel elements. Some procedures are also carried out in hot cells at ECF.

Generation of the Waste. LLW is generated by the naval reactor prototypes as a result of activities such as reactor coolant sampling, maintenance, repair, and refueling, these actions require interface with the contaminated plant internals. LLW is generated at ECF as a result of fuel examination work. The majority of the waste originating at the prototype plants is compactible waste (e.g., plastic bags, rubber gloves, blotter paper, and other materials used to contain contamination) with very low levels of radioactivity. In addition to this compactible and largely incinerable waste, there have also been occasional metal valves and piping sections that are not compactible and that can contain higher quantities of radioactivity. Metal tanks and drums containing spent ion-exchange resins and sludge from water processing systems add to the noncompactible component of the waste streams.

The majority of both the radioactivity (curies) and the volume of waste that has been transferred from NRF to the RWMC has come from ECF. Most of the radioactivity emerging from ECF is in highly corrosion-resistant metal structural materials removed during the naval fuel examinations. This material is loaded into metal containers which, in turn, fit into large shielded shipping casks. These casks are then taken to the RWMC, where the containers are removed and buried.

General Availability of Information. The main source of data pertaining to waste shipments from NRF is the RWMIS database of shipping and disposal records, as amended by information from Bartolomucci (1989). In addition, over 20 other documents (such as reports, engineering design files, and letters) were examined in a search for additional or corroborating data. Copies of the original waste transfer records were also scanned for specific data. Nieslanik (1994), Bartolomucci (1989), and RWMIS provided most of the data used. The two documents contain the results of extensive analyses by NRF and Bettis Atomic Power Laboratory personnel based on reactor operating histories and nuclear physics calculations. Vigil (1990) contained some expository material that validated the data gatherer's recollection of how the scrap casks from ECF were handled.

Earlier records, especially for the period before 1960, have been difficult to find. When they do exist, they often lack information of interest to this task. For example, there is little information on the existence of hazardous chemicals, such as lead and asbestos. The information on hazardous chemicals can sometimes be deduced, however, from other information in the records and from interviews with former NRF and RWMC workers.

Another problem with the early records is the lack of information on radionuclide content. In the early years, the waste transfer forms were limited to recording information of interest to people handling the waste, such as the radiation level, a brief description of the material, approval signatures, and date. Later, the forms recorded estimates of activity in the shipment, usually listing Fe-59 or Co-60 as the only nuclide.

The assumption that Co-60 was the predominant nuclide was probably accurate, but that assumption overlooked the possibility that other contributors were present as well, and information on the other contributors is not available now. Only in recent years has waste material been subjected to isotopic analysis, providing a more accurate estimate of the activity and radionuclide distribution. One end result of these gaps in the records is that there is a great deal of uncertainty regarding the radionuclide content of the waste, as previously discussed.

Two important sources of information on the NRF waste are the two letters issued by NRF: Bartolomucci (1989) and Nieslanik (1994). These two letters document efforts made by NRF to improve the information available on (a) the distribution of radionuclides within the identified NRF waste and (b) the total number of curies shipped from NRF in the scrap casks from 1955 through 1983. Between 1955 and the time when ECF began operations, some core structural scrap was shipped from the S1W building. Nieslanik (1994) documents all of the scrap shipped from 1955 through 1975.

The method used by NRF to determine the total activity and radionuclide distribution in scrap cask inserts shipped from ECF from 1976 through 1989 was outlined in Bartolomucci (1989). This method was based on knowledge of the metal alloys in the reactor core structural materials and the reactor core radiation history. This information allowed NRF to calculate the extent of expected

neutron activation of the core structural material. As pointed out in Bartolomuicci (1989), this technique is similar to the calculation methods used to determine power levels and lifetimes for nuclear cores, and it has been validated empirically. The same method was used for the scrap cask shipments from 1955 through 1975 that were provided in Nieslanik (1994).

Data-Collection Approach. The approach selected for data collection for the NRF waste was initially to take data from both the RWMIS database and the original waste transfer records. The figures from both sources were frequently checked against each other, helping to resolve conflicts and answer questions that arose during the investigation. Computer-aided searches of the database were augmented and spot-checked by referring to copies of the original records. A limited amount of information was obtained from former workers, although these people were generally unable to recall specific details regarding events that took place decades ago. These sources *were* able to answer some questions regarding the mention of lead shielding in some of the transfer records, verifying that the lead listed was a shipping container and that it was not buried at the RWMC.

The data in Bartolomucci (1989) had already been factored into the RWMIS database; RWMIS was checked against that letter to make certain that the database was current, at least regarding the changes brought about by the letter. The radionuclide distribution numbers from the letter were also used because Bettis/NRF would have the most detailed information concerning what materials went into the core structurals. After Nieslanik (1994) became available, it was used to refine the data pertaining to scrap cask shipments before 1976.

Description of Waste Streams. The NRF waste was divided into 11 waste streams (see Table 2-14). The five most important waste streams from NRF are discussed in detail below.

As stated previously, the majority of the radioactivity from NRF came from ECF in scrap cask inserts. Four NRF waste streams encompass this waste: NRF-618-2H (1955–1975), NRF-618-3H (1976–1980), NRF-618-4H (1981–1983), and NRF-618-5H (1955–1975). The waste was divided into these four streams based on the three indicated sequential time periods because of changes in radionuclide distribution within the waste streams. The fourth stream, NRF-618-5H, was included because the zirconium also was shipped out in the scrap casks. For each of the five streams, the discussion tells how the stream was generated, the principal contaminants in the stream, the specific information sources reviewed and used, and the assumptions and analyses used to estimate the quantities of the contaminants.

NRF-618-2H (Naval core structural scrap, 1955–1975)

- **Genèration of the waste stream.** Structural material was cut from naval fuel before the fuel elements were sent to ICPP for reprocessing. This waste stream, as well as NRF-618-3H and NRF-618-4H, consisted of this irradiated structural material, mostly stainless steel, with some inconel and zircaloy. The scrap material was highly radioactive; it was shipped to the RWMC in shielded scrap casks and remotely handled. This stream included shipments from 1955 through 1975.

- **Principal radiological contaminants.** Starting with the nuclide with the greatest activity, the principal radionuclides in this waste stream are Co-60, Fe-55, Ni-63, Sb-125, and Sn-119m.

Table 2-14. Waste streams originating at the Naval Reactors Facility.

Waste stream number	Description of waste
NRF-601-1H	Low-level compactible and noncompactible waste from operation of the S1W reactor and related activities
NRF-617-1H	Low-level compactible and noncompactible waste resulting from operation of the A1W reactors and related activities
NRF-617-2H	Lead and asbestos
NRF-618-1H	Dissolved pressurized water reactor fuel rods absorbed in vermiculite
NRF-618-2H	Structural components from Navy core fuel bundles; end boxes and other components—1955–1975
NRF-618-3H	Structural components from Navy core fuel bundles; end boxes and other components—1976–1980
NRF-618-4H	Structural components from Navy core fuel bundles; end boxes and other components—1981–1983
NRF-618-5H	Zirconium alloy (zircaloy) cladding from Navy cores
NRF-618-6H	Solidified sludge, resin, waste liquids in vermiculite
NRF-618-7H	Low-level compactible and noncompactible waste resulting from work at ECF water pits and hot cells
NRF-633-1H	Low-level compactible and noncompactible waste resulting from operation of the S5G reactor

- **Information sources reviewed and used.** The above radionuclide distribution was taken from Nieslanik (1994). Several inventory reports were reviewed, but no additional information on this stream was located.

- **Assumptions and analysis.** An assumption was made that the variations in radionuclide content in the scrap at various time periods from 1955 through 1975 were unimportant and that the scrap could be considered to be generally homogeneous. The data presented in Nieslanik (1994) were accepted as being the most reliable currently available.

NRF-618-3H (Naval core structural scrap, 1976–1980)

- **Generation of the waste stream.** The same process generated this stream as generated NRF-618-2H; the time period is 1976 through 1980.

- **Principal radiological contaminants.** The principal radionuclides in this waste stream are Fe-55, Co-60, Sb-125, Zr-95, Sn-119m, and Ni-63.

- **Information sources reviewed and used.** Data were taken from RWMIS as amended by Bartolomucci (1989).

- **Assumptions and analysis.** The data presented in Bartolomucci (1989) were accepted as being the most reliable currently available.

NRF-618-4H (Naval core structural scrap, 1981–1983)

- **Generation of the waste stream.** The same process generated this stream as generated NRF-618-2H; the time period is 1981 through 1983.

- **Principal radiological contaminants.** The principal radionuclides in this waste stream are Ni-63, Co-60, Fe-55, and Co-58.

- **Information sources reviewed and used.** The data were taken from RWMIS, as amended by Bartolomucci (1989).

- **Assumptions and analysis.** The data presented in Bartolomucci (1989) were accepted as being the most reliable currently available.

NRF-618-5H (Zirconium alloy scrap)

- **Generation of the waste stream.** This waste stream was generated by the same process as waste streams NRF-618-2H, NRF-618-3H, and NRF-618-4H. Structural material was cut from naval cores before the fuel elements were sent to ICPP for reprocessing. This stream consisted of zirconium alloy (zircaloy) cladding and fuel element end pieces. This material, generated during cutting and milling operations on the fuel elements in the ECF water pits, was collected from the bottom of the ECF water pits and placed into 5-gal cans; the cans were loaded into a scrap cask insert for transfer to the RWMC. These shipments

were handled differently from other scrap shipments because of the need to keep the zirconium covered with water until it was buried under soil. The objective was to prevent fires in the pyrophoric zirconium fines.

- **Principal contaminants.** The contaminant of interest in this waste stream is zircaloy. This material contains a principal radiological contaminant, Zr-95, as well as a principal nonradiological contaminant, zirconium. The zirconium is considered a hazard because of its pyrophoric nature.

- **Information sources reviewed and used.** Information on the number, volume, and weight of zircaloy shipments was obtained from RWMIS and from the individual original waste transfer records. Several inventory reports were reviewed, but no additional information on this stream was located. Zirconium activity was taken from Bartolomucci (1989) and Nieslanik (1994).

- **Assumptions and analyses.** Estimates of the weight of zirconium in given shipments were obtained from 1965 waste transfer forms. From these data, an average weight was determined for zirconium shipments. This average was then applied to earlier shipments for which such information was not given. In this way, an estimate was made for the total weight and activity of zirconium transferred to the RWMC from ECF.

NRF-618-7H (ECF compactible and noncompactible waste)

- **Generation of the waste stream.** Operation of a fuel examination facility such as ECF involves the handling of highly radioactive materials, both in the water pits and in the hot cells. Daily operations create large quantities of rags, plastic, blotter paper, rubber gloves, and other materials that become contaminated with radionuclides when used to limit the spread of radioactive contamination. Noncompactible items such as sections of contaminated ventilation ducts, piping, valves, tools, and glassware, are frequently packed with the compactible component of the waste stream. The radioactive material in this waste stream is in particulate form. This material is enclosed in plastic bags, and the bags are then packed into cardboard boxes for transfer.

- **Principal radiological contaminants.** The principal radionuclides in this waste stream are Co-60, Fe-55, and Ni-63.

- **Information sources reviewed and used.** This information was taken from Nieslanik (1994).

- **Assumptions and analysis.** The curie content contained in waste streams NRF-618-1H through NRF-618-6H, as listed in RWMIS, was verified by comparison with original transfer forms. The summed activity in curies in these six streams was then subtracted from the total activity listed in RWMIS for ECF, and the balance was assumed to be the activity contained in the ECF compactible and noncompactible waste stream. A second assumption was made that the distribution of radionuclides in the ECF compactible and noncompactible waste was constant over the period of time studied (1960 through 1983), and was given by Nieslanik (1994).

2.4.5 Argonne National Laboratory-West

The Generator. ANL-W is located in the southeastern part of the INEL, approximately 56 km (35 mi) west of Idaho Falls (see Figure 2-1).

Since the beginning of operation, the mission of ANL-W has been the research and development of liquid metal-cooled reactors and advanced nuclear power plant technology. The primary focus for ANL-W research until 1994 was the Integral Fast Reactor (IFR) Project integrated with an onsite fuel recycling process called pyroprocessing. The objectives were to increase reactor safety, reduce radioactive waste components and concentrations, and improve reactor fuel efficiency.

ANL-W consists of seven major complexes: (1) the EBR-II, (2) the Transient Reactor Test Facility (TREAT), (3) the Zero Power Physics Reactor (ZPPR), (4) the Hot Fuel Examination Facility (HFEF), (5) the Fuel Cycle Facility (FCF), (6) the Fuel Manufacturing Facility (FMF), and (7) the Laboratory and Office (L&O) Building and support facilities such as the Radioactive Liquid Waste Treatment Facility (RLWTF), the Sodium Components Maintenance Shop (SCMS), and the Sodium Process Facility (SPF).

EBR-II consists of a sodium-cooled reactor with a thermal power rating of 62.5 MW, an intermediate closed loop of secondary sodium, and a steam plant that produces 19 MW of electrical power through a conventional turbine generator. The original emphasis in the design and operation of EBR-II was to demonstrate a complete breeder reactor power plant with onsite reprocessing of metallic fuel. The demonstration was successfully carried out from 1964 to 1969. The emphasis at EBR-II was then shifted to irradiation testing of fuels and materials for future, larger liquid metal reactors. The EBR-II has also been used to provide electrical power for ANL-W and the INEL. The EBR-II cooling tower, SCMS, and SPF are also associated with EBR-II. The SCMS facility is used to remove sodium from reactor components for repair or replacement.

The TREAT reactor is an uranium oxide-fueled, graphite-moderated, air-cooled reactor. It was designed to produce short, controlled bursts of nuclear energy to simulate accident conditions leading to nuclear fuel damage. The reactor became operational in 1959. Tests at TREAT provide data on fuel cladding damage, fuel motion, coolant channel blockages, molten fuel/coolant interactions, and potential explosive forces during an accident.

ZPPR is the national facility for testing the physics properties of advanced, fast-spectrum reactors. ZPPR is designed to study the properties of experimental reactor cores. Experimental cores are built by hand-loading plates of reactor materials into drawers, which are then put into the designed pattern. The designs are tested at low power levels to determine characteristics of the core.

FCF (formerly called HFEF/S) became operational in 1964 and was used to demonstrate pyrometallurgical fuel reprocessing for EBR-II fuel during the first few years of operation. In that mode of operation, a remotely operated production line was used for processing and refabricating spent EBR-II fuel and returning it to the reactor. After successfully demonstrating this process in 1969, this mission was discontinued, and the facility was used to examine irradiated fuels and material experiments from EBR-II and TREAT and to provide other reactor support services such as spent fuel transfer to ICPP. FCF consists of two hot cells: one with an air atmosphere and the other with an inert argon-gas atmosphere. There are 23 hot cell work stations around the outside perimeter of the

FCF hot cells and 4 active work stations in the center work space of the argon cell. FCF is now being modified for use in demonstrating new remote recycling and refabrication fuel cycle processes for DOE. The facility has been upgraded and reequipped with new process equipment to carry out this demonstration.

HFEF (formerly HFEF/N) went into operation in 1975 and is used for examining irradiation experiments. Examinations conducted in the HFEF provide data that are essential for determining the performance and conditions of fuels and materials irradiated in the EBR-II reactor, the TREAT reactor, and other DOE reactor facilities. HFEF consists of two shielded hot cells: the decontamination cell, which contains an air atmosphere, and the main cell, which contains an argon gas atmosphere. Each of the 21 work stations in HFEF is equipped with shielded windows and master/slave manipulators. The main cell is used for work involving exposure of materials such as sodium, plutonium, and other materials that would react chemically with air.

The FMF contains the entire operation for the manufacturing of metallic fuel elements within a single building. The building contains a casting furnace and large gloveboxes for encapsulating and bonding the cast fuel slugs in a stainless-steel jacket.

Within the L&O Building is the analytical laboratory, which consists of hot cells, chemistry laboratories, and the Experimental Fuels Laboratory (EFL). The analytical laboratory provides chemistry support for ANL-W in the areas of environmental compliance, fuel chemistry, sodium/water chemistry, and waste classification analysis. The EFL is used in the development and fabrication of prototype metallic nuclear fuels.

The RLWTF receives low-level radioactive liquid waste from ANL-W facilities and stores the waste in storage tanks before evaporation in the shielded hot air drum evaporators. The L&O Building, FCF, and HFEF pipe liquid waste to the RLWTF facility directly. The RLWTF began operating in June 1983. Before June 1983, the low-level liquid evaporation process took place in the basement of the L&O Building.

Generation of the Waste. Solid radioactive waste generated at ANL-W was primarily associated with irradiated experimental fuel subassemblies and capsules from EBR-II and, to a lesser degree, TREAT. (*The term "experimental fuel" does not include spent EBR-II driver fuel, which was historically shipped to ICPP. "Spent nuclear fuel," as defined in DOE Order 5820.2A, was not stored or processed at ANL-W during the time period covered by this report.*) After irradiation in ANL-W reactors, the subassemblies and capsules were conveyed to appropriate facilities for dismantling, sampling, and examination. If they were not contaminated with sodium (the coolant used in EBR-II), these reactor pieces and parts were shipped to the RWMC as remote-handled waste. Sodium-contaminated reactor parts were stored in the Radioactive Scrap and Waste Facility (RSWF) at ANL-W.

Various types of radioactive waste were generated during routine reactor and hot cell operations, maintenance activities, and cleanup and decontamination processes at ANL-W. Examples of ways in which various types of waste were generated include

- **Dry active waste.** Generated routinely in general plant operation, maintenance, decontamination, and monitoring activities. Major generators of ANL-W dry active waste were EBR-II, TREAT, HFEF, FCF, and the analytical laboratory.

- **Hot cell waste.** Generated from hot cell operations at FCF and HFEF. Most of this waste stream was stored in the RSWF, but some was sent to the RWMC.

- **Junior caves waste.** Generated from operations of the ANL-W hot cells.

- **Nonstandard waste forms.** Out-of-the-ordinary waste types (usually large pieces of excess or demolished equipment) nonroutinely shipped to the RWMC. This type of waste was shipped from all ANL-W radiological control areas.

- **Concreted evaporator bottoms.** Radioactive liquids were received and evaporated at the central liquids processing area in the basement of the analytical laboratory. Generators of the liquids were FCF, HFEF, and TREAT.

General Availability of Information. Most ANL-W waste information was found in library and archival storage at the INEL or was retrieved from the Federal Records Center in Seattle, Washington. Information included old waste shipment records, printouts from RWMIS, personal interviews with long-time employees, National Environmental Policy Act documents, miscellaneous reports (some in draft versions), technical studies, and correspondence.

Historical data analyzed were sufficient to verify total waste volumes shipped to the RWMC. Waste volumes reported in RWMIS were usually verified in the various studies and reports. Also, the information reported over the years 1962 to 1983 usually differentiated various waste types adequately (e.g., remote-handled versus contact-handled or "dry active waste" versus reactor components). To this extent, the data are reliable. However, the data, especially from the 1960s and 1970s, were usually vague in providing radionuclide information. Occasionally, specific radionuclides were reported in the waste shipment records. However, radionuclides were usually reported only as MAP and/or MFP in the early years (1962 through 1972).

In the 1960s, the reported radioactivity in waste shipments was only a gross calculation based on radiation readings from the waste packages. The same formula was used to calculate radioactivity for many container types; thus, the radioactivity determinations for the period are suspect.

Beginning about 1971, improved algorithms were used to quantify total radioactivity from radiation readings. Formulae were developed for different container types. The revised algorithms gave better indications of the actual amounts of radioactivity contained in the waste shipments to the RWMC.

Conservative generalizations were made about ANL-W radionuclide distributions for instances in which the contaminants were listed as MAP, MFP, or unidentified beta-gamma. A previous study based on RWMIS records (Plansky and Hoiland 1992) suggested a generic radionuclide profile for ANL-W LLW sent to the burial grounds since 1961. This generic profile listed Sr-90 as one of the constituents. More recent studies (Grant 1992; Nielsen 1993) propose an even greater presence of Sr-90 in ANL-W waste streams, taken as a whole, than that suggested by Plansky and Hoiland. In

addition, subassembly hardware contains Cr-51, which was not identified by Plansky and Hoiland in the ANL-W MAP. The ANL-W radionuclide distribution used here for generic entries is as follows:

- MAP: 55% Co-60, 20% Cr-51, 15% Mn-54, and 10% Co-58
- MFP and unidentified beta/gamma-emitters: 50% Sr-90, 30% Cs-137, and 20% Ce-144
- No appreciable amount of radioactivity from ANL-W was listed as unidentified alpha.

ANL-W waste information gave few details about nonradiological contaminants in shipments to the RWMC. Some clues were given in some waste descriptions (e.g., source storage pig, lead pipe, and thermometer) in RWMIS and shipping records. In a study performed in 1987, ANL-W facilities estimated their historical use of chlorinated solvents. When found, such information (e.g., Pohto 1980) about nonradiological contaminants is listed on the appropriate waste stream data forms.

Data-Collection Approach. ANL-W Records Management archives were searched for information germane to the study. Most pertinent shipping records and health physics logs for the time period (1962 to 1983) had been sent to the Federal Records Center in Seattle. The records were retrieved and examined. Other ANL-W archival storage areas were searched.

Some reports on ANL-W waste management and the ANL-W section of the INEL Environmental Impact Statement (ERDA 1977) were found and used. Also, more recent analyses of ANL-W waste were used (e.g., Grant 1992; Nielson 1993). RWMIS was used in the absence of other data.

Description of Waste Streams. The ANL-W waste is divided into eight waste streams (see Table 2-15). The four most important waste streams are discussed in detail below. For each of these streams, the discussion tells how the stream was generated, the principal contaminants in the stream, the specific information sources reviewed and used, and the assumptions and analysis used to estimate the quantities of the contaminants.

ANL-752-3H (Concreted evaporator bottoms)

- **Generation of the waste stream.** This waste stream consisted of liquid radioactive waste from FCF (the principal generator), HFEF, and the L&O Building. The liquid was processed through a steam-heated tube bundle. About 1,500 gal of liquid was evaporated down to 15 gal of viscous liquid. Initially, the resulting liquid was divided into two 7.5-gal portions. Each portion was placed into a container, which was then encapsulated in a concrete-lined, 55-gal drum. Because of the high radiation fields associated with the concentrated liquids, the process was modified in 1974. After modifications, the concentrated liquid waste stream was directed into shielded hot drum evaporators (15-gal drums encased in concrete).
- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Co-60 and Cs-137.
- **Information sources reviewed and used.** Shipping records from the study period were used to identify the volumes and radioactivity of waste disposed of. Correspondence and files with documents describing the use of the evaporator system were also used. In

Table 2-15. Waste streams originating at Argonne National Laboratory-West.

Waste stream number	Description of waste
ANL-752-1H	Dry active waste routinely generated in facility monitoring, operations, and maintenance activities; laboratory and sample waste
ANL-752-2H	Combustibles (paper, cloth, etc.); plastic; metal; and filters
ANL-752-3H	Concreted evaporator bottoms
ANL-765-1H	Dry active waste routinely generated in facility monitoring, operations, and maintenance activities
ANL-765-2H	Subassembly hardware (from nuclear fuel and material experiments), gloves, coveralls, plastic, and building materials
ANL-767-1H	Dry active waste routinely generated in facility monitoring, operations, and maintenance activities
ANL-785-1H	Subassembly hardware (from nuclear fuel and material experiments), rags, plastic sheeting, and equipment
ANL-EBRI-1H	A wide range of waste from EBR-I

addition, information was obtained through interviews with health physics personnel who worked in the area during the years of operation.

- **Assumptions and analysis.** Shipping records of the evaporator bottoms waste characterized the waste to be 90% MFP. This characterization was retained, with the remaining 10% assumed to be MAP. No uranium or transuranium radionuclides were assumed to be contained in the waste. The most likely concentrated heavy metals in the liquids are cadmium and chromium.

ANL-765-1H (FCF dry active waste—combustibles, filters, metals)

- **Generation of the waste stream.** This waste stream was generated during routine reactor operations, maintenance procedures, and cleanup and decontamination processes. Solids in this waste include paper, plastic, rubber, wood, metal pieces, and floor sweepings.

- **Principal nonradiological contaminants.** The principal nonradiological contaminant in this waste stream is lead.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Mn-54, Co-58, Co-60, Sr-90, Cs-137, and Ce-144.

- **Information sources reviewed and used.** Documents by Witbeck and Fryer (1979) and ANL-W (1973) were used, along with shipping records.

- **Assumptions and analysis.** The staging area for this waste stream, the truck lock building (ANL-765) was also the accumulation area for waste from other ANL-W buildings, especially after 1972. Although radionuclide distributions probably varied somewhat from building to building, the relative percentages of radionuclides were assumed to be constant throughout the waste stream. Radioactivity amounts reported by the information sources were almost always obtained by radiation readings on waste containers. Finally, personnel over the years reported the radioactivity to be principally MFP, so it was assumed that only 10% of the radioactive contaminants were MAP.

ANL-765-2H (FCF hot cell waste—principally subassembly hardware)

- **Generation of the waste stream.** This waste was generated during routine operations of hot cells. The waste was primarily subassembly hardware and other highly irradiated metal pieces. The waste also included a significant amount (approximately 25%) of dry active waste-type materials.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Mn-54, Co-58, Co-60, Sr-90, Cs-137, Cr-51, and Ce-144.

- **Information sources reviewed and used.** Documents by Witbeck and Fryer (1979) and ANL-W (1973) were used, along with shipping records.

- **Assumptions and analysis.** The relative percentages of radionuclides were assumed to be constant throughout the waste stream. Activities reported by the information sources were often obtained by radiation readings on waste containers. Sometimes, radionuclide profiles of hot cell waste were determined by analyses of smears. It is known from smear analysis that the radioactivity was mostly from MAP (70%). The remainder was assumed to be from the MFP radionuclides listed above.

ANL-785-1H (HFEF hot cell waste—principally subassembly hardware)

- **Generation of the waste stream.** This waste was generated during routine operations of hot cells. The waste was primarily subassembly hardware and other highly irradiated metal pieces. The waste also included dry active waste-type materials.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Mn-54, Co-58, Co-60, Cr-51, Sr-90, Cs-137, and Ce-144.

- **Information sources reviewed and used.** Documents by Witbeck and Fryer (1979) and ANL-W (1973) were used, along with shipping records.

- **Assumptions and analysis.** The relative percentages of radionuclides were assumed to be constant throughout the waste stream. Activities reported by the information sources were often obtained by radiation readings on waste containers. Radionuclide profiles of hot cell waste sometimes were determined by analyses of smears. It is known from smear analysis that the radioactivity was mostly from MAP (70%). The remainder was assumed to be from the MFP radionuclides listed above.

2.4.6 Rocky Flats Plant

The Generator. The RFP is located west of Denver, Colorado, and north of Golden, Colorado. It was one of DOE's nuclear weapons production facilities, but it recently ceased production activities. The RFP used specialized machine shops to process raw nuclear material into the finished components required by the warhead designs. Plutonium and beryllium components were fabricated into the shells of fissionable materials, called pits. Presently, the RFP mission is to disassemble the pits from retired weapons. The recovered plutonium is chemically processed to remove americium. Plutonium scrap recovery is also performed at the RFP.

Before 1960, the main plutonium purification process was dissolution followed by a solvent extraction step that used tributylphosphate as the solvent and dodecane as the diluent. The solvent extraction step was followed by cation exchange. Around 1960, solvent extraction was eliminated from the recovery process because the materials going through the process were becoming more and more varied and could not be adequately handled by the process. The solvent extraction process was replaced by dissolution in nitric acid followed by ion exchange and peroxide precipitation. The purified plutonium oxide was converted to plutonium fluoride and reduced to plutonium metal using calcium (ChemRisk 1992a). Other chemical processes, such as molten salt extraction, have also been used at the RFP.

A need to process americium arose because of a personnel exposure problem from its gamma ray emissions. From late 1957 until the late 1970s, americium was recovered and purified at the plant for resale. The demand for americium dropped off in the late 1970s, and the americium was processed as waste (ChemRisk 1992a).

Depleted uranium operations were a significant part of the original manufacturing performed at the plant. Operations included casting, machining, rolling, and forming. Alloying of depleted uranium with niobium began in 1966, although full-scale production did not occur until the early 1970s (ChemRisk 1992a). Depleted uranium, which contains less than 0.7% U-235 by mass, is rich in the U-238 radionuclide. The RFP depleted uranium is assumed to be material type U-12, which is comprised of 99.78% U-238, 0.215% U-235, 0.006% U-236, and 0.001% U-234 by mass according to the *Solid Waste Information Management System (SWIMS) Users Manual* (EG&G Idaho 1985a).

Enriched uranium, containing about 93% U-235 by mass, was processed at the RFP from 1952 to 1964. This concentration of U-235 is material type U-38, which is comprised of 93.08% U-235, 5.65% U-238, 0.93% U-234, and 0.34% U-236 by mass, according to EG&G Idaho (1985a). The

enriched uranium manufacturing processes included casting, forming, machining, assembly, recovery, and purification.

The enriched uranium chemical recovery line began operations in 1954. The chemical recovery used a solvent extraction process with dibutylethylcarbutol as the solvent and dodecane as the diluent. This process was similar to the early solvent extraction process used for plutonium recovery. A solvent still was operated at the plant, and some of the distilled solvent was reused. The discarded solvent and oils were drummed and later became part of the organic sludge waste stream. Enriched uranium operations were shut down in 1962 and left the plant in 1964 (ChemRisk 1992a).

Some U-233 was processed from the late 1950s to the early 1970s. The U-233 processing included casting, machining, aqueous processing, and separations (ChemRisk 1992a). Records indicate that the INEL received 56 g of U-233 as waste from the RFP in 1967 (Lee 1971). No details are currently available on this waste.

Generation of the Waste. All of the plutonium operations are carried out in enclosures that are operated under subatmospheric pressure to minimize uncontrolled releases of radioactive material into the operating area. These enclosures are called gloveboxes, and their ventilation systems pass through a high-efficiency particulate air (HEPA) filter system. Leaded rubber gloves are used to protect operations personnel from the gamma activity associated with the plutonium and americium.

The filters from the ventilation systems and the filters used in other systems eventually become waste. The leaded rubber becomes contaminated and also becomes waste. Some of the processes used produce liquid waste streams. These liquid streams are converted to a sludge or solid with adsorbents or cements. Contaminated equipment, clothing, and tools end up as radioactive waste. Waste is also generated by decontamination projects and modifications to facilities.

All radioactive waste from the RFP that was sent to the INEL from 1954 to 1970 was buried at the RWMC. Transuranic waste received after October 1970 has been stored aboveground at the TSA (Card 1977). Uranium waste from the RFP was received and buried at the RWMC through 1972. The uranium waste was not part of any of the plutonium waste streams. The plutonium waste contains varying amounts of americium, depending on the part of the process where the waste originated.

Thousands of small-scale releases and accidents were identified by the 1992 ChemRisk study. Many of the widely reported historical events are described in the ChemRisk (1992a, 1992b) reports. Some of these events, such as the 1957 fire in Building 771 and the 1969 fire in Buildings 776 and 777, slowed down or stopped waste generation by some parts of the manufacturing or recovery processes. However, waste generation was increased in the areas connected with cleanup after the accidents. Any changes in the amount of waste generated in a particular waste stream because of any of these accidents was not tracked. Any changed amount in the total volume of waste shipped each year (Lee 1971) because of a particular event is not available.

General Availability of Information. The information available on RFP waste buried at the RWMC is quite general. Tables I and II of a letter from the RFP (Lee 1971) provide an estimate of the volume of waste and the amount of plutonium, americium, and uranium radionuclides shipped annually to the RWMC from 1954 to 1970. Until now, this was the best available information on

RFP waste buried at the RWMC, but the reliability of the information on the activities of the radionuclides has long been questioned (e.g., Darnell 1981).

Recent information (Appendix C) based on RFP-wide mass balances has provided current best estimates of the total amount of plutonium, Am-241, and enriched uranium that was buried at the RWMC from 1954 to 1972. (TRU waste was not buried after 1970.) However, this information does not supply data on the nonradiological contaminants or the physical or chemical forms. No other documents are known that would supply this information on the buried waste from the RFP. Although some of the buried waste was retrieved in the Initial Drum Retrieval Program (McKinley and McKinney 1978) and the Early Waste Retrieval Program (Bishoff and Hudson 1979), the hazardous nature of the waste severely limited the information gained about its characteristics.

More specific information is available on the stored TRU waste received after 1970 from the RFP. The TRU waste information is related to RFP content codes, which differ from the RWMIS content codes. Examples of the information available on the stored RFP waste content codes are

- Average amount of plutonium and americium per waste container (Clements 1982)
- Average weight of each waste container (Clements 1982)
- Waste description, including how and where it was generated and how it was packaged (Clements 1982)
- Types and estimated quantities of nonradiological contaminants per container (Kudera 1989).

Data-Collection Approach. Because of the general lack of information (other than the amounts of plutonium, Am-241, and uranium) on the buried waste from the RFP, a unique approach was developed to provide estimates of the quantities of nonradiological contaminants and the physical and chemical form of all the contaminants. The approach is described below and is more complex than the approach used for the other generators.

A detailed description of how the stored waste was generated and packaged is available and allows a reasonable estimate of the physical and chemical form of the waste and the radiological and nonradiological contaminants. However, for the information on the RFP content codes to be useful as buried waste information, it must be related to how much of each RFP content code was buried. Therefore, the data-collection approach chosen involves adapting information on the stored waste to represent the corresponding parameters of the buried waste. Although the RFP grew in physical size over the years, the nature of the processes and the general types of materials used in these processes have remained largely the same since the 1950s (ChemRisk 1992a).

Information on 39 RFP-stored waste content codes that can be used to represent the RFP waste buried at the RWMC was assembled and entered into a separate database. The information on these stored waste content codes was combined, for similar content codes, into 14 buried waste streams. This combination of content codes into waste streams is based on the recommended waste form classifications at the INEL (Clements 1991). The content codes were combined as shown in Table 2-16.

Table 2-16. Combination of Rocky Flats Plant stored waste content codes to form plutonium buried waste streams.

Buried waste stream	Content codes for RFP stored waste
Benelex, plexiglas	464
Cemented sludges	004
Uncemented sludges	001, 002, 290
Combustibles	330, 336, 337, 900, 970
Concrete, brick	371, 960
Filters	335, 338, 360, 490
Glass	440, 441–442[a]
Glovebox gloves	463
Metals	320, 480, 481
Mixed waste[b]	950
Nonmetal molds and crucibles	300, 301, 370
Particulate waste	310, 311, 374, 375, 391, 393, 420, 421, 422, 425
Resins	430
Salts	410, 411

a. Content codes 441 and 442 have been combined on one data sheet.

b. This stream is a mixture of some of the other buried waste streams, such as combustibles, metals, and glass. The term is not used here in the usual sense of describing waste that is regulated under the Atomic Energy Act and RCRA.

The extrapolation of the stored waste data to make it apply to the 14 buried waste streams required a series of calculations. Table 2-17 summarizes the calculations used and helps describe the calculations. The letter designations from the blocks in Table 2-17 are included in the following descriptions for clarity.

When the stored waste content codes were combined to form the 14 buried waste streams, it was necessary to generate the following information:

- **B.a.** The total annual quantity "disposed of" for each hazardous chemical and each radionuclide in all of the plutonium-stored waste content codes that were combined to one waste stream.

- **B.b.** The ratio of the quantity of each hazardous chemical to the quantity of plutonium in each combined waste stream. This was obtained by dividing the quantity of each hazardous chemical derived in B.a. by the quantity of plutonium derived in B.a.

Table 2-17. Summary of calculations to convert Rocky Flats Plant stored waste data to buried waste data before 1970.

A. Stored waste content codes (CC) (after 1970)	B. Buried waste streams (BWSs) (1–14) (after 1970)		C. Buried waste streams (BWSs) (1–14) (before 1971)	D. Uranium buried waste streams (before 1973)
A.a. Sum the annual quantity "disposed of" for each hazardous chemical or each radionuclide (Part C or D of the data form) for each CC to be combined ——>	**B.a.** Quantity of each hazardous chemical or radionuclide in each BWS (after 1970)		**C.a.** Estimate of total plutonium and americium buried at the RWMC (Appendix C) (before 1971)	**D.a.** Total quantity of depleted uranium buried at the RWMC (Lee 1971; Litteer 1988) (before 1973)
	B.a.Pu. Quantity of plutonium in each BWS (after 1970)	C.a. × B.d. =	**C.b.** Total amount of RFP plutonium in each BWS (before 1971)	**D.b.** Estimate of total enriched uranium buried at the RWMC (Appendix C) (before 1973)
	B.a.Haz Chem Quantity of each hazardous chemical in each BWS (after 1970)	C.b. × B.b. =	**C.c.** Total amount of each hazardous chemical in each BWS (before 1971)	**D.c.** Estimate of total U-233 buried at the RWMC (Lee 1971) (before 1973)
$\frac{\text{B.a.HazChem}}{\text{B.a.Pu}}$ =	**B.b.** Ratio of each hazardous chemical to plutonium in each BWS (after 1970)	Σ_{1}^{14} C.c. =	**C.d.** Sum of the quantities of each hazardous chemical in all of the BWSs (before 1971)	
Σ_{1}^{14} B.a.Pu =	**B.c.** Sum of the quantities of plutonium in all of the BWSs (1–14) (after 1970)			
B.a.Pu/B.c. =	**B.d.** Fraction of plutonium in each BWS (after 1970)			

To extrapolate the stored waste data to the waste that is buried at the RWMC, a plutonium percent of each of the combined waste streams must be obtained (B.d.). This was calculated by dividing the total average annual quantity of plutonium "disposed of" for a buried waste stream (B.a.Pu) by the combined average annual quantity of plutonium "disposed of" for all waste streams (B.c.). This provided the average plutonium percent of a buried waste stream expressed as a decimal fraction. This calculation was performed for each buried waste stream. The total of the average plutonium percents for all 14 buried waste streams is 100%.

The extrapolation was then made by multiplying the average percent, as a decimal fraction, B.d., of each waste stream by the estimate of the total quantity of plutonium shipped from the RFP before 1971 (C.a.). This provided the total amount of plutonium in each waste stream shipped to the RWMC before 1971 (C.b.). For information, the best estimate of the total amount of plutonium, americium, and enriched uranium (predominantly U-235) buried at the RWMC (from Appendix C) is shown in Table 2-18 in terms of kilograms.

The total quantity of each hazardous chemical for each buried waste stream before 1971 (C.c.) was obtained by multiplying the total amount of plutonium in each buried waste stream (C.b.) by the ratio of the quantity of each hazardous chemical to the quantity of plutonium in each combined waste stream (B.b.). The quantity of each hazardous chemical in all of the buried waste streams (C.d.) was obtained by calculating the total of all of the quantities derived in C.c.

For two other plutonium buried waste streams, sufficient information was available to characterize the streams directly, rather than by using the indirect method just described. These streams are discussed below. In addition, three uranium buried waste streams do not contain any data on nonradiological constituents because of a lack of information. Finally, a nonplutonium-nonuranium waste stream, consisting of a few drums containing radiation sources, is discussed.

Organic Sludge—Organic chemicals used as degreasing agents and for other processes were stored at the RFP for several years because there was no method for processing them into an acceptable waste form. A process to convert the organic chemicals into a sludge was developed. The first drums of this content code, 003 Organic Sludge, were shipped to the RWMC in 1966. The backlog of stored organic chemicals was processed and shipped to the RWMC over the next 3 years. This has been a continuous waste stream since that time.

Table 2-18. Best estimates and upper bounds of Rocky Flats Plant plutonium, americium, and enriched uranium (mass at time of disposal) buried at the Radioactive Waste Management Complex.

Radionuclide	Best estimate (kg)	Upper bound (kg)
Plutonium	1,102	1,455
Am-241	44	58
Enriched uranium	386	603

Detailed annual data were available on this waste stream. The waste stream was buried at the RWMC only from 1966 through October 1970. Therefore, it was decided to enter the data directly as a buried waste stream; the above extrapolation technique does not apply to this waste. This approach artificially increases, slightly, the total amount of plutonium that is estimated to have been buried (Appendix C). However, the amount of the difference is very small compared with the total amount of plutonium shipped from the RFP to the RWMC.

Evaporator Salts—Liquid effluents from the second stage of treatment of aqueous process waste and all other plant-generated liquid waste not requiring treatment were concentrated in solar evaporation ponds. The liquid was then pumped from the ponds to an evaporator, concentrated, and dried to form a salt residue. The salt residue was packaged in 55-gal drums. The first drums of this evaporator salt, content code 005, were shipped to the RWMC in 1967. This waste was not considered TRU waste because the concentration of the TRU radionuclides was normally less than 10 nCi/g. It was buried through 1972. This evaporator salt waste was then placed on Pad A through 1978, when its shipment to the INEL was halted. The Pad A waste is addressed here as if it were from a separate waste generator and is included in the data for this report. Therefore, these salt waste data cover only the years from 1967 through 1972.

As discussed in Section 2.4.8, the waste disposed of on Pad A (which received waste from 1972 through 1978) was addressed separately from the other waste disposed of in the HDT, regardless of the generator that produced the Pad A waste.

Specific data on the number of evaporator salt drums received from 1967 through 1970 are available in a letter from T. L. Clements to J. D. McKinney (Clements 1980a). The evaporator salt drums received in 1971 and 1972 were buried in Pits 11 and 12. The number of evaporator salt drums in these pits is available in the *Initial Drum Retrieval Final Report* (McKinley and McKinney 1978). Specific details on the composition of the salt waste were taken from the Clements (1982) report. Some additional information on the composition of the salt waste was obtained from a Pad A report (Halford et al. 1993). This information was combined and reported as a buried waste stream.

Uranium Waste Streams—There are three uranium waste streams: the depleted uranium waste stream, the enriched uranium waste stream, and the U-233 waste stream.

The quantity of depleted uranium (primarily U-238 by mass) that was shipped from the RFP to the RWMC from 1954 through 1970 was obtained from Table II of the RFP letter of 1971 (Lee 1971). Detailed characteristics of this depleted uranium waste stream are not available. The RWMIS database (Litteer 1988) indicates that the RFP sent waste containing depleted uranium to the RWMC until 1972. The depleted uranium data from RWMIS were used for 1971 and 1972. This total for depleted uranium is the quantity derived in D.a. of Table 2-17.

The best estimate of the total amount of enriched uranium buried from 1954 to 1972 was obtained from Appendix C and is shown in Table 2-18. This total is the quantity represented by D.b. in Table 2-17. Detailed characteristics are not available.

The best estimate of the total amount of U-233 (which was received only in 1967) was obtained from Lee (1971). This total is the quantity represented by D.c. in Table 2-17. Detailed characteristics are not available.

Radiation Sources Waste Stream—Between 1965 and October 1970, the RFP shipped 31 radiation sources to the INEL for burial. The information on shipment of these radiation sources was taken from an engineering design file (Clements and Darnell 1994) that documented the shipments form 1965 through 1979. Most of these radiation sources were shipped in drums of other RFP waste streams. Therefore, this stream does not add any volume to that buried in the SDA. The total activity of the radionuclides in this waste stream is very small compared with the totals buried in the SDA. The radiation sources disposed of in the SDA from the RFP are Co-60, Cs-137, H-3, radium/beryllium neutron sources, and Ra-226 from gauges. These radiation sources also contribute some lead and beryllium to the nonradiological contaminants shipped from the RFP to the INEL.

Description of Waste Streams. With the addition of the organic sludge, evaporator salts, three uranium streams, and a radiation sources stream, there are 20 buried waste streams from the RFP. Table 2-19 provides a list of all of the buried waste streams.

The 13 most important waste streams from the RFP are discussed in detail below. Each of the following waste stream summaries describes how the stream was generated and the principal radiological and nonradiological contaminants of the stream.

Detailed information on the data-collection approach chosen, the analysis performed, and the assumptions used to arrive at the stated values is provided in this section under the heading "Data-Collection Approach." Data on the first 14 waste streams were arrived at by extrapolating information on stored waste from the RFP. The amount of plutonium and americium in each container and the method of generating the waste were taken from the stored waste information in the Clements (1982) report. The quantities of nonradiological contaminants that were calculated from the extrapolation procedure were derived by using information from the Kudera (1989) report. The information available for the other six waste streams (organic sludge, evaporator salts, uranium, and radiation sources waste streams) is provided in the applicable waste stream summary.

RFO-DOW-3H (Uncemented sludges)

- **Generation of the waste stream.** Wet sludge was produced by precipitation of aqueous process waste, such as ion-exchange effluent, distillates, and caustic scrub solutions. For the sorption of free liquids, Portland cement was added on top of the wet sludge in the drum, but a monolith did not result.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, Pu-241, and Am-241.

  Because most of this waste was generated by hydroxide precipitation, it is expected that the plutonium and americium exist as hydrated oxides, such as $PuO_2 \cdot 2H_2O$. If the sludge is dried, it would be expected to lose some or all of the water of hydration and exist as the oxide.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this stream are methylene chloride and 1,1,2-trichloro-1,2,2-trifluoroethane (Freon).

Table 2-19. Waste streams originating at the Rocky Flats Plant.

Waste stream number	Description of waste
RFO-DOW-1H	Benelex and plexiglass
RFO-DOW-2H	Cemented sludges
RFO-DOW-3H	Uncemented sludges
RFO-DOW-4H	Paper, rags, plastic, clothing, cardboard, wood, and polyethylene bottles
RFO-DOW-5H	Concrete, brick
RFO-DOW-6H	Filters
RFO-DOW-7H	Glass
RFO-DOW-8H	Glovebox gloves
RFO-DOW-9H	Glove boxes, equipment (bottles, drill presses, etc.) pumps, motors, control panels, and office equipment
RFO-DOW-10H	Conduit, pipes, control panels, office equipment, and glass
RFO-DOW-11H	Nonmetal molds and crucibles
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot
RFO-DOW-13H	Resins
RFO-DOW-14H	Salts
RFO-DOW-15H	Organic sludge
RFO-DOW-16H	Depleted uranium
RFO-DOW-17H	Evaporator salts
RFO-DOW-18H	Enriched uranium
RFO-DOW-19H	U-233
RFO-DOW-20H	Radiation sources

The methylene chloride was used at the plant as a paint stripper. It was estimated to be present in this waste stream at a level of about 700 ppm. The Freon was used for the degreasing of metal. It was estimated to be present in this waste stream at a level of about 100 ppm.

RFO-DOW-4H (Combustibles)

- **Generation of the waste stream.** This stream consists of combustible materials such as paper, rags, plastics, cloth coveralls and booties, cardboard, wood, and polyethylene. Some of the waste was packaged in a damp or moist condition. This waste was generated during cleanup or normal operations and maintenance.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, Pu-241, and Am-241.

  The plutonium and americium in this waste are normally expected to be in oxide form. However, nitrates may be present on some of the damp or moist combustibles.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this stream are methylene chloride, 1,1,2-trichloro-1,2,2-trifluoroethane (Freon), carbon tetrachloride, and 1,1,1-trichloroethane.

  The methylene chloride was used at the plant as a paint stripper. It was estimated to be present in this waste stream at a level of about 750 ppm. The Freon, carbon tetrachloride, and 1,1,1-trichloroethane were used for the degreasing of metal. Freon was estimated to be present in this waste stream at a level of about 1,500 ppm, carbon tetrachloride at about 750 ppm, and 1,1,1-trichloroethane at about 2,000 ppm.

RFO-DOW-6H (Filters)

- **Generation of the waste stream.** This stream consists of asbestos or fiberglass filters in wood or aluminum frames and asbestos-type insulation, gloves, and fireblankets. Some Chemical Warfare Service (CWS)-type cylindrical filters are also in this waste stream. The waste was generated during normal operations, maintenance, and cleanup.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, Pu-241, and Am-241.

  Most of the plutonium and americium in this waste is expected to be in oxide form. However, nitrates may be present on the CWS filters.

RFO-DOW-7H (Glass)

- **Generation of the waste stream.** This stream consists of glass in the form of sample vials and bottles; lead-taped sample vials; ion-exchange columns; dissolver pots; laboratory glassware; glovebox windows (glass, plexiglas, or leaded glass); crushed or ground glass;

and borated raschig rings. The raschig rings were used in liquid storage tanks to minimize neutron multiplication and, therefore, reduce the chances of an accidental criticality.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, and Pu-241.

  Most of the plutonium in this waste stream is expected to be in the form of plutonium oxide. Some of the raschig rings and other glass types may have been exposed to plutonium nitrates, but the small amounts have probably been oxidized because of exposure to air.

RFO-DOW-8H (Glovebox gloves)

- **Generation of the waste stream.** This stream consists of glovebox gloves and aprons made from leaded rubber. The leaded rubber was used as shielding to minimize the exposure of workers to radiation.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, and Pu-241.

  Most of the plutonium in this waste is expected to be in the form of plutonium oxide. Some of the glovebox gloves may have been exposed to plutonium nitrates, but the small amounts have probably been oxidized because of exposure to air.

- **Principal nonradiological contaminants.** The principal nonradiological contaminant in this stream is lead. The lead is present as leaded rubber in glovebox gloves and aprons.

RFO-DOW-9H (Metals)

- **Generation of the waste stream.** This stream consists of metal waste such as gloveboxes, furnaces, lathes, ducting, motors, electronic equipment, power tools, hand tools, metal crucibles, and metal office equipment. The waste was generated from normal plant operations, maintenance work, and cleanup and renovation projects.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, and Pu-241.

  The plutonium in this waste is normally expected to be in the form of plutonium oxide. However, plutonium metal is probably the predominant composition of the plutonium on the metal crucibles.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this waste stream are methylene chloride, 1,1,2-trichloro-1,2,2-trifluoroethane (Freon), and lead.

  The methylene chloride was used at the plant as a paint stripper and was estimated to be present in this waste stream at a level of about 200 ppm. The Freon was used for the

degreasing of metal and was estimated to be present in this waste stream at a level of about 75 ppm. The lead is present mostly as shielding in gloveboxes and was estimated to be present at a level of about 2,000 ppm.

RFO-DOW-11H (Nonmetal molds and crucibles)

- **Generation of the waste stream.** This stream consists of graphite molds used in casting plutonium metal and small silicate-based ceramic crucibles used for chemical analysis of the carbon content of plutonium metal.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, and Pu-241.

  The plutonium in this waste is expected to be in the form of plutonium metal. There could be some oxide coating on the metal.

RFO-DOW-12H (Particulate waste)

- **Generation of the waste stream.** This stream consists of significant quantities of dispersible fines. The waste was generated from graphite crucibles, magnesium oxide crucibles, blacktop, concrete, dirt, and some wet combustible waste that contains noncombustible Oil-Dri.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Pu-238, Pu-239, Pu-240, Pu-241, and Am-241.

  Most of the plutonium and americium in this waste is expected to be in oxide form. Initially, very small pieces of plutonium metal may have existed on the crucibles, but they have probably been oxidized because of exposure to air.

- **Principal nonradiological contaminants.** The principal nonradiological contaminant in this stream is methylene chloride.

  The methylene chloride was used at the plant as a paint stripper. It was estimated to be present in this waste stream at a level of about 700 ppm.

RFO-DOW-15H (Organic sludge)

- **Generation of the waste stream.** This stream was produced from treatment of liquid organic waste generated by various plutonium and nonplutonium operations. The organic waste was mixed with calcium silicate to form a grease or paste-like material. No chemical reaction within the waste is expected to change the form of any of the organic constituents. Small amounts of Oil-Dri absorbent were usually mixed with the waste.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this waste stream are trichloroethene (trichloroethylene), carbon tetrachloride, 1,1,1-trichloroethane, and tetrachloroethene (tetrachloroethylene or perchloroethylene).

The carbon tetrachloride was mixed with Texaco Regal oil and used as a lathe coolant for the machining of plutonium. The 1,1,1-trichloroethane, trichloroethene, and tetrachloroethene were all used for the degreasing of metal.

- **Information sources reviewed and used; assumptions and analysis.** The quantities of carbon tetrachloride in this waste stream were obtained by a review of the RFP Waste Management monthly reports for the appropriate time periods (Kudera 1987). These monthly reports contained data on the amount of lathe coolant (which was 40% carbon tetrachloride and 60% Texaco Regal oil) received for processing each month. These reports also listed the total volume of used oil, 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene that was received by the waste treatment facility each month. However, no information was available to allow a further breakdown of the individual quantities of each of these chemicals.

  Because the quantities of these "other organics" are substantial, it is desirable to provide a best estimate of the individual amounts. ChemRisk (1992a) discusses the uses of these organics at the RFP and also provides annual quantities in a 1974 RFP harmful materials inventory. To estimate the quantities of 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene in this volume of "other organics," it was conservatively assumed that no used oil was present. It was also assumed that the ratios of 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene in this "other organic" were the same as their ratios in the 1974 harmful materials inventory at the RFP (ChemRisk 1992a). Because this method provides only an estimate of the relative amounts of each of the volatile organic compounds in the volume of "other organics," the percentages of each were rounded to 45%, 45%, and 10% when making the best estimates.

RFO-DOW-16H (Depleted uranium); RFO-DOW-18H (enriched uranium); RFO-DOW-19H (U-233)

- **Generation of the waste stream.** Depleted uranium operations consisted of casting, machining, rolling, and forming. The enriched uranium operations included recovery and purification processes in addition to the casting, forming, and machining. The main part of the purification was by a solvent extraction process. The RFP also reported sending 56 g of U-233 to the INEL in 1967 (Lee 1971). It is assumed that this U-233 was not mixed with the depleted or enriched uranium waste streams.

- **Principal radiological contaminants.** The principal radiological contaminants in the depleted uranium (approximately 0.2% U-235 by mass) waste stream are U-238, U-234, U-235, and U-236. These calculations are based on the mass fractions for the radionuclides in material type U-12 from the (EG&G Idaho 1985a).

  The principal radiological contaminants in the enriched uranium (approximately 93% U-235 by mass) waste stream are U-234, U-235, U-236, and U-238. The calculated compositions are based on the mass fractions for the radionuclides in material type U-38 from EG&G Idaho (1985a).

  The principal radiological contaminant in the U-233 waste stream is U-233 (Lee 1971).

RFO-DOW-17H (Evaporator salts)

- **Generation of the waste stream.** This waste stream consists of dried salt residue that was formed from concentrated evaporator sludge. Liquid effluents from the second stage of treatment of aqueous process waste and all other plant-generated liquid waste not requiring treatment were concentrated in solar evaporation ponds. The liquid was then pumped from the ponds to an evaporator, concentrated, and dried to form a salt residue. The approximate chemical makeup of the salt is 60% sodium nitrate, 30% potassium nitrate, and 10% miscellaneous.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this waste stream are sodium nitrate and potassium nitrate.

  The liquid effluents that were fed to this waste stream usually were dilute nitric acid solutions. The solutions that contained above-discard levels of plutonium were made basic with caustic solution to precipitate the plutonium as the hydroxide. The effluent from this precipitation contained sodium and potassium from the caustic solution and nitrate from the nitric acid solution. The concentration and evaporation of these solutions formed the sodium and potassium nitrates.

With the exception of the radiation sources waste stream, RFP waste does not contain activation products or fission products, so terms such as MAP and MFP are not encountered in the records for RFP waste.

2.4.7 Other Generators

The Generators. The remaining generators are referred to here as the "other generators." They include both offsite and other onsite (INEL) generators, and they contributed less than 10% of the volume of waste disposed of in the SDA.

Onsite generators (see Figure 2-1) include minor INEL contributors, such as the Auxiliary Reactor Area (ARA), CFA, D&D activities, PBF/Power Excursion Reactor facility (PER), and the RWMC itself as a waste generator.

ARA is located in the south-central part of the INEL and consists of four main areas: ARA-I, ARA-II, ARA-III, and ARA-IV. These areas were collectively called the Army Reactor Area until 1965, when the Army's programs at the INEL were phased out. ARA was originally built to house and support the SL-1 reactor, the Army Gas-Cooled Reactor Experiment (GCRE), and the ML-1 reactor. By the mid-1980s, D&D of some of the facilities was in progress, and the remainder of the facilities were essentially closed.

CFA is also located in the south-central portion of the INEL. Some of the facilities in use at CFA were built in the 1940s and 1950s to support and house Naval Gunnery Range personnel. These facilities have been modified continually over the last 40 years to meet the changing needs of the INEL. CFA currently operates as a centralized location to support the other INEL facilities, including administrative support, service shops, sanitary landfill, warehousing, security support, laboratory services, training, medical services, and receiving and storage.

The D&D of INEL nuclear facilities has been in progress as a separate function since 1975. D&D programs that contributed waste to the SDA through 1983 include D&D of the Army Re-Entry Vehicle site; the Boiling Water Reactor Experiment (BORAX)-V reactor area; the IET Facility; the LOFT reactor area; the Organic Moderated Reactor Experiment Facility; the S1-G reactor vessel; the Special Power Excursion Reactor Test (SPERT)-IV reactor building; and underground tanks, a liquid waste evaporator system, and a concrete pad at TAN.

The PBF area is located approximately 10 km (6 mi) northeast of CFA. This area originally contained reactors constructed for the SPERT experiments. Four SPERT reactors were built beginning in the late 1950s as part of an early investigation involving reactor transient behavior tests and safety studies on water-moderated, enriched-fuel reactor systems. All of the reactors have been removed, and most of the facilities have undergone D&D. The last of these reactors was placed on standby status in 1970. PBF began operations in 1972. PBF presently consists of the PBF reactor area (north of SPERT-I), PBF control area, Waste Engineering Development Facility (at the SPERT-II site), Waste Experimental Reduction Facility (at the SPERT-III site), and Mixed Waste Storage Facility (SPERT-IV).

The RWMC was established at the INEL in 1952 to accommodate the radioactive waste generated by laboratory operations. Minimal amounts of waste were generated directly by the RWMC and disposed of in the SDA. The waste consisted primarily of effluents from the decontamination of shipping and transportation equipment.

Offsite generators (other than the RFP) consisted primarily of commercial and government LLW generators that shipped waste to the SDA during the 4-year period from 1960 to 1963. During this period, the RWMC was designated by the AEC, predecessor agency to DOE, as a national disposal site for licensees that generated LLW. These generators are listed in Table 2-20.

Generation of the Waste. The other generators predominantly disposed of scrap metals and combustible materials that were radiologically contaminated. A variety of waste streams and processes were identified that contributed minor volumes of waste to the SDA. More than 100 waste streams have been identified for these generators. As many as six processes may have contributed waste to any one stream. Because these generators contributed less than 10% by volume of the overall waste to the SDA, it would be inappropriate to attempt to discuss each process in detail. Therefore, the discussions of the waste generation processes from these generators are general. Waste streams and associated processes that contribute significantly to the overall waste inventory are discussed in more detail.

Waste from ARA consisted primarily of radioactive contaminants from the short-term production and operation of the Army GCRE, the ML-1 reactor, the SL-1 reactor, and the radiochemistry laboratory. Solvents, thinners, acids, and mineral oils were routinely used, and waste was generated. However, all available information indicates that the nonradiological contaminants from ARA were not disposed of in the SDA.

Waste from CFA is from several facilities, past and present, including the CFA laundry, machine shops, maintenance shops, lead shops, laboratory facilities, sewage treatment facilities, and Radiological and Environmental Sciences Laboratory (RESL). Radioactive waste from CFA typically

Table 2-20. Commercial and government offsite generators who shipped waste to the Subsurface Disposal Area.[a]

American Electronics, Inc., Los Angeles, California
Atlas Foundry and Machine Co., Tacoma, Washington
Atomics International, Canoga Park, California
Babcock & Wilcox Co., Nuclear Facilities, Lynchburg, Virginia
Birdwell Division of Seismograph Services Corporation, Tulsa, Oklahoma
California Salvage Co., San Pedro, California
Colorado School of Mines, Research, Golden, Colorado

Dugway Proving Ground, Dugway, Utah
Fort Douglas, Utah, Commanding Officer, Salt Lake City, Utah
Fort Lewis, Washington, Commanding General Fourth Infantry Division, Washington
General Dynamics/General Atomics Division, San Diego, California
General Dynamics, Fort Worth, Texas
General Electric Co., Vallecitos Atomic Laboratory, Pleasanton, California
Department of Health, Education, and Welfare, Radiological Health Public Health Service, Washington, D.C.
Isotope Specialties Co., Burbank, California

Industrial X-Ray Engineers, Seattle, Washington
Laboratory of Nuclear Medicine and Radiological Biology, University of California, Los Angeles, California
Lawrence Radiation Laboratory, University of California, Berkeley, California
Marine Corporation Supply Center, Barstow, California
Memorial Hospital of Sheridan County, Sheridan, Wyoming
Metallurgical Engineers, Inc., Portland, Oregon
Nuclear Engineering Co., Pleasanton, California

Nuclear Power Field Office, Fort Belvoir, Virginia
Oregon Metallurgical Corporation, Albany, Oregon
PM-1 Nuclear Power Plant, Sundance AFS, Sundance, Wyoming
SAAMA, Kelly Air Force Base, Texas
Sacramento Signal Depot, Commanding General, Sacramento, California
Thiokol Chemical Corporation, Brigham City, Utah
U.S. Army Chemical Center, Maryland
U.S. Bureau of Mines, Albany, Oregon

U.S. Army Edgewood Arsenal, Maryland
U.S. Naval Radiological Defense Laboratory, San Francisco, California
University of Utah, Radiobiology Division, Department of Anatomy, Salt Lake City, Utah
University of Washington, Radiological Safety Division, Seattle, Washington
USARAL Support Command and Fort Richardson, Seattle, Washington
U.S. Nuclear Corporation, Burbank, California
Wah Chang Corporation, Albany, Oregon
Washington State University, Pullman, Washington

a. Other minor offsite generators that contributed waste to the SDA include Argonne National Laboratory-East from 1980 to 1983 and Battelle Northwest Laboratories in 1983.

includes contaminated combustibles, scrap metal, and nuclear radiation sources. Nonradiological contaminants from CFA were not routinely disposed of in the SDA.

Waste generated by D&D programs consists primarily of surface-contaminated metal, lumber, and soils. D&D operations concentrate on the dismantling and decommissioning of buildings and building components.

The PBF area contributed radioactive waste to the SDA from operations associated with the four SPERT reactors. This waste consisted primarily of metals, combustibles, and core and loop components. Minor volumes of nonradiological waste (solvents, resins, cleaning solutions, and acids) were included with waste shipments to the SDA.

Waste from the RWMC was generated over a 7-year period and consists primarily of radiologically contaminated materials (combustibles, soil, and plastic) associated with decontamination processes at the RWMC.

Commercial and government offsite generators contributed waste primarily as a result of radiological research. These contaminants in the waste were predominantly radionuclides with short half-lives. Nonradiological contaminants are not well documented, and they consist primarily of solvents and cleaning solutions.

ANL-E waste is from programs including fundamental research in physical, biomedical, and environmental sciences and from energy research and development.

Battelle Northwest Laboratories (BNL) waste is from radionuclide research and plutonium studies. Only one shipment from BNL was received, and it occurred during 1983.

General Availability of Information. Information concerning waste streams from the other generators is limited to a few reports that often do not describe the processes that generated the waste. This is particularly true for nonradiological contaminants in the waste and for the physical and chemical forms.

Information concerning types and volumes of waste was derived from several types of sources. These sources included process information, previous reports, shipping records, waste disposal practices, interviews with personnel familiar with waste streams from the other generators, and the process knowledge of data gatherers familiar with specific facilities and their waste streams.

For the various generators, the sources of information listed in Table 2-21 were used.

Additional related reports that were reviewed but not used include Arrenholz and Knight (1991), Dolenc (1980), EG&G Idaho (1985b), McCusker (1986), Plansky and Hoiland (1992), Smith (1978), Smith and Hine (1982), and Yrene and McCusker (1986). These reports were not used, either because the data included in the reports were also included in the reports listed in Table 2-21 or because the reports do not contain useful data for this evaluation.

Data-Collection Approach. The data-collection approach taken to evaluate the other generators involved the following steps. Available reports discussing radiological and nonradiological

Table 2-21. Sources of information used for the other generators.

Generator	Documents	Additional sources
ANL-E	Kee (1982)	Shipping records
ARA	EG&G Idaho (1986)	Shipping records, interviews
BNL	—	Shipping records, interviews
CFA	EG&G Idaho (1986), Hiaring (1993)	Shipping records, interviews
D&D programs	Hine (1980), Huntsman (1979), Schoonen (1984), Smith (1979), Smith (1980), Smith (1983)	Shipping records, interviews
LOFT	EG&G Idaho (1986)	Shipping records, process information
Offsite generators	Clements (1979), Clements (1980b)	Shipping records
PER/PBF	EG&G Idaho (1986)	Interviews, shipping records, process information
RWMC	EG&G Idaho (1986)	Interviews, shipping records

waste generation information, waste disposal practices, and facility process information were reviewed. RWMIS printouts were obtained by generator (for offsite generators) or building number (for INEL facilities). The original shipping manifests were located for each shipment and compared against RWMIS and the reports. Personnel familiar with the waste generation process were interviewed. For example, operator interviews were used to obtain additional waste stream information for many of the CFA and PBF/PER generators. Past facility experience and process knowledge were used, in part, for determining waste streams at ARA and LOFT. Discrepancies in data collected from more than one source were identified and discussed. For generators producing very small waste volumes or activities, including BNL and many of the CFA generators, the evaluation was based only on shipping records.

For MAP and MFP entries, the assumed radionuclide breakdown varied by waste stream. Unidentified beta-gamma and unidentified alpha entries were extremely small in radioactivity.

Description of Waste Streams. The waste from the other generators was divided into 111 streams (see Table 2-22).

The 12 most important waste streams from the other generators are discussed here. For each of these streams, the discussion tells how the stream was generated, the principal contaminants in the stream, the specific information sources reviewed and used, and the assumptions and analysis used to estimate the quantities of the contaminants.

Table 2-22. Waste streams originating from other generators.

Waste stream number	Description of waste
ALE-ALE-1H	Building rubble, electric wires, piping, machinery, radioactive tracers and sources, glass, gloves, paper, filters, and vermiculite
ARA-601-1H	One each, Davis water filter units
ARA-602-1H	Waste from the SL-1 cleanup: a 1,000-gal tank, a demineralizer with resin, various building materials, pipes, soil, wire, concrete, insulation, etc.
ARA-602-2H	Low levels of items listed as "scrap" and "rad waste not otherwise specified (NOS)" that were taken from the ML-1 site during cleanup. There is a small amount of paper and wood.
ARA-602-3H	Hot cell waste consisting of some fuel residue. Some metals (copper, cadmium, stainless steel, and aluminum); some soil; HEPA filters; and cleanup supplies (rags, paper, mops, etc.).
ARA-606-1H	Contaminated soil and scrap building material
ARA-607-1H	Depleted uranium and U-238 milling chips
ARA-608-1H	<0.1 Ci UO_2; tank, pump, valves, gauges, wire scrap metal, sludge NOS, concrete masonry, and asphalt gravel
ARA-616-1H	ML-1 and GCRE waste consisting of various scrap metals (stainless steel, silver, aluminum, iron, potassium, and lead); resin; burnables; sludge; and some boric acid crystals
ARA-626-1H	Some fuel scraps, waste from disassembly of facilities, and hot cell waste
ARA-627-1H	Plastic bags, brick, HEPA filters, scrap, glove boxes, and fuel (U-235 and U-238)
BNL-BNL-1H	Primary operations at BNL involved producing plutonium from U-238 *(no other information available)*
CFA-601-1H	Miscellaneous scrap metal, gas cylinders, lead batteries, insulated wire, glass, soil, aluminum, beryllium, cadmium, and general cleanup waste

Table 2-22. (continued).

Waste stream number	Description of waste
CFA-605-1H	Lead slag/floor sweepings. One metal hood, some stainless steel and some plastic vials containing graphite. There is some natural and some depleted uranium alloyed with aluminum and zirconium.
CFA-606-1H	One safe from AEC security and some metal samples that were found on the shuttle bus
CFA-609-1H	1.1 m^3 (40 ft^3) of contaminated lumber and one camera
CFA-610-1H	Undershirt, two pairs of pants, hat, shirt, and lunchbox. Also, mercury batteries and contaminated mud.
CFA-611-1H	Miscellaneous items: radios and other items confiscated as a result of a security investigation
CFA-613-1H	Soil and paper
CFA-616-1H	Soil from auger sampling
CFA-617-1H	Plastic, paper, and rags
CFA-626-1H	Unknown—MFP
CFA-633-1H	Basic trash—metal, wood, gravel, sand, etc.
CFA-638-1H	Two shielded casks with a Co-60 source in each
CFA-639-1H	Wood and metal scrap with beryllium contamination
CFA-640-1H	Machine shop waste (various types of metal chips and cleanup materials). Batteries and a cabinet from SL-1. Some stainless steel and some lead. (The batteries from SL-1 contained acid.)
CFA-646-1H	Radioactively contaminated combustibles (paper, cloth, wood, etc.)
CFA-646-2H	HF and HNO_3 liquid waste
CFA-649-1H	Waste NOS

Table 2-22. (continued).

Waste stream number	Description of waste
CFA-654-1H	Scrap metals (steel, beryllium, and lead); zirconium; depleted uranium; sewer sludge; machine coolant; two radium sources; weeds; and combustibles (paper, rags, etc.)
CFA-659-1H	Plastic and cloth
CFA-660-1H	Metal, wood
CFA-665-1H	Two truck beds, three trailers, one forklift, one straddle carrier, some tires and wheels, an air compressor, and some wood
CFA-666-1H	U-235, contaminated waste from simulated fire
CFA-666-2H	Depleted uranium turnings in mineral oil
CFA-667-1H	Clothing, plastic bags, and sweepings
CFA-667-2H	Contaminated lead
CFA-669-1H	Combustibles, dirt
CFA-674-1H	Laboratory waste contaminated with P-32, U-235, and U-238; excess property (furniture, machinery, valves, boxes, wire, and filters); and combustible waste
CFA-683-1H	Contaminated crane, two pickups, tanker, trailer, traveler wheels, scrap metal, and some wood
CFA-684-1H	Irradiated steel specimens, rags, paper, plastic bags, and some graphite
CFA-685-1H	Metal, paper, and cloth (oil soaked)
CFA-687-1H	Scrap metal and lead
CFA-690-1H	Combustibles, animal carcasses and feces, scrap metal, sources, sand, and gravel
CFA-691-1H	Sewage plant sludge, plant waste, wood, and metal
CFA-698-1H	Beryllium samples that were contaminated by ATR, primary coolant

Table 2-22. (continued).

Waste stream number	Description of waste
CFA-766-1H	Sludge tank sludge, soil, piping, cans, and wood
CFA-CFA-1H	Laundry waste, general plant waste, graphite, stainless-steel tubes and samples, Mark 'B7 specimens, rubber fabric hose, and some steel backhoe parts
CFA-EBR-1H	Contaminated soil, concrete, bricks, piping, components, metal scrap, rags, mops, filters, wooden pallets, and plastic wrapping
CFA-EFS-1H	Contaminated sod, wood, and blotting paper
CFA-ZPR-1H	Various rip-out materials, including contaminated tubing, a uranium film sampler, structural metals, concrete, rags, paper, and plastic
D&D-ARV-1H	Wood and scrap metal
D&D-BOR-1H	Soil
D&D-IET-1H	Heat exchangers, pump cases, pump diffuser, and impeller
D&D-LOF-1H	Cloth, paper compactibles
D&D-LOF-2H	Paper, poly, rags
D&D-LOF-3H	Paper, cloth, compactibles
D&D-OMR-1H	Metal, concrete, soil
D&D-S1G-1H	Decontaminated reactor vessel and processing equipment, components, and piping
D&D-SPT-1H	Piping, tanks, valves
D&D-TAN-1H	PM-2A underground tanks, PM-2A liquid waste evaporator system, and TSF-3 concrete pad
LOF-650-1H	Combustibles (paper, cloth, wood, etc.)
OFF-AEF-1H	Scrap metal, combustibles, glass, concrete
OFF-AEI-1H	Radiation sources, laboratory waste, and solidified Ce-144/Cl_3 solution

Table 2-22. (continued).

Waste stream number	Description of waste
OFF-AFM-1H	Co-60 source
OFF-ATI-1H	Irradiated fuel and chemical byproducts from nuclear reactor research
OFF-BWC-1H	Empty stainless-steel fuel rods
OFF-BWD-1H	Miscellaneous laboratory equipment
OFF-CSC-1H	Laboratory equipment and animal carcasses and feces
OFF-CSM-1H	Magnesium fluoride slag with 1% natural uranium, steel metallic salts and silicates, miscellaneous laboratory waste
OFF-DPG-1H	Animal waste and laboratory waste
OFF-FLW-1H	Radioactive electronic tubes
OFF-GDA-1H	Fuel fabrication items, laboratory equipment, activated metal, and irradiated fuel
OFF-GDW-1H	Waste NOS
OFF-GEC-1H	Core, reactor vessel, and loop components
OFF-GEO-1H	Waste NOS
OFF-HEW-1H	Radium-contaminated laboratory waste
OFF-ISC-1H	Magnesium-thorium scrap, laboratory equipment, and sources
OFF-IXE-1H	Radiation sources
OFF-LRL-1H	Biological waste
OFF-LRL-2H	Concrete, bricks, and asphalt
OFF-MCS-1H	Electronic tubes and metascopes
OFF-MEI-1H	Probably sources
OFF-MHS-1H	Thirty-nine Co-60 wires sealed in concrete

Table 2-22. (continued).

Waste stream number	Description of waste
OFF-NEC-1H	Aluminum heat exchanger and waste containing U-235 and U-238
OFF-NMR-1H	Biological waste
OFF-NPF-1H	Control rods
OFF-OMC-1H	Paper, graphite, clothing, steel, copper crucibles, and acid carboy
OFF-PM1-1H	Resin storage tank, cement, and empty tank
OFF-SAM-1H	Missile structural components, jet engine parts, fragments of fuel tanks, paper, and ash
OFF-SAM-2H	Reactor shield, miscellaneous metals (magnesium alloy, copper, tin, aluminum, and stainless steel); insulation; rubber; plastic; paper; glass; wire; dirt; wood; concrete; and ash
OFF-SSD-1H	Radio transmitting and receiving sets, switchboards, tubes, plastic, electric instruments, and cobalt resinate
OFF-TCC-1H	Rags, wipes, tape, concrete, graphite, and solvent
OFF-UAC-1H	Radioactive waste packed in cement
OFF-UBM-1H	Ore processing waste [includes rare earth elements (U_3O_8, Fe_2O_3, thorium oxide, uranium chlorides, and iron oxides)]
OFF-UEA-1H	Paper, disposable syringes, glass, plastic containers, and animal carcasses
OFF-UNR-1H	Laboratory waste (paper, wood, glassware, empty bottles, etc.); Co-60 sources; Sr-90 sources; and H-3
OFF-UOU-1H	Biological waste
OFF-UOW-1H	Animals, animal tissue, isotopic solutions, evaporated residues, paper, syringes, clothing, laboratory glassware, planchets, benzene, carbon tetrachloride, methyl alcohol, and other biomedical waste
OFF-USC-1H	Resin-filled demineralizers

Table 2-22. (continued).

Waste stream number	Description of waste
OFF-USN-1H	Animal carcasses, waste paper towels, glassware, tools, and similar laboratory items
OFF-WCC-1H	Paper rags, furnace coke, carbon baffles, wax brick refractory, and small hand tools
OFF-WSU-1H	Bird, animal, and crayfish carcasses; kim-wipes; paper towels; gloves; aluminum; and stainless-steel planchets
PER-601-1H	Combustibles (paper, cloth, wood, etc.)
PER-612-1H	Glove box, vacuum pump, air conditioner, capsule, and radioactive source
PER-613-1H	Core structure components, reactor vessel, and loop components
PER-617-1H	Irradiated and unirradiated fuel
PER-620-1H	Paper, cloth, wood, resin, insulation, batteries, concrete, asphalt, and radioactive sources
PER-623-1H	Irradiated fuel powder and pellets
PER-ORM-1H	Paper, cloth, wood, barrels of Santo-R wax, and empty barrels
WMC-WMC-1H	Soil, pond sediment, scrap metal, and equipment

D&D-S1G-1H

- **Generation of the waste stream.** This waste stream consisted of the waste generated from D&D of the S1-G reactor vessel at TRA in 1983. The S1-G reactor vessel was comprised of three concentric cylinders of heavy-wall steel designed for pressure containment. It contained solidified sodium coolant and weighed in excess of 100 tons. The purpose of the D&D operations was to remove the metallic sodium from the vessel and dispose of the intact vessel in the SDA.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are H-3, Co-60, Ni-63, Fe-55, Ni-59, and Nb-94. All sodium was removed from the reactor vessel before disposal. The reactor vessel was sealed before disposal; however, 3,300 Ci of H-3 remained in the vessel.

- **Information sources reviewed and used.** Table 2-21 and the list of additional related reports identify reports reviewed and used. Additional information concerning this waste stream was obtained from discussions with Richard Meservey, former manager of the D&D program, and from shipping records.

- **Assumptions and analysis.** Based on interviews and available reports, few nonradiological contaminants were included in the D&D program waste streams disposed of in the SDA. No assumptions were made concerning the radiological contaminants in the waste streams.

OFF-AEF-1H

- **Generation of the waste stream.** Waste from the AEC San Francisco Operations Office, now NRC Region V, originated from an AEC cleanup operation of the Coastwise Marine Disposal Company warehouse located in Long Beach, California. Coastwise was a radioactive waste disposal company and serviced a number of commercial and government facilities. Information is unavailable on the processes and waste streams of these facilities. The AEC permanently revoked the Coastwise license in 1961 and assumed responsibility for disposal of the Coastwise waste. Because the majority of solid waste stored at Coastwise had previously been packaged for ocean disposal, the nature of the waste received at the INEL is uncertain.

- **Principal radiological contaminants.** The principal radiological contaminants listed in disposal records for this waste stream include Co-60, Ra-226, and Sr-90.

- **Information sources reviewed and used.** Table 2-21 and the list of additional related reports identify reports reviewed and used. Additional information concerning this waste stream was obtained from shipping records.

- **Assumptions and analysis.** Reports on the operations and processes associated with this generator did not quantify the types of contaminants in the waste stream with precision. MFP was assumed to be Sr-90 for this generator based on a lack of information to determine a further breakdown. Because shipping records give only a total radioactivity

and a list of radionuclides, the total radioactivity was divided equally among Co-60, Ra-226, and Sr-90. According to available reports, nonradiological contaminants were not routinely stored or disposed of by Coastwise. Consequently, nonradiological contaminants were assumed not to be part of the waste stream.

OFF-ATI-1H

- **Generation of the waste stream.** Waste received from Atomics International Division, Rockwell International, Canoga Park, California, was derived from research and development, design, construction, and testing of several nuclear reactors and associated systems. Among these were the series of Systems for Nuclear Auxiliary Power (SNAP) reactors, the Sodium Reactor Experiment (SRE), the Hallam reactor, and the Piqua reactor. The SNAP reactors were fueled with hydrided uranium-zirconium alloy and were NaK-cooled. The SRE cores were fueled either by thorium-uranium alloy or unalloyed uranium and were NaK-cooled. The Hallam reactor was fueled by uranium-molybdenum or uranium carbide and was sodium-cooled. The Piqua reactor was fueled with a uranium-molybdenum alloy and cooled with an organic mixture of terphenyls. A majority of the waste received at the INEL from this generator was derived from operations associated with the SNAP and SRE reactors.

- **Principal radiological contaminants.** The principal radiological contaminants listed for this waste stream include Cs-137, Pu-239, U-235, U-238, and U-234.

- **Information sources reviewed and used.** Table 2-21 and the list of additional related reports identify reports reviewed and used. Additional information concerning this waste stream was obtained from shipping records.

- **Assumptions and analysis.** Reports on the operations and processes associated with this generator did not quantify the types of contaminants in the waste stream with precision. Uranium radionuclides were divided into the appropriate percentages based on the enrichment curves for uranium. MFP were converted to Cs-137 for this waste stream based on the suite of radionuclides listed in disposal records and on the generation processes. Based on available reports, nonradiological contaminants could be included in the waste stream, but typically they were sent elsewhere for disposal. Nonradiological contaminants mentioned in the report, but for which disposal at the INEL is in question, are listed with unknown quantities.

OFF-ISC-1H

- **Generation of the waste stream.** Waste generated from the now-closed Isotope Specialists Co., Burbank, California, consisted of wipes, gloves, glassware, etc., associated with radionuclide labeling operations.

- **Principal radiological contaminants.** The principal radiological contaminants in this waste stream are Co-60, Ra-226, Cs-137, and Th-232.

- **Information sources reviewed and used.** Table 2-21 and the list of additional related reports identify reports reviewed and used. Additional information concerning this waste stream was obtained from shipping records.

- **Assumptions and analysis.** Only four sentences from a single report could be located describing this generator and associated waste streams; consequently, detailed quantification of the waste stream is impossible. A magnesium and thorium alloy is reported to have been in the waste stream disposed of at the INEL. The volume of the alloy was estimated because quantities are not given. Seventy-one percent of the total volume of the shipment was estimated to represent the metal, excluding the box volume, based on assumptions concerning empty space in the containers.

OFF-USN-1H

- **Generation of the waste stream.** The waste generated from the U.S. Naval Radiological Defense Laboratory, San Francisco, California, consisted of radiologically contaminated animal carcasses, paper, wood, glassware, empty bottles, etc. This waste was generated from studies of the effects of fallout, instrumentation tests, metabolic studies, radionuclide uptake and retention studies, chemical separations, and decontamination studies.

- **Principal radiological contaminants.** In descending order of abundance, the principal radiological contaminants in this waste stream are Cs-137, Co-60, Po-210, Ra-226, Sr-90, Ir-192, Ba-137, Sb-124, Tm-170, Y-90, and C-14.

- **Information sources reviewed and used.** Table 2-21 and the list of additional related reports identify reports reviewed and used. Additional information concerning this waste stream was obtained from shipping records.

- **Assumptions and analysis.** Radionuclides in this waste stream are well documented in reports and on shipping records. No assumptions were made concerning the radionuclide waste stream. Reports indicate that animal carcasses were preserved in formaldehyde before shipment. The volume of formaldehyde included in the waste stream was estimated to be 5.5% of the volume that contained carcasses. Reports mention that nitric acid was used in this process. However, the acid is not believed to have been disposed of with the waste shipped from this generator.

CFA-640-1H

- **Generation of the waste stream.** This waste stream was derived from a machine shop at CFA. Reports do not specify details on the waste stream or the processes that generated the waste. Based on shipping records and what information is available in reports, the waste consisted of radioactively contaminated metal filings, chips, stainless steel, lead, and cleanup materials. In addition, the waste included batteries and a contaminated filing cabinet from the SL-1 reactor area.

- **Principal nonradiological contaminants.** The principal nonradiological contaminants in this stream are lead and a small quantity of sulfuric acid.

- **Information sources reviewed and used.** Table 2-21 and the list of additional related reports identify reports reviewed and used. Additional information concerning this waste stream was obtained from shipping records.

- **Assumptions and analysis.** Lead was mentioned as a constituent of each shipment. Volumes of the lead were not given, so an assumption was made that the lead accounted for 65% of all shipment weights. Sulfuric acid was assumed to be present in batteries that were disposed of. It was assumed that 1 L (0.3 gal) of sulfuric acid is contained in each battery.

  Radionuclides in this waste stream include MAP and MFP, and they account for less than 1 Ci for the entire stream. MAP were assumed to be all Co-60, and MFP were assumed to be Sr-90 in the absence of evidence to determine a distribution.

CFA-687-1H

- **Generation of the waste stream.** This waste stream was derived from the Lead Shop at CFA. Radioactively contaminated lead was sized, packaged, and shipped to the RWMC for disposal. Other contaminated scrap metals, dirt, and soil were included with the lead shipments.

- **Principal nonradiological contaminants.** The principal nonradiological contaminant in this stream is lead.

- **Information sources reviewed and used.** Table 2-21 and the list of additional related reports identify reports reviewed and used. Additional information concerning this waste stream was obtained from shipping records.

- **Assumptions and analysis.** Lead was mentioned as a constituent of each shipment. Volumes of the lead were not given; however, shipments of waste to the RWMC included lead with soil, dirt, and other scrap metals. Based on the composition of the waste stream, an assumption was made that the lead accounted for one-half of all shipment weights.

  Radionuclides in this waste stream include MAP and MFP, and they account for less than 1 Ci for the entire stream. MAP were assumed to be all Co-60, and MFP were assumed to be Sr-90 in the absence of evidence to determine a distribution.

PER-601-1H, PER-612-2H, PER-613-1H, PER-620-1H, PER-ORM-1H

Several waste streams from PER (PER-601-1H, PER-612-1H, PER-613-1H, PER-620-1H, and PER-ORM-1H) were important contributors to the inventory of certain nonradiological contaminants. These waste streams were derived primarily from cleanup of reactor components at the SPERT reactors and contained 2-butanone and toluene. These contaminants were determined to have been shipped to the RWMC on rags and wipes used for cleanup. It is likely, however, that these

contaminants volatilized to a large extent before disposal. An additional contaminant of importance in the waste streams from PBF is silver. The silver waste stream was derived from the SPERT-IV facility and originated from silver zeolite. Silver was routinely recovered when silver prices were high in the early 1980s. Based on interviews with operators of the facility, an estimate was made of the silver that was not recovered and that was disposed of in a glass matrix. Other nonradiological contaminants of importance in this stream are antimony and chromium.

2.4.8 Waste Disposed of on Pad A

The Generators and Rationale for Separate Reporting. From 1972 through 1978, waste suspected of containing TRU radionuclides in concentrations less than 10 nCi/g was disposed of aboveground on Pad A in the SDA (see Section 1.2 and Figure 1-2). In the HDT, this waste was grouped into two waste streams: stream PDA-RFO-1A consists of the Pad A waste that was shipped from the RFP, and stream PDA-INEL-1A consists of the remaining Pad A waste, which was shipped from several INEL facilities.

In the HDT, the information on the Pad A waste was compiled separately from the waste disposed of elsewhere in the SDA using the particular stream designators given above. The waste stream designators begin with the letters "PDA" and include the suffix "A," both of which refer to the Pad A disposal location. This method allows easy reporting of waste on Pad A separately from the other waste. The method does not imply that Pad A was a generator of waste, only that Pad A was a separate disposal location.

The total amount of waste from RFP can be determined by adding the stream PDA-RFO-1A to the sum of all streams that begin with "RFO-." Because the stream PDA-INEL-1A includes waste from several generators at the INEL, the HDT data cannot be used to assign that waste to the individual generators that produced it.

Whenever total contaminant quantities are provided in this report, the waste on Pad A is included in the inventory, unless otherwise stated.

Description of Waste Streams. The Pad A waste was divided into two waste streams (see Table 2-23). Both streams are discussed in detail below. For each of these streams, the discussion tells how the waste was generated, the principal contaminants in the stream, and the specific information sources reviewed and used.

Table 2-23. Waste streams disposed of on Pad A.

Waste stream number	Description of waste
PDA-RFO-1A	Evaporator salts
PDA-INEL-1A	Fuel production scrap and miscellaneous waste

PDA-RFO-1A (Evaporator salts)

- **Generation of the waste stream.** Section 2.4.6 discusses RFP waste and the generation of this waste stream during the time when it was buried belowgrade (from the inception of the stream in 1967 through 1972). The generation of the stream was essentially unchanged during the time it was disposed of on Pad A (from 1972 through 1978).

- **Principal Radiological Contaminants.** The principal radiological contaminants in this waste stream are U-238, U-234, and U-235.

- **Principal Nonradiological Contaminants.** The principal nonradiological contaminants in this stream are sodium nitrate and potassium nitrate.

- **Information Sources Reviewed and Used.** The information used was taken from RWMIS and from Halford et al. (1993).

PDA-INEL-1A (Fuel production scrap and miscellaneous waste)

- **Generation of the waste.** This waste stream was generated by a variety of experiments and processes at several generators involving very small activities of plutonium and uranium. Much of the waste was generated from processes involving unirradiated fuel.

- **Principal Radiological Contaminants.** This waste stream contains minute activities of plutonium and uranium.

- **Information Sources Reviewed and Used.** The information used was taken from RWMIS and from Halford et al. (1993).

2.5 Data Qualification Process

As shown in Figure 2-2, after the waste information for each generator was collected and entered onto data forms (one form for each waste stream), the information was subjected to a qualification process. That process is described briefly here.

Completed draft forms were logged in at a central point, and copies were reviewed by a three-person committee. One of the three people was knowledgeable about the physical, chemical, and radiological nature of the waste; another was an experienced risk assessor responsible for BRA activities; and the third was a statistician responsible for the treatment of uncertainty on the task. The completed draft forms were reviewed for completeness, clarity, consistency, reasonableness of assumptions, use of appropriate scientific units, possible duplication or overlap of coverage with forms completed for other waste streams, and compatibility with the structure of the database.

The committee members discussed their comments with the data gatherer who had prepared the draft forms. After agreement was reached on resolution of the comments, the original preparer made any necessary revisions to the forms.

The forms were then relogged in at the central point and transmitted to database personnel for entry. All data entered into the database (discussed in Section 2.6) were independently checked for correct entry. During data entry, several validation tables were used to ensure that only valid information was entered into several data fields. The validation tables contain prespecified "acceptable" values for the following types of information (data fields): nuclide, chemical name, Chemical Abstract Services (CAS) number, generator, building, etc. As a final check, the database printouts were then reviewed by the data gatherers who had completed the original forms.

The information in this report, including the waste inventory printouts, underwent peer review by technical, program management, regulatory compliance, and waste generator personnel.

2.6 Contaminant Inventory Database for Risk Assessment

A convenient method was needed to use the large body of data captured on the data forms for the HDT and the companion study (Lockheed 1995). Therefore, the Contaminant Inventory Database for Risk Assessment (CIDRA) database was created to manage the data gathered in both studies.

All data contained in CIDRA originated from completed data forms. Appendix A provides a blank version of the forms.

The CIDRA application was created in FoxPro and is accessible in dBASE.

Textual information captured in the database can be aggregated over different fields in the database (e.g., by waste stream or by generator). However, query and sort capabilities on the text fields are limited. This information was electronically captured to maintain a record of how the waste stream information was obtained and other pertinent details about the waste stream. The data tracking form is hierarchical—each subsequent section of the form contains more detailed information about a waste stream inventory.

The CIDRA report software application was developed to support reporting. The application can produce the following set of standard reports:

- Hazardous chemicals (Part C) data by various groupings [e.g., waste stream, generator(s)]
- Radionuclides (Part D) information by various groupings [e.g., waste stream, generator(s)].

The information in these reports consists of the quantities and respective units of radiological and nonradiological contaminants.

Report generation is augmented by an algorithm that was developed to perform simplified decay calculations on the radionuclides. The user may specify any date to which decay is calculated, and CIDRA produces a data set with the decayed quantities.

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3. RESULTS

This section discusses the results of compiling the contaminant inventory information for the data form entries with a known quantity. Section 3.1 provides an introduction, summary rollup tables of the inventory over all generators, and explanatory information for the entire inventory. Sections 3.2 through 3.8 present corresponding rollup tables and discussions for the seven major waste generators.

Because Section 3 contains many tables, the tables are placed at the end of the section for the convenience of the reader.

Section 4 discusses radionuclides and chemicals with contaminant quantities listed as "unknown" on the data forms.

3.1 Introduction and Totals

3.1.1 Introduction and Conventions Followed

All information on the contaminant inventory and the waste characteristics gathered in this task resides in the CIDRA database. Appendix B (Volumes 2 through 5 of this report) contains a complete printout of the information in CIDRA. For each of the 234 waste streams, the data forms provide the compiled information concerning the processes that generated the stream, the contaminant quantities and characteristics, the sources of information, and the assumptions made regarding the contaminants present.

Tables 3-1 and 3-2 provide the total best-estimate quantities of each contaminant in the inventory, covering all waste streams from all generators. Table 3-1 lists the nonradiological contaminants in terms of grams; Table 3-2 lists the radiological contaminants in terms of curies at the time of disposal.

For convenience, tables of contaminant inventories in this section are each given in two versions. The tables are designated with an "a" or "b." The "a" tables present the contaminants in the waste in order of best estimate quantity; the "b" tables present the contaminants in alphabetical order.

For several contaminants in the tables, the best-estimate quantities are indicated as "unknown." This means that mention of the contaminant was found in historical data sources, but insufficient information was available for a defensible quantification of the amount. The text fields in CIDRA for the affected waste streams provide the full extent of information compiled for the indicated contaminants.

The tables also give upper and lower bounds on the quantities of the contaminants. Section 5 discusses the statistical methodology used for evaluating the uncertainties in the inventories and for calculating the upper and lower bounds. Section 5 also discusses the major sources of uncertainty, which vary depending on the waste generator.

All inventories in this report are given to only two significant digits. Using more significant digits would give an erroneous impression of the accuracy to which the inventories can be estimated.

The task described in this report went beyond the compilation of an inventory based on waste-related records. The task also considered the technical adequacy of the measurement methods by which the data were originally generated. As a result, although many (generally minor) revisions were made to the estimated contaminant quantities in individual waste streams based on technical considerations, major across-the-board revisions were also incorporated. As discussed primarily in Section 5, these revisions affect many waste streams. The total inventories in Tables 3-1 and 3-2 are, therefore, significantly different from the corresponding quantities reported in RWMIS and in earlier reports. The differences and their bases are discussed in detail in Section 6.

A brief but important explanation is needed about handling radioactive decay products (progeny) in the inventory of radiological contaminants (e.g., in Table 3-2). Because of radioactive decay, the progeny of radionuclides begin forming (growing in) as soon as the parent radionuclides are formed. The relative abundance of the progeny compared with that of the parent depends on the relative half-lives of the parent and progeny and on the time elapsed since production of the parent. For some radionuclides that are often predominant in waste inventories, the half-lives of the progeny are very short compared with those of the parents. Example combinations of parent and progeny are Sr-90 and Y-90, Cs-137 and Ba-137m (metastable), and Ru-106 and Rh-106m. In such cases, radioactive equilibrium (termed secular equilibrium) is established within hours or days between the parent and the progeny. In these circumstances, each curie of the parent radionuclide is in equilibrium with one curie of the progeny (unless branching occurs).

Not all of the preparers of the original shipping and other records included secular equilibrium considerations in the data entries. In the present task, the inventories generally were not adjusted to reflect secular equilibrium. Instead, the adjustment was deferred to the risk assessment. This approach allows easier comparison of the inventory with previous inventory compilations. Adjustments for secular equilibrium will be made before using the inventory in the risk assessment and will be combined with the effort involving complete radioactive decay calculations. The abundance of the progeny will be calculated in computer codes developed for that purpose or in decay models built into environmental transport codes.

Because the progeny have very short half-lives, they exist only as long as the parent radionuclide exists. Therefore, omitting the progeny from the inventory at the time of waste disposal will not affect the inventory of the progeny used in the risk assessment for times longer than a few days or weeks. The equilibrium that is quickly established in producing the progeny will be modeled in the radioactive decay equations.

For easier comparison of the inventory with previous inventory compilations, radionuclides with very short half-lives were not identified. Again, complete calculations of radioactive decay will be performed before using the inventory in the risk assessment.

Although radioactive decay and ingrowth are not factored into this inventory and are deferred for evaluation in the risk assessment, one other nuclear physics consideration is factored into the inventory. The consideration is the relative percentages of U-234, U-235, and U-238 in uranium entries in the inventory. In natural uranium, the relative percentages of these radionuclides by mass are 0.0055%, 0.72%, and 99.2745%, respectively. By radioactivity, the percentages are 48%, 3%, and 49%, respectively. When natural uranium is enriched in the concentration of U-235 for use in nuclear reactors or weapons, in facilities designed for that purpose, the relative proportions of the three radionuclides change considerably. Many of the waste streams in the inventory contain uranium, but the records generally identified only the one or two uranium radionuclides that were predominant by mass. In the present study, a more thorough approach was taken for all waste

streams listed in the records as containing >0.1 Ci of any of the three listed uranium radionuclides. For those waste streams, the degree of enrichment of the uranium (e.g., enrichment corresponding to that of depleted uranium, natural uranium, slightly enriched uranium, or highly enriched uranium) was estimated based on the source and nature of the waste. Standard curves (Rich et al. 1988; EG&G Idaho 1985) were consulted that indicate the relative proportions of the uranium radionuclides for various degrees of enrichment. The appropriate mixture of uranium radionuclides was then ascribed to the uranium in the waste stream, totaling the same amount of uranium as the records indicated.

Some contaminants (e.g., uranium) are not only radioactive, but they also present nonradiological hazards. Such contaminants are listed in this report under only the radiological heading. The nonradiological hazards of materials that are radioactive will be considered in the risk assessment.

As the titles of inventory tables for radiological contaminants indicate, the radioactivity is given at the time of disposal. There is one exception to this convention. For waste stream TRA-670-1H (see Section 2.4.2), the radioactivity is listed as of the time of generation because (a) the radioactivity was calculated by evaluating the generation mechanism and (b) the time of disposal was often many years after the time of generation. For this stream, the data form makes it clear that the primary period of radionuclide generation was 1963 through 1977, and the time of disposal was 1969 through 1977.

The CAS number is given for each nonradiological contaminant in the tables. In some cases, the contaminant listed is a class of contaminants, so a specific CAS number cannot be given.

As Section 1.2 stated, two programs in the 1970s demonstrated the experimental retrieval of part of the waste buried in the SDA. The waste retrieved in those programs has not been subtracted from the CIDRA inventory. Thus, the CIDRA inventory represents what was buried, rather than what remains, in the disposal units of interest. CIDRA is the parent inventory for the SDA waste; special applications of CIDRA are created for risk assessment, with portions of the inventory removed depending on the scope of the application. This approach was judged to provide the greatest flexibility in using the inventory information.

The current inventory is not suitable for direct, immediate use in the risk assessment. As Figure 2-2 indicates, the risk assessor needs to apply additional calculations and judgment before using the inventory values in environmental transport codes and other risk assessment methods. Using the information requires careful consideration of factors such as (a) the physical and chemical characteristics of individual waste streams and of contaminants within a waste stream, (b) waste packaging methods, (c) likely burial methods for the particular type of waste at the particular time, and (d) any migration of contaminants that might have occurred to date. A discussion of this evaluation process is beyond the scope of this report.

3.1.2 Rollup of Nonradiological Contaminants Over All Generators

Table 3-1 lists the nonradiological contaminants identified in the inventory.

Organic liquids are key contaminants, including 1.2E+08 g (120,000 kg) of carbon tetrachloride, 1.1E+08 g (110,000 kg) of 1,1,1-trichloroethane, 1.0E+08 g (100,000 kg) of trichloroethylene, and 2.7E+07 g (27,000 kg) of tetrachloroethylene. There are lesser quantities of methylene chloride and methyl isobutyl ketone. Nitrates are also present in large quantities, including

1.8E+09 g (1,800,000 kg) of potassium nitrate, 1.2E+09 g (1,200,000 kg) of sodium nitrate, and 1.9E+08 g (190,000 kg) of aluminum nitrate nonahydrate. Among the toxic metals, the largest quantities are 5.8E+08 g (580,000 kg) of lead, 1.9E+07 g (19,000 kg) of zirconium, 5.9E+06 g (5,900 kg) of zirconium alloys, and 1.5E+07 g (15,000 kg) of beryllium. Acids are abundant, with large quantities of nitric acid and hydrofluoric acid. There are lesser quantities of many other nonradiological contaminants.

Numerous nonradiological contaminants were identified as being present but in unknown quantities. As stated previously, Section 4 documents the attempts to attach estimates to the unknown quantities, even if those estimates are inexact and not defendable.

3.1.3 Rollup of Radiological Contaminants Over All Generators

Table 3-2 lists the radiological contaminants identified in the inventory, which totals an estimated 12 million Ci at the time of disposal. The largest entry is the activation product Fe-55, at 3.8 million Ci. Other predominant activation products include Co-60 at 2.8 million Ci and Ni-63 at 740,000 Ci.

The predominant fission products in Table 3-2 include Cs-137 at 700,000 Ci, Sr-90 at 450,000 Ci, and Ce-144 at 150,000 Ci.

As shown in Table 3-2, actinides (many of which are very long-lived) are present in large quantities. Included are Pu-241 at 400,000 Ci, Am-241 at 150,000 Ci, Pu-239 at 66,000 Ci, and Pu-240 at 15,000 Ci, as well as lesser activities of Pu-238, Cm-242, and U-238.

Another key radionuclide is tritium (H-3), at 1.2 million Ci. The vast majority of the H-3 was generated as an activation product in beryllium, as discussed in Section 2.4.2. Tritium has a half-life of approximately 12 years.

The activities of several of the radionuclides in Table 3-2 were estimated in this study almost exclusively by means of calculations with nuclear physics computer codes. (The calculations either were performed as part of this study or had been performed previously and were extracted from the reports referenced in Section 2.) These radionuclides were frequently not listed on shipping records because their radiation is difficult to detect. The radiation exhibits either weak or no gamma ray and is often absorbed within the waste materials or the container walls. Examples of these radionuclides are H-3, C-14, Sr-90, Tc-99, and I-129. As Section 6.2 shows, the calculated activities of radionuclides of this type are much larger than the corresponding activities indicated in the shipping record compilations of RWMIS.

3.2 Test Area North

3.2.1 Nonradiological Contaminants

Table 3-3 lists the inventory of nonradiological contaminants in the waste from TAN. The predominant contaminant is trimethylolpropane-triester, followed by beryllium.

The minimal reporting of nonradiological contaminants may reflect, in part, the practice at TAN of packaging waste through the TAN-607/633 complex, causing some loss of waste identity. For example, lead was mentioned in RWMIS and the shipping manifests several times without quantitative estimates. These are likely small amounts in solid form that had adsorbed some surface radioactivity.

Large amounts of mercury (>50 tons) were present at TAN in association with the ANP Program. However, sources such as Hiaring et al. (1991) indicate that the mercury was reclaimed by a commercial contractor. RWMIS, shipping records, and Hiaring et al. (1991) indicate that only a very small amount of mercury from TAN was buried in the SDA.

3.2.2 Radiological Contaminants

Table 3-4 lists the inventory of radiological contaminants in the waste from TAN. The best estimate for the total radioactivity is approximately 35,000 Ci.

About 70% of the radioactivity in Table 3-4 is due to radionuclides of cobalt, manganese, nickel, and iron, which originate in structural materials. These are relatively immobile. About 10% of the radioactivity comes from the fission products Cs-137 and Sr-90. The actinide radionuclides total less than 10 Ci.

Because RWMIS contains no data for TAN before 1960 (the period during which the majority of the ANP Program was conducted), reports, operating logs, and interviews with ANP Program personnel (some of whom are now retired) were used to reconstruct estimates of hazardous and radioactive material in waste shipments from TAN for this period. Reliable curie estimates for TAN for the years 1958 through 1960 were available from AEC annual reports, so reconstruction of the curie values of these early data was feasible. A total of 9,000 Ci were added to the inventory for the years 1956 through 1959, years not included in RWMIS. The distribution of radionuclides for this radioactivity was calculated based on reported operations using a nuclear physics computer code and engineering judgment.

For the years 1960 through 1970, the radionuclide distributions were calculated and distributed for the two categories by combining data provided in reports and engineering judgment according to projects that were performed during that period. The RWMIS yearly curie values were corroborated with waste shipping papers to verify values. After 1970, the radionuclides were distributed by the method described in Section 2.4.1; the amount of H-3 was reduced to reflect the operations conducted at TAN during this period.

3.3 Test Reactor Area

3.3.1 Nonradiological Contaminants

Table 3-5 lists the inventory of nonradiological contaminants in the waste from TRA. The largest contributors are lead and beryllium. The beryllium represents the total mass of the beryllium reflectors removed from MTR, ETR, and ATR. There are also substantial quantities of cadmium and asbestos.

Other than the contaminants listed above, few nonradiological contaminants from TRA were identified. Some additional nonradiological contaminants may have been included in the waste, but they are difficult to confirm. One example involves the MTR and ETR cooling towers. The cooling water that passed through these wooden towers contained a chromate-based fungicide. The fungicide may have been absorbed into the wood and subsequently buried with the wood at the RWMC, but this could not be confirmed. Another example is organic solvents, such as carbon tetrachloride. There have been reports of such contaminants in the TRA waste sent to the RWMC. However, the reports could not be confirmed based on discussions with TRA personnel who were involved with operations at the time period of interest.

Very few liquids from TRA were disposed of at the RWMC. The liquids were usually transferred to ICPP for treatment or to the disposal ponds at TRA.

3.3.2 Radiological Contaminants

Table 3-6 lists the inventory of radiological contaminants in the waste from TRA. The waste from TRA contained more total radioactivity (6.6 million Ci) than the waste from any other generator that shipped to the SDA.

The dominant radionuclide in the TRA waste is Fe-55 at 2.7 million Ci.

Another major contributor is H-3 at 1.2 million Ci. Tritium was an activation product formed in the beryllium reflectors in the reactor cores. Tritium was also formed as a fission product of ternary fission. The half-life of H-3 is approximately 12 years. The total mass of the H-3 in the inventory is approximately 125 g.

Other major contributors are the activation products Co-60, Cr-51, and Ni-63, and the fission products Cs-137 and Sr-90. The dominant radionuclides in the TRA waste are what would generally be expected based on the reactor operations that generated the waste.

TRA is the principal generator of three radionuclides: C-14, I-129, and Tc-99. These radionuclides are of particular interest because of their very long half-lives and their relatively high mobilities in groundwater once released from confinement, even though their activities are not extremely large. As discussed in Section 2.4.2, the estimated activities of these three radionuclides are based primarily on (a) nuclear physics calculations performed for the current task and (b) Tables 2-7 through 2-10, which in turn derive from calculations and laboratory data obtained at the INEL and at the Electric Power Research Institute (EPRI) (see Harker 1995a and 1995b). The activities are considerably higher than those listed in the shipping records for these three radionuclides, because they are very difficult to measure. There is considerable uncertainty in the present estimates.

3.4 Idaho Chemical Processing Plant

3.4.1 Nonradiological Contaminants

Table 3-7 lists the inventory of nonradiological contaminants in the waste from ICPP.

In the 1950s, liquid waste containing chemicals, some of which are now classified as hazardous substances, was disposed of in a special pit located outside the RWMC. The chemicals contained in this waste are included in Table 3-7. Subsequent enlargement of the RWMC area incorporated this liquid disposal area within the RWMC boundaries, and the disposal of liquids at the RWMC was discontinued. Only very small quantities of radionuclides were contained in this liquid waste. The waste originated primarily from "cold runs" of processes being tested for use in the ICPP process building for the recovery of uranium. The major chemicals in the liquid waste are aluminum nitrate nonahydrate, nitric acid, hydrofluoric acid, sodium nitrate, mercury nitrate monohydrate, and uranyl nitrate. As listed in Table 3-7, smaller quantities of other chemicals were also disposed of. Large quantities of lime were added to the pit to neutralize the acid.

In addition to the aqueous waste, some organic liquids were discharged to a special pit at the RWMC. The major contaminants are methyl isobutyl ketone and tributyl phosphate.

In addition to the contaminants in the liquid waste, a large amount of lead (about 26,000 kg), in the form of lead bricks or lead sheets, was disposed of at the SDA. A large quantity of zirconium scrap left over from developing a process for extracting uranium from zirconium/uranium fuel was also disposed of. A small amount of asbestos in the form of pipe insulation, as well as small amounts of other contaminants, were also buried as listed in Table 3-7.

3.4.2 Radiological Contaminants

Table 3-8 lists the inventory of radiological contaminants in the waste from ICPP. The total radioactivity is approximately 690,000 Ci. The dominant contributors are the activation products Co-60, Co-58, Cr-51, and Mn-54 and the fission products Cs-137, Ce-144, and Pr-144.

ICPP received highly enriched fuel routinely from the reactors at TRA, NRF, and EBR-II and intermittently from several other test reactors. This fuel was stored under water, the nonfuel-containing end boxes were cut off if necessary, and the fuel was processed. Millions of curies of radionuclides were separated from the uranium during processing, but only 690,000 Ci of this total is estimated to have ended up in process waste or fuel end boxes disposed of at the RWMC during the period 1952 through 1983. The remainder was retained as liquid high-level waste stored at ICPP in underground stainless-steel tanks. This liquid waste was eventually processed in the Waste Calcining Facility and stored in underground stainless-steel bins at ICPP as granular solid high-level waste.

Approximately 500,000 Ci was associated with the constituents of the fuel end boxes. The end boxes were cut off from the fuel assemblies before processing the fuel and were transported directly to the RWMC. The radionuclides in the end boxes were primarily short-lived, gamma-emitting activation products. The radionuclide Co-60 provides the greatest amount of radiation, with a half-life of approximately 5 years. The radionuclides in the end boxes are an integral part of the stainless-steel metal. No uranium or fission products were contained in the end boxes. The large quantities of activation products, such as Co-60, are to be expected because of the irradiation of the fuel in the EBR-II reactor.

Another 25,000 Ci of the radionuclide inventory is associated with the sludge from the fuel storage building. The sludge contains radionuclides with long half-lives, such as Cs-137 and Sr-90.

3.5 Naval Reactors Facility

3.5.1 Nonradiological Contaminants

Table 3-9 lists the inventories of nonradiological contaminants in the NRF-generated waste that was buried in the SDA. Only four nonradiological contaminants were identified in the search of information sources. Approximately 5,900 kg of zirconium alloy (zircaloy) has been sent from NRF for burial at the SDA. Some of the zirconium is in the form of small chips and saw fines. Zirconium and its alloys are pyrophoric, especially when finely divided. The presence of these alloys mixed with the other waste requires careful handling to avoid fires if exposed to the air.

Small quantities of an acid, possibly hydrofluoric acid, with dissolved fuel rods were absorbed in vermiculite and placed in polyethylene bottles. The records do not show the quantity of acid shipped from NRF; the records only show the curies of activity involved. The amount of acid is likely to be minor.

Unknown quantities of lead and asbestos were also present in the NRF waste. Although probably substantial, the quantities of these two contaminants are believed to be smaller than the quantities from other generators who shipped waste to the RWMC.

3.5.2 Radiological Contaminants

The best estimate for the total quantity of radioactive material shipped from NRF to the RWMC from 1952 through 1983 is approximately 2.9 million Ci. The distribution of that total among the principal radionuclides is shown in Table 3-10.

The majority of the activity listed is Co-60, with an approximately 5-year half-life, and Fe-55, with a half-life of approximately 2.7 years. The list includes 220,000 Ci of Ni-63, with a half-life of 100 years, and 140,000 Ci each of Sr-90 and Cs-137, both with approximately 30-year half-lives. Most of the other major contributors—Sb-125, Zr-95, Sn-119m and Co-58m—have half-lives ranging from a few months to a few years.

One conclusion of this investigation is that the majority of the radioactivity transferred from NRF for burial at the RWMC is in the form of solid, monolithic pieces of activated metal (core structural materials). In addition, significant fractions of the activity were short-lived radionuclides, and much of that has decayed since burial. There remains a considerable amount of long-lived radionuclides, principally Co-60, Ni-63, Sr-90, and Cs-137. Of these, the activation products Co-60 and Ni-63 are immobilized in large pieces of stainless steel. However, the probable principal hazards two or three decades after burial, Sr-90 and Cs-137, are *not* immobile. The Sr-90 and Cs-137 assumed for this waste must be considered to be in particulate form and probably soluble.

The radionuclides listed and their quantities are what would be expected in the waste from a facility such as NRF. The reactors would generate large volumes of compactible waste with small concentrations of activated metals. The ECF would generate large quantities of activated metals associated with core structural materials, some fission products resulting from examination of fuel samples, and large quantities of zirconium alloy scrap from the fuel elements. The sludges are typical for facilities that have a need to maintain water purity and clarity.

3.6 Argonne National Laboratory–West

3.6.1 Nonradiological Contaminants

Table 3-11 lists the inventory of nonradiological contaminants in the waste from ANL-W.

Lead and small quantities of chloroform, aqua regia, and carbon tetrachloride were the only nonradiological contaminants identified and quantified in the waste. Small quantities of chromium and cadmium are also believed to have been disposed of; however, the quantities are unknown. The quantity of asbestos is also unknown. Radiologically contaminated aerosol cans, paint containers, solvent-wet rags, or other small items probably made their way into ANL-W waste streams. However, any toxic materials in these waste shipments could not be identified and are assumed to be very small.

3.6.2 Radiological Contaminants

Table 3-12 lists the inventory of radiological contaminants in the waste from ANL-W. The total radioactivity is approximately 1.1 million Ci.

The largest contributor to the activity (about 330,000 Ci) is Co-60, with a half-life of approximately 5 years. The next largest contributor is Sr-90 (220,000 Ci). Other key radionuclides are Cs-137, Cr-51, Ce-144, and Mn-54. Plutonium and uranium radionuclides with very long half-lives are present in small amounts.

3.7 Rocky Flats Plant

3.7.1 Nonradiological Contaminants

Table 3-13 lists the inventory of nonradiological contaminants in waste from the RFP.

The largest nonradiological contributors are lead (which is present in leaded rubber gloves and aprons and as pieces of lead sheeting used for shielding); nitrates; and several volatile organic compounds (VOCs): carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene. The estimated quantities of the VOCs are expected to be conservatively high because of unknown losses to evaporation before the waste was packaged and shipped. The conservative estimates are used as upper bounds, and the best estimates of the amount buried are taken to be three-fourths of the upper bounds. The sodium and potassium nitrate are present in evaporator salts, which contain small quantities of plutonium.

3.7.2 Radiological Contaminants

Table 3-14 lists the inventory of radiological contaminants in waste from the RFP. The total radioactivity is approximately 620,000 Ci.

The largest contributor to the radioactivity is Pu-241 (390,000 Ci), which has a half-life of about 14 years and decays to Am-241. Americium-241, Pu-239, and Pu-240 make up most of the balance of the radioactivity. These three radionuclides have long half-lives that range from approximately 430 to 24,000 years. Although the activities of U-235 and U-238 are rather small, these nuclides are present in very large quantities in terms of mass because of their low specific activity.

The plutonium and americium radionuclides and the depleted uranium reached a peak annual disposal quantity around 1966. The enriched uranium reached a peak disposal rate around 1960.

3.8 Other Generators and Waste Disposed of on Pad A

Inventories are reported based on the 10 major categories[e] of other generators. Those categories are offsite generators (OFF) not otherwise specified; Argonne National Laboratory-East (ALE); Auxiliary Reactor Area (ARA), including SL-1; Battelle Northwest Laboratories (BNL); Central Facilities Area (CFA); decontamination and decommissioning projects (D&D); Loss of Fluid Test Reactor facility (LOF); Power Excursion Reactor/Power Burst Facility (PER); Waste Management Complex (WMC); and waste disposed of on Pad A, regardless of the generator (see Section 2.4.8).

e. For consistency, the acronyms used in Section 3.8 for the miscellaneous generators are those used in RWMIS. They may differ from the acronyms conventionally used at the INEL and elsewhere in this report.

3.8.1 Nonradiological Contaminants

Tables 3-15 through 3-18 list the inventories of nonradiological contaminants generated in waste from the other generators. Nonradiological contaminants were identified and quantified for only 4 of the 10 generators: CFA, OFF, PER, and waste on Pad A. The nonradiological contaminants from these four generators and the remaining other generators are discussed below.

Based on available reports and interviews, quantifiable nonradiological contaminants were not identified in the waste streams from ALE, ARA, BNL, D&D, LOF, or WMC.

The majority of the CFA nonradiological contaminants were reported to have been disposed of primarily in the CFA landfill, percolation ponds, sewage drain fields, and french drains. Of the reported nonradiological contaminants in Table 3-15, all contaminants were estimates based on information obtained from shipping records. The largest contaminants in mass are lead, sodium-potassium, and zirconium. Cyanide and mercury are listed as "unknown" because there is a mention of these contaminants in RWMIS, but no verification of the quantities could be located. The sodium-potassium listing is from cleanup of EBR-I and is reported to have been reacted with water in a strongly basic solution (NaOH/KOH); the solution was solidified by evaporation and cooling and was disposed of as a solid waste.

The OFF nonradiological contaminants listed in Table 3-16 were obtained from Clements (1980) and shipping records. The largest contaminants in mass are lead and magnesium. The chemicals listed in which the quantities or volumes are unknown are based on the following considerations:

- Generators reported that these contaminants were possible in their waste streams, but quantities were minute
- These contaminants were typically in the waste streams, but the nonradiological constituents were shipped elsewhere for disposal
- It was questionable if these contaminants were included in the waste disposed of at the RWMC.

Based on the uncertainties described, defendable estimates of the quantities of these contaminants could not be made.

The PER nonradiological contaminants listed in Table 3-17 represent the best estimates derived from numerous interviews and the data gatherer's process knowledge of the facility. The largest contaminants in mass are lead, trichloroethylene, and xylene.

The lead listed in Tables 3-15 through 3-17 was typically in the form of shielding. Liquid organic contaminants, such as formaldehyde, toluene, acetone, and trichloroethene, were reported to have been solidified before disposal or are generally included as absorbed liquids on paper or cloth used in cleanup activities. Acidic liquid waste—sulfuric acid, nitric acid, and hydrogen fluoride—is believed to have been disposed of in the Acid Pit as liquid waste and neutralized in the pit with the addition of lime. Metals such as zirconium, magnesium, beryllium, and cadmium were generated from a wide variety of processes and account for only a small percentage of the total mass of nonradiological contaminants.

The nonradiological contaminants disposed of on Pad A are listed in Table 3-18. The contaminants identified and quantified are all large quantities of sodium and potassium salts (chlorides, nitrates, and sulfates) from the RFP.

From 1980 through 1983, lead is the only nonradiological contaminant listed in ALE shipments and is reported as negligible. It is unlikely that other nonradiological contaminants were included in shipments from ALE during the 1980s.

Based on interviews and on the EG&G Idaho (1986), all nonradiological contaminants included in the waste streams from ARA were disposed of either at ARA or processed through ICPP. The chemical leach field at ARA-I, leach fields at ARA-III, septic tanks at ARA-III, the CFA landfill, and ICPP were reported to have received all of the nonradiological contaminants generated at this facility. Rags with an undetermined absorbed volume of cleaning fluid may have been shipped from ARA to the RWMC.

BNL contributed a very small volume of waste to the SDA in 1983. Because only 4.655 m^3 (164.3 ft^3) of BNL waste was disposed of and based on the results of interviews, nonradiological contaminants are not suspected in the BNL waste stream.

D&D projects did not dispose of nonradiological waste at the RWMC, with the possible exception of asbestos pipe insulation, copper, and sodium. Conducting interviews and reviewing numerous reports could not provide defendable quantitative information on these contaminants.

Reports and process information were used to determine the extent of nonradiological contaminants disposed of from LOF. No information was available to indicate that these contaminants were included in the waste streams from LOF.

WMC waste was disposed of from 1977 through 1983. Based on interviews, the types of waste disposed, and process information, nonradiological contaminants are not suspected in the waste stream.

3.8.2 Radiological Contaminants

Tables 3-19 through 3-28 list the inventories of radiological contaminants in waste from the other generators.

The total activity of radioactive material from all other generators is approximately 49,000 Ci. Of that total, approximately one-half is Cs-137, and the remainder is mostly H-3, Sr-90, and the activation products Co-60 and Fe-59.

Actinides represent only a very small percentage of the total activity. The waste on Pad A (Table 3-28) contains a large quantity of depleted uranium (primarily U-238) and a small quantity of plutonium. Much of the remaining activity is represented by radionuclides with short half-lives, such as Zr-95, received primarily from offsite generators involved in isotope research.

Because most of the disposal records evaluated for the radionuclide type listed only MFP, much of the Cs-137 and Sr-90 activity was derived by converting disposal record listings of MFP to the appropriate radionuclides. The H-3 was received primarily from D&D of the S1G reactor vessel and from the University of California, Lawrence Radiation Laboratories. The Co-60 and Fe-59 were derived primarily from converting MAP listed on disposal records into the respective radionuclides.

Table 3-1a. Inventory of nonradiological contaminants (listed by quantity) from all generators.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7757-79-1	Potassium nitrate	1.8E+09	1.3E+09	2.4E+09
7631-99-4	Sodium nitrate	1.2E+09	8.4E+08	1.6E+09
7439-92-1	Lead	5.8E+08	4.9E+08	6.8E+08
7784-27-2	Aluminum nitrate nonahydrate	1.9E+08	1.5E+08	2.4E+08
7757-82-6	Sodium sulfate	1.6E+08	1.2E+08	2.1E+08
7647-14-5	Sodium chloride	1.6E+08	1.2E+08	2.1E+08
56-23-5	Carbon tetrachloride	1.2E+08	1.1E+08	1.4E+08
71-55-6	1,1,1-trichloroethane	1.1E+08	9.5E+07	1.2E+08
79-01-6	Trichloroethylene	1.0E+08	9.1E+07	1.2E+08
7778-80-5	Potassium sulfate	8.0E+07	5.9E+07	1.1E+08
7447-40-7	Potassium chloride	8.0E+07	5.9E+07	1.1E+08
10101-89-0	Sodium phosphate	8.0E+07	5.9E+07	1.1E+08
7697-37-2	Nitric acid	5.0E+07	3.9E+07	6.2E+07
7778-77-0	Potassium phosphate	4.0E+07	3.0E+07	5.4E+07
127-18-4	Tetrachloroethylene	2.7E+07	2.3E+07	3.1E+07
7440-67-7	Zirconium	1.9E+07	1.6E+07	2.3E+07
7440-41-7	Beryllium	1.5E+07	1.4E+07	1.6E+07
75-09-2	Methylene chloride	1.4E+07	1.4E+07	1.5E+07
76131	1,1,2-trichloro-1,2,2-trifluoroethane	9.1E+06	8.5E+06	9.8E+06
7439-95-4	Magnesium	9.0E+06	7.4E+06	1.1E+07
108-10-1	Methyl isobutyl ketone	8.9E+06	7.0E+06	1.1E+07
7664393	Hydrofluoric acid	7.6E+06	6.0E+06	9.6E+06
—	Zirconium alloys	5.9E+06	4.7E+06	7.3E+06
10588-01-9	Sodium dichromate	4.1E+06	3.0E+06	5.4E+06
7778-50-9	Potassium dichromate	2.3E+06	1.7E+06	3.0E+06
11135-81-2	Sodium potassium	1.7E+06	1.2E+06	2.4E+06
7440-43-9	Cadmium	1.6E+06	9.2E+05	2.5E+06
1332-21-4	Asbestos	1.2E+06	4.7E+05	2.6E+06
15625-89-5	Trimethylolpropane-triester	1.2E+06	8.4E+05	1.6E+06

Table 3-1a. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
126-73-8	Tributyl phosphate	1.0E+06	7.8E+05	1.3E+06
1330-20-7	Xylene	8.5E+05	7.2E+05	1.0E+06
7783-34-8	Mercury nitrate monohydrate	8.1E+05	6.3E+05	1.0E+06
7664417	Ammonia	7.8E+05	2.7E+05	1.8E+06
7790-86-5	Cerium chloride	5.1E+05	4.2E+05	6.2E+05
26140-60-3	Terphenyl	4.5E+05	1.6E+05	1.0E+06
67-56-1	Methyl alcohol	2.2E+05	2.0E+05	2.5E+05
10102064	Uranyl nitrate	2.2E+05	1.7E+05	2.8E+05
108-88-3	Toluene	1.9E+05	1.3E+05	2.6E+05
50-00-0	Formaldehyde	1.4E+05	1.3E+05	1.5E+05
7783-40-6	Magnesium fluoride	1.4E+05	1.3E+05	1.4E+05
7664-93-9	Sulfuric acid	1.2E+05	9.9E+04	1.5E+05
67-64-1	Acetone	1.1E+05	9.8E+04	1.3E+05
71363	Butyl alcohol	9.9E+04	9.0E+04	1.1E+05
7440-23-5	Sodium	6.8E+04	6.1E+04	7.5E+04
78-93-3	2-butanone	3.2E+04	2.5E+04	4.0E+04
64175	Ethyl alcohol	2.2E+04	1.8E+04	2.8E+04
7440-22-4	Silver	5.9E+03	4.7E+03	7.3E+03
8032-32-4	Benzine	4.0E+03	3.3E+03	4.8E+03
7440-02-0	Nickel	2.2E+03	1.0E+03	4.1E+03
302012	Hydrazine	1.8E+03	1.3E+03	2.3E+03
7440-47-3	Chromium	1.0E+03	6.8E+02	1.5E+03
143-33-9	Sodium cyanide	9.4E+02	3.2E+02	2.2E+03
7440-36-0	Antimony	4.5E+02	1.6E+02	1.0E+03
3251-23-8	Copper nitrate	3.3E+02	2.6E+02	4.1E+02
120-12-7	Anthracene	2.0E+02	7.0E+01	4.6E+02
1310-73-2	Sodium hydroxide	1.5E+02	5.1E+01	3.4E+02
67-66-3	Chloroform	3.7E+01	3.6E+01	3.7E+01
—	Aqua regia	3.1E+01	3.0E+01	3.2E+01

Table 3-1a. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
—	Organophosphates	Unknown	NA[b]	NA
—	Versenes	Unknown	NA	NA
—	Organic acids	Unknown	NA	NA
—	Nitrocellulose	Unknown	NA	NA
—	Dibutylethylcarbutol	Unknown	NA	NA
—	Cyanide	Unknown	NA	NA
—	Alcohols	Unknown	NA	NA
7580-67-8	Lithium hydride	Unknown	NA	NA
7440-50-8	Copper	Unknown	NA	NA
7439-97-6	Mercury	Unknown	NA	NA
7439-96-5	Manganese	Unknown	NA	NA
71-43-2	Benzene	Unknown	NA	NA
60-29-7	Ether	Unknown	NA	NA
56-49-5	3-methylcholanthrene	Unknown	NA	NA
55914	Diisopropylfluorophosphate	Unknown	NA	NA
4165-60-0	Nitrobenzene	Unknown	NA	NA
1806-34-4	1,4-bis(5-phenyloxazol-2-YL)benzene	Unknown	NA	NA
1336363	PCB	Unknown	NA	NA
1309-48-4	Magnesium oxide	Unknown	NA	NA
1304-56-9	Beryllium oxide	Unknown	NA	NA
12057-24-8	Lithium oxide	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-1b. Inventory of nonradiological contaminants (listed alphabetically) from all generators.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
71-55-6	1,1,1-trichloroethane	1.1E+08	9.5E+07	1.2E+08
76131	1,1,2-trichloro-1,2,2-trifluoroethane	9.1E+06	8.5E+06	9.8E+06
1806-34-4	1,4-bis(5-phenyloxazol-2-YL)benzene	Unknown	NA[b]	NA
78-93-3	2-butanone	3.2E+04	2.5E+04	4.0E+04
56-49-5	3-methylcholanthrene	Unknown	NA	NA
67-64-1	Acetone	1.1E+05	9.8E+04	1.3E+05
—	Alcohols	Unknown	NA	NA
7784-27-2	Aluminum nitrate nonahydrate	1.9E+08	1.5E+08	2.4E+08
7664417	Ammonia	7.8E+05	2.7E+05	1.8E+06
120-12-7	Anthracene	2.0E+02	7.0E+01	4.6E+02
7440-36-0	Antimony	4.5E+02	1.6E+02	1.0E+03
—	Aqua regia	3.1E+01	3.0E+01	3.2E+01
1332-21-4	Asbestos	1.2E+06	4.7E+05	2.6E+06
71-43-2	Benzene	Unknown	NA	NA
8032-32-4	Benzine	4.0E+03	3.3E+03	4.8E+03
7440-41-7	Beryllium	1.5E+07	1.4E+07	1.6E+07
1304-56-9	Beryllium oxide	Unknown	NA	NA
71363	Butyl alcohol	9.9E+04	9.0E+04	1.1E+05
7440-43-9	Cadmium	1.6E+06	9.2E+05	2.5E+06
56-23-5	Carbon tetrachloride	1.2E+08	1.1E+08	1.4E+08
7790-86-5	Cerium chloride	5.1E+05	4.2E+05	6.2E+05
67-66-3	Chloroform	3.7E+01	3.6E+01	3.7E+01
7440-47-3	Chromium	1.0E+03	6.8E+02	1.5E+03
7440-50-8	Copper	Unknown	NA	NA
3251-23-8	Copper nitrate	3.3E+02	2.6E+02	4.1E+02
—	Cyanide	Unknown	NA	NA
—	Dibutylethylcarbutol	Unknown	NA	NA
55914	Diisopropylfluorophosphate	Unknown	NA	NA
60-29-7	Ether	Unknown	NA	NA

Table 3-1b. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
64175	Ethyl alcohol	2.2E+04	1.8E+04	2.8E+04
50-00-0	Formaldehyde	1.4E+05	1.3E+05	1.5E+05
302012	Hydrazine	1.8E+03	1.3E+03	2.3E+03
7664393	Hydrofluoric acid	7.6E+06	6.0E+06	9.6E+06
7439-92-1	Lead	5.8E+08	4.9E+08	6.8E+08
7580-67-8	Lithium hydride	Unknown	NA	NA
12057-24-8	Lithium oxide	Unknown	NA	NA
7439-95-4	Magnesium	9.0E+06	7.4E+06	1.1E+07
7783-40-6	Magnesium fluoride	1.4E+05	1.3E+05	1.4E+05
1309-48-4	Magnesium oxide	Unknown	NA	NA
7439-96-5	Manganese	Unknown	NA	NA
7439-97-6	Mercury	Unknown	NA	NA
7783-34-8	Mercury nitrate monohydrate	8.1E+05	6.3E+05	1.0E+06
67-56-1	Methyl alcohol	2.2E+05	2.0E+05	2.5E+05
108-10-1	Methyl isobutyl ketone	8.9E+06	7.0E+06	1.1E+07
75-09-2	Methylene chloride	1.4E+07	1.4E+07	1.5E+07
7440-02-0	Nickel	2.2E+03	1.0E+03	4.1E+03
7697-37-2	Nitric acid	5.0E+07	3.9E+07	6.2E+07
4165-60-0	Nitrobenzene	Unknown	NA	NA
—	Nitrocellulose	Unknown	NA	NA
—	Organic acids	Unknown	NA	NA
—	Organophosphates	Unknown	NA	NA
1336363	PCB	Unknown	NA	NA
7447-40-7	Potassium chloride	8.0E+07	5.9E+07	1.1E+08
7778-50-9	Potassium dichromate	2.3E+06	1.7E+06	3.0E+06
7757-79-1	Potassium nitrate	1.8E+09	1.3E+09	2.4E+09
7778-77-0	Potassium phosphate	4.0E+07	3.0E+07	5.4E+07
7778-80-5	Potassium sulfate	8.0E+07	5.9E+07	1.1E+08
7440-22-4	Silver	5.9E+03	4.7E+03	7.3E+03

Table 3-1b. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7440-23-5	Sodium	6.8E+04	6.1E+04	7.5E+04
7647-14-5	Sodium chloride	1.6E+08	1.2E+08	2.1E+08
143-33-9	Sodium cyanide	9.4E+02	3.2E+02	2.2E+03
10588-01-9	Sodium dichromate	4.1E+06	3.0E+06	5.4E+06
1310-73-2	Sodium hydroxide	1.5E+02	5.1E+01	3.4E+02
7631-99-4	Sodium nitrate	1.2E+09	8.4E+08	1.6E+09
10101-89-0	Sodium phosphate	8.0E+07	5.9E+07	1.1E+08
11135-81-2	Sodium potassium	1.7E+06	1.2E+06	2.4E+06
7757-82-6	Sodium sulfate	1.6E+08	1.2E+08	2.1E+08
7664-93-9	Sulfuric acid	1.2E+05	9.9E+04	1.5E+05
26140-60-3	Terphenyl	4.5E+05	1.6E+05	1.0E+06
127-18-4	Tetrachloroethylene	2.7E+07	2.3E+07	3.1E+07
108-88-3	Toluene	1.9E+05	1.3E+05	2.6E+05
126-73-8	Tributyl phosphate	1.0E+06	7.8E+05	1.3E+06
79-01-6	Trichloroethylene	1.0E+08	9.1E+07	1.2E+08
15625-89-5	Trimethylolpropane-triester	1.2E+06	8.4E+05	1.6E+06
10102064	Uranyl nitrate	2.2E+05	1.7E+05	2.8E+05
—	Versenes	Unknown	NA	NA
1330-20-7	Xylene	8.5E+05	7.2E+05	1.0E+06
7440-67-7	Zirconium	1.9E+07	1.6E+07	2.3E+07
—	Zirconium alloys	5.9E+06	4.7E+06	7.3E+06

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-2a. Inventory of radiological contaminants (listed by quantity) from all generators (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Fe-55	3.8E+06	31.5	2.2E+06	6.0E+06
Co-60	2.8E+06	23.8	2.2E+06	3.7E+06
H-3	1.2E+06	9.8	7.5E+05	1.8E+06
Ni-63	7.4E+05	6.2	4.7E+05	1.1E+06
Cr-51	7.3E+05	6.1	1.6E+04	4.5E+06
Cs-137	7.0E+05	5.8	4.9E+05	9.5E+05
Sr-90	4.5E+05	3.8	1.0E+05	1.3E+06
Pu-241	4.0E+05	3.3	2.9E+05	5.4E+05
Mn-54	1.8E+05	1.5	3.7E+04	5.4E+05
Co-58	1.6E+05	1.3	4.7E+04	4.0E+05
Ce-144	1.5E+05	1.3	2.6E+04	5.2E+05
Am-241	1.5E+05	1.3	1.1E+05	2.0E+05
Sb-125	1.3E+05	1.1	1.1E+05	1.4E+05
Fe-59	9.1E+04	0.8	2.0E+03	5.6E+05
Zr-95	7.6E+04	0.6	7.0E+04	8.2E+04
Pu-239	6.6E+04	0.5	4.7E+04	8.9E+04
Pr-144	4.2E+04	0.4	3.2E+03	1.9E+05
Sn-119m	2.7E+04	0.2	2.5E+04	3.0E+04
Y-90	1.9E+04	0.2	1.8E+03	8.2E+04
C-14	1.6E+04	0.1	7.8E+02	8.5E+04
Pu-240	1.5E+04	0.1	1.0E+04	2.2E+04
Eu-155	1.5E+04	0.1	7.9E+02	7.6E+04
Ru-106	6.8E+03	<0.05	5.0E+03	9.0E+03
Rh-106	6.8E+03	<0.05	5.0E+03	9.0E+03
Ni-59	5.1E+03	<0.05	2.4E+02	2.7E+04
Eu-154	3.0E+03	<0.05	8.8E+01	1.7E+04
Pu-238	2.5E+03	<0.05	4.3E+02	8.6E+03
Nb-95	2.4E+03	<0.05	1.4E+03	3.9E+03
Cs-134	2.2E+03	<0.05	3.7E+02	7.4E+03

Table 3-2a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Sb-124	1.8E+03	<0.05	1.0E+01	1.3E+04
La-140	7.7E+02	<0.05	3.2E+01	4.2E+03
Ce-141	7.6E+02	<0.05	3.7E+01	4.0E+03
Ba-140	6.6E+02	<0.05	2.8E+01	3.6E+03
Pr-143	6.2E+02	<0.05	2.1E+01	3.6E+03
Y-91	5.3E+02	<0.05	2.2E+01	2.9E+03
Sr-89	4.7E+02	<0.05	2.0E+01	2.6E+03
Zn-65	3.6E+02	<0.05	3.8E+00	2.5E+03
Ru-103	3.6E+02	<0.05	1.5E+01	1.9E+03
Rh-103m	2.7E+02	<0.05	9.2E+00	1.5E+03
Tc-99	2.6E+02	<0.05	1.2E+01	1.4E+03
Eu-152	2.4E+02	<0.05	2.1E+02	2.6E+02
U-238	1.1E+02	<0.05	7.0E+01	1.8E+02
Cm-242	9.1E+01	<0.05	1.2E+01	3.4E+02
Pm-147	8.1E+01	<0.05	9.6E-01	5.5E+02
Cm-244	8.0E+01	<0.05	4.9E+00	4.0E+02
Po-210	7.5E+01	<0.05	1.4E+00	4.8E+02
U-234	6.4E+01	<0.05	5.0E+01	8.2E+01
Ra-226	5.9E+01	<0.05	4.4E+01	7.6E+01
Ir-192	5.4E+01	<0.05	1.4E+00	3.2E+02
Sc-46	5.3E+01	<0.05	2.9E-01	3.8E+02
Nb-94	4.9E+01	<0.05	2.5E+01	8.8E+01
Be-10	4.3E+01	<0.05	2.9E-01	3.1E+02
Mn-56	2.7E+01	<0.05	1.6E-01	2.0E+02
Ta-182	8.5E+00	<0.05	3.5E-01	4.6E+01
U-232	8.4E+00	<0.05	6.8E+00	1.0E+01
Rb-86	7.1E+00	<0.05	1.1E-01	4.6E+01
U-235	5.1E+00	<0.05	4.2E+00	6.0E+00
Co-57	4.8E+00	<0.05	9.6E-02	3.0E+01

Table 3-2a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Zr-93	4.0E+00	<0.05	2.4E+00	6.4E+00
Tm-170	3.4E+00	<0.05	1.6E-02	2.4E+01
Ba-137m	3.4E+00	<0.05	1.6E-02	2.4E+01
U-236	2.5E+00	<0.05	1.9E+00	3.3E+00
Np-237	2.4E+00	<0.05	1.7E-01	1.1E+01
I-131	1.5E+00	<0.05	8.2E-03	1.1E+01
Th-232	1.3E+00	<0.05	1.1E+00	1.6E+00
Kr-85	1.3E+00	<0.05	6.2E-03	9.5E+00
U-233	1.1E+00	<0.05	7.8E-01	1.6E+00
Mo-99	1.0E+00	<0.05	1.5E-02	6.6E+00
Pu-242	9.9E-01	<0.05	7.3E-01	1.3E+00
Ag-110	8.4E-01	<0.05	4.6E-03	6.1E+00
Cs-136	7.7E-01	<0.05	2.6E-02	4.4E+00
Cd-109	4.1E-01	<0.05	1.1E-02	2.5E+00
Hf-181	3.6E-01	<0.05	3.0E-03	2.6E+00
Be-7	3.5E-01	<0.05	7.1E-03	2.2E+00
Cl-36	3.1E-01	<0.05	3.1E-03	2.2E+00
Na-22	3.0E-01	<0.05	5.4E-03	2.0E+00
Am-243	2.3E-01	<0.05	2.4E-03	1.6E+00
I-129	9.9E-02	<0.05	6.2E-03	4.8E-01
P-32	9.2E-02	<0.05	1.4E-03	6.1E-01
S-35	8.8E-02	<0.05	1.6E-03	5.6E-01
I-133	5.0E-02	<0.05	2.5E-04	3.6E-01
Sr-85	2.9E-02	<0.05	1.5E-04	2.1E-01
I-125	2.9E-02	<0.05	5.9E-04	1.8E-01
Y-88	2.5E-02	<0.05	5.0E-04	1.6E-01
Sc-44	2.5E-02	<0.05	5.0E-04	1.6E-01
Th-230	1.8E-02	<0.05	1.4E-02	2.2E-02
Hg-203	1.2E-02	<0.05	5.8E-05	8.7E-02

Table 3-2a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Cf-252	1.0E-02	<0.05	9.8E-05	6.9E-02
Am-242	7.6E-03	<0.05	4.0E-05	5.5E-02
Yb-164	7.6E-03	<0.05	7.4E-05	5.3E-02
Er-169	7.6E-03	<0.05	7.4E-05	5.3E-02
Mn-53	1.0E-03	<0.05	2.0E-05	6.3E-03
Tl-204	6.7E-04	<0.05	3.2E-06	4.8E-03
Ca-45	6.7E-04	<0.05	3.2E-06	4.8E-03
Ba-133	5.4E-04	<0.05	2.8E-06	3.9E-03
Pb-212	2.0E-05	<0.05	4.0E-07	1.3E-04
Pb-210	9.1E-06	<0.05	1.8E-07	5.7E-05
Ra-225	2.0E-06	<0.05	1.5E-06	2.5E-06
Rn-222	1.0E-06	<0.05	2.0E-08	6.3E-06
Cd-104	1.5E-07	<0.05	3.0E-09	9.5E-07
Total	1.2E+07	99.8[a]		

a. Total in table does not equal 100.0% due to rounding.

Table 3-2b. Inventory of radiological contaminants (listed alphabetically) from all generators (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ag-110	8.4E-01	<0.05	4.6E-03	6.1E+00
Am-241	1.5E+05	1.3	1.1E+05	2.0E+05
Am-242	7.6E-03	<0.05	4.0E-05	5.5E-02
Am-243	2.3E-01	<0.05	2.4E-03	1.6E+00
Ba-133	5.4E-04	<0.05	2.8E-06	3.9E-03
Ba-137m	3.4E+00	<0.05	1.6E-02	2.4E+01
Ba-140	6.6E+02	<0.05	2.8E+01	3.6E+03
Be-10	4.3E+01	<0.05	2.9E-01	3.1E+02
Be-7	3.5E-01	<0.05	7.1E-03	2.2E+00
C-14	1.6E+04	0.1	7.8E+02	8.5E+04
Ca-45	6.7E-04	<0.05	3.2E-06	4.8E-03
Cd-104	1.5E-07	<0.05	3.0E-09	9.5E-07
Cd-109	4.1E-01	<0.05	1.1E-02	2.5E+00
Ce-141	7.6E+02	<0.05	3.7E+01	4.0E+03
Ce-144	1.5E+05	1.3	2.6E+04	5.2E+05
Cf-252	1.0E-02	<0.05	9.8E-05	6.9E-02
Cl-36	3.1E-01	<0.05	3.1E-03	2.2E+00
Cm-242	9.1E+01	<0.05	1.2E+01	3.4E+02
Cm-244	8.0E+01	<0.05	4.9E+00	4.0E+02
Co-57	4.8E+00	<0.05	9.6E-02	3.0E+01
Co-58	1.6E+05	1.3	4.7E+04	4.0E+05
Co-60	2.8E+06	23.8	2.2E+06	3.7E+06
Cr-51	7.3E+05	6.1	1.6E+04	4.5E+06
Cs-134	2.2E+03	<0.05	3.7E+02	7.4E+03
Cs-136	7.7E-01	<0.05	2.6E-02	4.4E+00
Cs-137	7.0E+05	5.8	4.9E+05	9.5E+05
Er-169	7.6E-03	<0.05	7.4E-05	5.3E-02
Eu-152	2.4E+02	<0.05	2.1E+02	2.6E+02
Eu-154	3.0E+03	<0.05	8.8E+01	1.7E+04

Table 3-2b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Eu-155	1.5E+04	0.1	7.9E+02	7.6E+04
Fe-55	3.8E+06	31.5	2.2E+06	6.0E+06
Fe-59	9.1E+04	0.8	2.0E+03	5.6E+05
H-3	1.2E+06	9.8	7.5E+05	1.8E+06
Hf-181	3.6E-01	<0.05	3.0E-03	2.6E+00
Hg-203	1.2E-02	<0.05	5.8E-05	8.7E-02
I-125	2.9E-02	<0.05	5.9E-04	1.8E-01
I-129	9.9E-02	<0.05	6.2E-03	4.8E-01
I-131	1.5E+00	<0.05	8.2E-03	1.1E+01
I-133	5.0E-02	<0.05	2.5E-04	3.6E-01
Ir-192	5.4E+01	<0.05	1.4E+00	3.2E+02
Kr-85	1.3E+00	<0.05	6.2E-03	9.5E+00
La-140	7.7E+02	<0.05	3.2E+01	4.2E+03
Mn-53	1.0E-03	<0.05	2.0E-05	6.3E-03
Mn-54	1.8E+05	1.5	3.7E+04	5.4E+05
Mn-56	2.7E+01	<0.05	1.6E-01	2.0E+02
Mo-99	1.0E+00	<0.05	1.5E-02	6.6E+00
Na-22	3.0E-01	<0.05	5.4E-03	2.0E+00
Nb-94	4.9E+01	<0.05	2.5E+01	8.8E+01
Nb-95	2.4E+03	<0.05	1.4E+03	3.9E+03
Ni-59	5.1E+03	<0.05	2.4E+02	2.7E+04
Ni-63	7.4E+05	6.2	4.7E+05	1.1E+06
Np-237	2.4E+00	<0.05	1.7E-01	1.1E+01
P-32	9.2E-02	<0.05	1.4E-03	6.1E-01
Pb-210	9.1E-06	<0.05	1.8E-07	5.7E-05
Pb-212	2.0E-05	<0.05	4.0E-07	1.3E-04
Pm-147	8.1E+01	<0.05	9.6E-01	5.5E+02
Po-210	7.5E+01	<0.05	1.4E+00	4.8E+02
Pr-143	6.2E+02	<0.05	2.1E+01	3.6E+03

Table 3-2b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Pr-144	4.2E+04	0.4	3.2E+03	1.9E+05
Pu-238	2.5E+03	<0.05	4.3E+02	8.6E+03
Pu-239	6.6E+04	0.5	4.7E+04	8.9E+04
Pu-240	1.5E+04	0.1	1.0E+04	2.2E+04
Pu-241	4.0E+05	3.3	2.9E+05	5.4E+05
Pu-242	9.9E-01	<0.05	7.3E-01	1.3E+00
Ra-225	2.0E-06	<0.05	1.5E-06	2.5E-06
Ra-226	5.9E+01	<0.05	4.4E+01	7.6E+01
Rb-86	7.1E+00	<0.05	1.1E-01	4.6E+01
Rh-103m	2.7E+02	<0.05	9.2E+00	1.5E+03
Rh-106	6.8E+03	<0.05	5.0E+03	9.0E+03
Rn-222	1.0E-06	<0.05	2.0E-08	6.3E-06
Ru-103	3.6E+02	<0.05	1.5E+01	1.9E+03
Ru-106	6.8E+03	<0.05	5.0E+03	9.0E+03
S-35	8.8E-02	<0.05	1.6E-03	5.6E-01
Sb-124	1.8E+03	<0.05	1.0E+01	1.3E+04
Sb-125	1.3E+05	1.1	1.1E+05	1.4E+05
Sc-44	2.5E-02	<0.05	5.0E-04	1.6E-01
Sc-46	5.3E+01	<0.05	2.9E-01	3.8E+02
Sn-119m	2.7E+04	0.2	2.5E+04	3.0E+04
Sr-85	2.9E-02	<0.05	1.5E-04	2.1E-01
Sr-89	4.7E+02	<0.05	2.0E+01	2.6E+03
Sr-90	4.5E+05	3.8	1.0E+05	1.3E+06
Ta-182	8.5E+00	<0.05	3.5E-01	4.6E+01
Tc-99	2.6E+02	<0.05	1.2E+01	1.4E+03
Th-230	1.8E-02	<0.05	1.4E-02	2.2E-02
Th-232	1.3E+00	<0.05	1.1E+00	1.6E+00
Tl-204	6.7E-04	<0.05	3.2E-06	4.8E-03
Tm-170	3.4E+00	<0.05	1.6E-02	2.4E+01

Table 3-2b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
U-232	8.4E+00	<0.05	6.8E+00	1.0E+01
U-233	1.1E+00	<0.05	7.8E-01	1.6E+00
U-234	6.4E+01	<0.05	5.0E+01	8.2E+01
U-235	5.1E+00	<0.05	4.2E+00	6.0E+00
U-236	2.5E+00	<0.05	1.9E+00	3.3E+00
U-238	1.1E+02	<0.05	7.0E+01	1.8E+02
Y-88	2.5E-02	<0.05	5.0E-04	1.6E-01
Y-90	1.9E+04	0.2	1.8E+03	8.2E+04
Y-91	5.3E+02	<0.05	2.2E+01	2.9E+03
Yb-164	7.6E-03	<0.05	7.4E-05	5.3E-02
Zn-65	3.6E+02	<0.05	3.8E+00	2.5E+03
Zr-93	4.0E+00	<0.05	2.4E+00	6.4E+00
Zr-95	7.6E+04	0.6	7.0E+04	8.2E+04
Total	1.2E+07	99.8[a]		

a. Total in table does not equal 100.0% due to rounding.

Table 3-3a. Inventory of nonradiological contaminants (listed by quantity) from Test Area North.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
15625-89-5	Trimethylolpropane-triester	1.2E+06	8.4E+05	1.6E+06
7440-41-7	Beryllium	2.2E+04	9.5E+03	4.4E+04
7440-02-0	Nickel	2.2E+03	1.0E+03	4.1E+03
7440-47-3	Chromium	5.5E+02	2.6E+02	1.0E+03
11135-81-2	Sodium potassium	2.7E+02	1.9E+02	3.7E+02
7439-97-6	Mercury	Unknown	NA[b]	NA
7439-92-1	Lead	Unknown	NA	NA
60-29-7	Ether	Unknown	NA	NA
1304-56-9	Beryllium oxide	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-3b. Inventory of nonradiological contaminants (listed alphabetically) from Test Area North.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7440-41-7	Beryllium	2.2E+04	9.5E+03	4.4E+04
1304-56-9	Beryllium oxide	Unknown	NA[b]	NA
7440-47-3	Chromium	5.5E+02	2.6E+02	1.0E+03
60-29-7	Ether	Unknown	NA	NA
7439-92-1	Lead	Unknown	NA	NA
7439-97-6	Mercury	Unknown	NA	NA
7440-02-0	Nickel	2.2E+03	1.0E+03	4.1E+03
11135-81-2	Sodium potassium	2.7E+02	1.9E+02	3.7E+02
15625-89-5	Trimethylolpropane-triester	1.2E+06	8.4E+05	1.6E+06

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-4a. Inventory of radiological contaminants (listed by quantity) from Test Area North (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Fe-55	9.4E+03	26.6	2.6E+03	2.4E+04
Co-60	9.0E+03	25.4	4.2E+03	1.7E+04
Ni-59	3.1E+03	8.8	5.6E+01	2.0E+04
Cs-137	2.0E+03	5.7	9.8E+02	3.6E+03
Mn-54	1.6E+03	4.7	4.1E+01	1.0E+04
Fe-59	1.3E+03	3.7	2.0E+01	8.6E+03
Cr-51	1.1E+03	3.2	1.7E+01	7.4E+03
Sr-90	9.5E+02	2.7	3.2E+01	5.4E+03
Co-58	8.8E+02	2.5	1.4E+01	5.8E+03
La-140	7.7E+02	2.2	3.2E+01	4.2E+03
Ce-141	7.1E+02	2.0	3.0E+01	3.8E+03
Ba-140	6.6E+02	1.9	2.8E+01	3.6E+03
Pr-143	6.2E+02	1.8	2.1E+01	3.6E+03
Zr-95	5.6E+02	1.6	2.4E+01	3.0E+03
Y-91	5.3E+02	1.5	2.2E+01	2.9E+03
Sr-89	4.7E+02	1.3	2.0E+01	2.6E+03
Ru-103	3.6E+02	1.0	1.5E+01	1.9E+03
Nb-95	3.1E+02	0.9	1.3E+01	1.7E+03
Rh-103m	2.7E+02	0.8	9.2E+00	1.5E+03
Ni-63	2.4E+02	0.7	6.9E+01	6.2E+02
Ce-144	2.0E+02	0.6	1.2E+01	1.0E+03
Pm-147	8.1E+01	0.2	9.5E-01	5.5E+02
H-3	2.2E+01	0.1	9.8E-01	1.2E+02
Ru-106	1.7E+01	<0.05	7.0E-01	9.5E+01
Y-90	1.4E+01	<0.05	1.8E-01	9.6E+01
Cs-134	1.3E+01	<0.05	3.8E-01	7.9E+01
Rb-86	7.1E+00	<0.05	1.1E-01	4.6E+01
Po-210	5.0E+00	<0.05	2.6E-02	3.6E+01
Rh-106	3.0E+00	<0.05	4.5E-02	1.9E+01

Table 3-4a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Pu-238	2.1E+00	<0.05	2.0E-02	1.4E+01
Ra-226	1.0E+00	<0.05	8.2E-01	1.2E+00
Cs-136	7.7E-01	<0.05	2.6E-02	4.4E+00
C-14	2.8E-01	<0.05	4.0E-03	1.9E+00
Eu-154	1.8E-01	<0.05	9.8E-04	1.3E+00
U-234	9.8E-02	<0.05	7.4E-02	1.3E-01
U-235	5.6E-02	<0.05	2.6E-02	1.1E-01
Sb-125	4.3E-02	<0.05	4.2E-04	3.0E-01
Eu-155	4.2E-02	<0.05	4.8E-04	2.9E-01
Pu-239	3.6E-02	<0.05	2.6E-04	2.6E-01
Hf-181	3.5E-02	<0.05	1.8E-04	2.5E-01
Nb-94	8.2E-03	<0.05	1.1E-04	5.5E-02
U-238	5.7E-03	<0.05	4.7E-03	6.8E-03
Pu-241	8.1E-04	<0.05	1.2E-05	5.3E-03
Tc-99	6.1E-05	<0.05	1.2E-06	3.8E-04
U-236	2.7E-07	<0.05	1.2E-07	5.5E-07
Cm-242	1.2E-09	<0.05	2.0E-11	8.0E-09
I-129	3.0E-10	<0.05	1.0E-11	1.9E-09
Total	3.5E+04	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-4b. Inventory of radiological contaminants (listed alphabetically) from Test Area North (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ba-140	6.6E+02	1.9	2.8E+01	3.6E+03
C-14	2.8E-01	<0.05	4.0E-03	1.9E+00
Ce-141	7.1E+02	2.0	3.0E+01	3.8E+03
Ce-144	2.0E+02	0.6	1.2E+01	1.0E+03
Cm-242	1.2E-09	<0.05	2.0E-11	8.0E-09
Co-58	8.8E+02	2.5	1.4E+01	5.8E+03
Co-60	9.0E+03	25.4	4.2E+03	1.7E+04
Cr-51	1.1E+03	3.2	1.7E+01	7.4E+03
Cs-134	1.3E+01	<0.05	3.8E-01	7.9E+01
Cs-136	7.7E-01	<0.05	2.6E-02	4.4E+00
Cs-137	2.0E+03	5.7	9.8E+02	3.6E+03
Eu-154	1.8E-01	<0.05	9.8E-04	1.3E+00
Eu-155	4.2E-02	<0.05	4.8E-04	2.9E-01
Fe-55	9.4E+03	26.6	2.6E+03	2.4E+04
Fe-59	1.3E+03	3.7	2.0E+01	8.6E+03
H-3	2.2E+01	0.1	9.8E-01	1.2E+02
Hf-181	3.5E-02	<0.05	1.8E-04	2.5E-01
I-129	3.0E-10	<0.05	1.0E-11	1.9E-09
La-140	7.7E+02	2.2	3.2E+01	4.2E+03
Mn-54	1.6E+03	4.7	4.1E+01	1.0E+04
Nb-94	8.2E-03	<0.05	1.1E-04	5.5E-02
Nb-95	3.1E+02	0.9	1.3E+01	1.7E+03
Ni-59	3.1E+03	8.8	5.6E+01	2.0E+04
Ni-63	2.4E+02	0.7	6.9E+01	6.2E+02
Pm-147	8.1E+01	0.2	9.5E-01	5.5E+02
Po-210	5.0E+00	<0.05	2.6E-02	3.6E+01
Pr-143	6.2E+02	1.8	2.1E+01	3.6E+03
Pu-238	2.1E+00	<0.05	2.0E-02	1.4E+01
Pu-239	3.6E-02	<0.05	2.6E-04	2.6E-01

Table 3-4b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Pu-241	8.1E-04	<0.05	1.2E-05	5.3E-03
Ra-226	1.0E+00	<0.05	8.2E-01	1.2E+00
Rb-86	7.1E+00	<0.05	1.1E-01	4.6E+01
Rh-103m	2.7E+02	0.8	9.2E+00	1.5E+03
Rh-106	3.0E+00	<0.05	4.5E-02	1.9E+01
Ru-103	3.6E+02	1.0	1.5E+01	1.9E+03
Ru-106	1.7E+01	<0.05	7.0E-01	9.5E+01
Sb-125	4.3E-02	<0.05	4.2E-04	3.0E-01
Sr-89	4.7E+02	1.3	2.0E+01	2.6E+03
Sr-90	9.5E+02	2.7	3.2E+01	5.4E+03
Tc-99	6.1E-05	<0.05	1.2E-06	3.8E-04
U-234	9.8E-02	<0.05	7.4E-02	1.3E-01
U-235	5.6E-02	<0.05	2.6E-02	1.1E-01
U-236	2.7E-07	<0.05	1.2E-07	5.5E-07
U-238	5.7E-03	<0.05	4.7E-03	6.8E-03
Y-90	1.4E+01	<0.05	1.8E-01	9.6E+01
Y-91	5.3E+02	1.5	2.2E+01	2.9E+03
Zr-95	5.6E+02	1.6	2.4E+01	3.0E+03
Total	3.5E+04	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-5a. Inventory of nonradiological contaminants (listed by quantity) from the Test Reactor Area.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7439-92-1	Lead	1.4E+08	7.8E+07	2.3E+08
7440-41-7	Beryllium	1.4E+07	1.4E+07	1.5E+07
7440-43-9	Cadmium	1.5E+06	8.4E+05	2.4E+06
1332-21-4	Asbestos	1.1E+06	3.8E+05	2.5E+06
7664417	Ammonia	7.8E+05	2.7E+05	1.8E+06
26140-60-3	Terphenyl	4.5E+05	1.6E+05	1.0E+06
7440-23-5	Sodium	6.8E+04	6.1E+04	7.5E+04
8032-32-4	Benzine	4.0E+03	3.3E+03	4.8E+03

a. CAS—Chemical Abstract Services.

Table 3-5b. Inventory of nonradiological contaminants (listed alphabetically) from the Test Reactor Area.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7664417	Ammonia	7.8E+05	2.7E+05	1.8E+06
1332-21-4	Asbestos	1.1E+06	3.8E+05	2.5E+06
8032-32-4	Benzine	4.0E+03	3.3E+03	4.8E+03
7440-41-7	Beryllium	1.4E+07	1.4E+07	1.5E+07
7440-43-9	Cadmium	1.5E+06	8.4E+05	2.4E+06
7439-92-1	Lead	1.4E+08	7.8E+07	2.3E+08
7440-23-5	Sodium	6.8E+04	6.1E+04	7.5E+04
26140-60-3	Terphenyl	4.5E+05	1.6E+05	1.0E+06

a. CAS—Chemical Abstract Services.

Table 3-6a. Inventory of radiological contaminants (listed by quantity) from the Test Reactor Area (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Fe-55	2.7E+06	40.9	1.3E+06	5.1E+06
Co-60	1.2E+06	18.1	6.5E+05	2.0E+06
H-3	1.2E+06	17.6	7.5E+05	1.7E+06
Cr-51	5.2E+05	7.8	5.6E+03	3.6E+06
Ni-63	5.0E+05	7.5	2.5E+05	8.9E+05
Cs-137	3.5E+05	5.3	1.9E+05	6.0E+05
Sr-90	6.5E+04	1.0	4.5E+03	3.1E+05
Fe-59	6.4E+04	1.0	6.8E+02	4.4E+05
C-14	1.6E+04	0.2	7.8E+02	8.5E+04
Eu-155	1.5E+04	0.2	7.7E+02	7.5E+04
Pu-241	1.2E+04	0.2	9.1E+02	5.3E+04
Ce-144	7.9E+03	0.1	4.8E+02	3.9E+04
Eu-154	2.7E+03	<0.05	6.4E+01	1.6E+04
Ni-59	1.4E+03	<0.05	1.3E+02	5.7E+03
Sb-125	1.1E+03	<0.05	8.4E+00	7.9E+03
Am-241	6.8E+02	<0.05	9.2E+01	2.5E+03
Pu-238	6.2E+02	<0.05	6.9E+00	4.3E+03
Zn-65	3.6E+02	<0.05	3.7E+00	2.5E+03
Tc-99	2.6E+02	<0.05	1.2E+01	1.4E+03
Cm-242	9.1E+01	<0.05	1.2E+01	3.4E+02
Pu-239	8.6E+01	<0.05	4.7E+00	4.3E+02
Cm-244	8.0E+01	<0.05	4.9E+00	4.0E+02
Mn-54	6.8E+01	<0.05	8.1E-01	4.6E+02
Sc-46	5.2E+01	<0.05	2.6E-01	3.7E+02
Mn-56	2.7E+01	<0.05	1.6E-01	2.0E+02
Pu-240	2.4E+01	<0.05	6.9E-01	1.4E+02
Zr-95	1.4E+01	<0.05	7.4E-02	1.0E+02
U-232	8.4E+00	<0.05	6.8E+00	1.0E+01
U-234	3.8E+00	<0.05	3.0E+00	4.8E+00

Table 3-6a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ce-141	3.0E+00	<0.05	1.6E-02	2.2E+01
Ra-226	2.5E+00	<0.05	2.2E+00	2.9E+00
Np-237	2.4E+00	<0.05	1.7E-01	1.1E+01
U-235	1.8E+00	<0.05	1.5E+00	2.0E+00
U-236	1.5E+00	<0.05	1.2E+00	1.8E+00
I-131	1.4E+00	<0.05	7.3E-03	1.0E+01
U-238	1.2E+00	<0.05	1.0E+00	1.5E+00
Ru-103	1.0E+00	<0.05	5.1E-03	7.3E+00
Co-58	9.9E-01	<0.05	5.6E-03	7.2E+00
Ta-182	5.0E-01	<0.05	2.5E-03	3.6E+00
Be-10	3.5E-01	<0.05	3.0E-02	1.6E+00
Hf-181	3.3E-01	<0.05	2.3E-03	2.4E+00
Am-243	2.3E-01	<0.05	2.4E-03	1.6E+00
Cs-134	1.3E-01	<0.05	6.9E-04	9.6E-01
La-140	1.2E-01	<0.05	9.9E-04	8.4E-01
I-129	9.9E-02	<0.05	6.2E-03	4.8E-01
Ba-140	9.0E-02	<0.05	4.6E-04	6.5E-01
Eu-152	7.4E-02	<0.05	7.3E-04	5.1E-01
I-133	5.0E-02	<0.05	2.5E-04	3.6E-01
Th-232	2.0E-02	<0.05	1.7E-02	2.5E-02
Nb-95	2.0E-02	<0.05	1.0E-04	1.4E-01
Pu-242	1.3E-02	<0.05	1.0E-04	9.1E-02
U-233	9.5E-03	<0.05	7.7E-03	1.2E-02
Am-242	7.6E-03	<0.05	4.0E-05	5.5E-02
Total	6.6E+06	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-6b. Inventory of radiological contaminants (listed alphabetically) from the Test Reactor Area (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Am-241	6.8E+02	<0.05	9.2E+01	2.5E+03
Am-242	7.6E-03	<0.05	4.0E-05	5.5E-02
Am-243	2.3E-01	<0.05	2.4E-03	1.6E+00
Ba-140	9.0E-02	<0.05	4.6E-04	6.5E-01
Be-10	3.5E-01	<0.05	3.0E-02	1.6E+00
C-14	1.6E+04	0.2	7.8E+02	8.5E+04
Ce-141	3.0E+00	<0.05	1.6E-02	2.2E+01
Ce-144	7.9E+03	0.1	4.8E+02	3.9E+04
Cm-242	9.1E+01	<0.05	1.2E+01	3.4E+02
Cm-244	8.0E+01	<0.05	4.9E+00	4.0E+02
Co-58	9.9E-01	<0.05	5.6E-03	7.2E+00
Co-60	1.2E+06	18.1	6.5E+05	2.0E+06
Cr-51	5.2E+05	7.8	5.6E+03	3.6E+06
Cs-134	1.3E-01	<0.05	6.9E-04	9.6E-01
Cs-137	3.5E+05	5.3	1.9E+05	6.0E+05
Eu-152	7.4E-02	<0.05	7.3E-04	5.1E-01
Eu-154	2.7E+03	<0.05	6.4E+01	1.6E+04
Eu-155	1.5E+04	0.2	7.7E+02	7.5E+04
Fe-55	2.7E+06	40.9	1.3E+06	5.1E+06
Fe-59	6.4E+04	1.0	6.8E+02	4.4E+05
H-3	1.2E+06	17.6	7.5E+05	1.7E+06
Hf-181	3.3E-01	<0.05	2.3E-03	2.4E+00
I-129	9.9E-02	<0.05	6.2E-03	4.8E-01
I-131	1.4E+00	<0.05	7.3E-03	1.0E+01
I-133	5.0E-02	<0.05	2.5E-04	3.6E-01
La-140	1.2E-01	<0.05	9.9E-04	8.4E-01
Mn-54	6.8E+01	<0.05	8.1E-01	4.6E+02
Mn-56	2.7E+01	<0.05	1.6E-01	2.0E+02
Nb-95	2.0E-02	<0.05	1.0E-04	1.4E-01

Table 3-6b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ni-59	1.4E+03	<0.05	1.3E+02	5.7E+03
Ni-63	5.0E+05	7.5	2.5E+05	8.9E+05
Np-237	2.4E+00	<0.05	1.7E-01	1.1E+01
Pu-238	6.2E+02	<0.05	6.9E+00	4.3E+03
Pu-239	8.6E+01	<0.05	4.7E+00	4.3E+02
Pu-240	2.4E+01	<0.05	6.9E-01	1.4E+02
Pu-241	1.2E+04	0.2	9.1E+02	5.3E+04
Pu-242	1.3E-02	<0.05	1.0E-04	9.1E-02
Ra-226	2.5E+00	<0.05	2.2E+00	2.9E+00
Ru-103	1.0E+00	<0.05	5.1E-03	7.3E+00
Sb-125	1.1E+03	<0.05	8.4E+00	7.9E+03
Sc-46	5.2E+01	<0.05	2.6E-01	3.7E+02
Sr-90	6.5E+04	1.0	4.5E+03	3.1E+05
Ta-182	5.0E-01	<0.05	2.5E-03	3.6E+00
Tc-99	2.6E+02	<0.05	1.2E+01	1.4E+03
Th-232	2.0E-02	<0.05	1.7E-02	2.5E-02
U-232	8.4E+00	<0.05	6.8E+00	1.0E+01
U-233	9.5E-03	<0.05	7.7E-03	1.2E-02
U-234	3.8E+00	<0.05	3.0E+00	4.8E+00
U-235	1.8E+00	<0.05	1.5E+00	2.0E+00
U-236	1.5E+00	<0.05	1.2E+00	1.8E+00
U-238	1.2E+00	<0.05	1.0E+00	1.5E+00
Zn-65	3.6E+02	<0.05	3.7E+00	2.5E+03
Zr-95	1.4E+01	<0.05	7.4E-02	1.0E+02
Total	6.6E+06	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-7a. Inventory of nonradiological contaminants (listed by quantity) from the Idaho Chemical Processing Plant.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7784-27-2	Aluminum nitrate nonahydrate	1.9E+08	1.5E+08	2.4E+08
7697-37-2	Nitric acid	4.8E+07	3.7E+07	6.1E+07
7439-92-1	Lead	2.6E+07	2.5E+07	2.8E+07
7440-67-7	Zirconium	1.8E+07	1.5E+07	2.2E+07
108-10-1	Methyl isobutyl ketone	8.9E+06	7.0E+06	1.1E+07
7664393	Hydrofluoric acid	7.5E+06	5.9E+06	9.5E+06
7631-99-4	Sodium nitrate	2.4E+06	1.9E+06	3.0E+06
71-55-6	1,1,1-trichloroethane	1.7E+06	1.4E+06	2.2E+06
126-73-8	Tributyl phosphate	1.0E+06	7.8E+05	1.3E+06
7783-34-8	Mercury nitrate monohydrate	8.1E+05	6.3E+05	1.0E+06
10102064	Uranyl nitrate	2.2E+05	1.7E+05	2.8E+05
1332-21-4	Asbestos	1.1E+05	9.3E+04	1.3E+05
7664-93-9	Sulfuric acid	1.1E+05	8.4E+04	1.4E+05
56-23-5	Carbon tetrachloride	2.6E+04	2.0E+04	3.2E+04
67-64-1	Acetone	2.2E+04	1.8E+04	2.8E+04
64175	Ethyl alcohol	2.2E+04	1.8E+04	2.8E+04
3251-23-8	Copper nitrate	3.3E+02	2.6E+02	4.1E+02
7440-41-7	Beryllium	1.1E+02	8.8E+01	1.4E+02
7440-47-3	Chromium	2.0E+01	1.5E+01	2.5E+01

a. CAS—Chemical Abstract Services.

Table 3-7b. Inventory of nonradiological contaminants (listed alphabetically) from the Idaho Chemical Processing Plant.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
71-55-6	1,1,1-trichloroethane	1.7E+06	1.4E+06	2.2E+06
67-64-1	Acetone	2.2E+04	1.8E+04	2.8E+04
7784-27-2	Aluminum nitrate nonahydrate	1.9E+08	1.5E+08	2.4E+08
1332-21-4	Asbestos	1.1E+05	9.3E+04	1.3E+05
7440-41-7	Beryllium	1.1E+02	8.8E+01	1.4E+02
56-23-5	Carbon tetrachloride	2.6E+04	2.0E+04	3.2E+04
7440-47-3	Chromium	2.0E+01	1.5E+01	2.5E+01
3251-23-8	Copper nitrate	3.3E+02	2.6E+02	4.1E+02
64175	Ethyl alcohol	2.2E+04	1.8E+04	2.8E+04
7664393	Hydrofluoric acid	7.5E+06	5.9E+06	9.5E+06
7439-92-1	Lead	2.6E+07	2.5E+07	2.8E+07
7783-34-8	Mercury nitrate monohydrate	8.1E+05	6.3E+05	1.0E+06
108-10-1	Methyl isobutyl ketone	8.9E+06	7.0E+06	1.1E+07
7697-37-2	Nitric acid	4.8E+07	3.7E+07	6.1E+07
7631-99-4	Sodium nitrate	2.4E+06	1.9E+06	3.0E+06
7664-93-9	Sulfuric acid	1.1E+05	8.4E+04	1.4E+05
126-73-8	Tributyl phosphate	1.0E+06	7.8E+05	1.3E+06
10102064	Uranyl nitrate	2.2E+05	1.7E+05	2.8E+05
7440-67-7	Zirconium	1.8E+07	1.5E+07	2.2E+07

a. CAS—Chemical Abstract Services.

Table 3-8a. Inventory of radiological contaminants (listed by quantity) from the Idaho Chemical Processing Plant (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-60	2.0E+05	28.9	1.2E+05	3.2E+05
Co-58	9.0E+04	13.0	6.3E+04	1.2E+05
Cr-51	8.4E+04	12.1	5.1E+04	1.3E+05
Mn-54	8.1E+04	11.7	6.0E+04	1.1E+05
Cs-137	4.2E+04	6.1	3.6E+04	4.8E+04
Ce-144	4.2E+04	6.1	3.2E+03	1.9E+05
Pr-144	4.2E+04	6.1	3.2E+03	1.9E+05
Ni-63	2.5E+04	3.6	1.5E+04	3.9E+04
Fe-59	2.5E+04	3.6	1.5E+04	3.8E+04
Sr-90	2.0E+04	2.8	1.9E+03	8.2E+04
Y-90	1.9E+04	2.8	1.8E+03	8.2E+04
Rh-106	6.8E+03	1.0	5.0E+03	9.0E+03
Ru-106	6.8E+03	1.0	5.0E+03	9.0E+03
Sb-125	2.9E+03	0.4	2.2E+03	3.9E+03
Nb-95	2.1E+03	0.3	1.6E+03	2.8E+03
Zr-95	2.1E+03	0.3	1.5E+03	2.8E+03
Cs-134	4.9E+02	0.1	3.0E+02	7.4E+02
Eu-154	2.9E+02	<0.05	1.3E+02	5.4E+02
Eu-152	2.4E+02	<0.05	2.1E+02	2.6E+02
Ni-59	1.6E+02	<0.05	9.7E+01	2.6E+02
Eu-155	1.1E+02	<0.05	3.6E+01	2.7E+02
Nb-94	4.7E+01	<0.05	2.8E+01	7.5E+01
C-14	4.3E+01	<0.05	2.6E+01	6.8E+01
Ce-141	3.1E+01	<0.05	2.8E+01	3.4E+01
U-234	4.8E+00	<0.05	3.8E+00	6.1E+00
Zr-93	4.0E+00	<0.05	2.4E+00	6.4E+00
Pu-241	1.5E+00	<0.05	1.4E+00	1.6E+00
Pu-238	1.0E+00	<0.05	4.6E-01	1.9E+00
U-238	6.6E-01	<0.05	5.5E-01	7.9E-01

Table 3-8a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Pu-239	4.8E-01	<0.05	2.1E-01	9.4E-01
U-235	1.6E-01	<0.05	1.2E-01	2.0E-01
Pu-242	1.0E-01	<0.05	9.0E-02	1.1E-01
Tc-99	3.0E-02	<0.05	1.8E-02	4.8E-02
Pu-240	1.0E-02	<0.05	9.0E-03	1.1E-02
U-236	4.0E-03	<0.05	3.6E-03	4.4E-03
Total	6.9E+05	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-8b. Inventory of radiological contaminants (listed alphabetically) from the Idaho Chemical Processing Plant (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
C-14	4.3E+01	<0.05	2.6E+01	6.8E+01
Ce-141	3.1E+01	<0.05	2.8E+01	3.4E+01
Ce-144	4.2E+04	6.1	3.2E+03	1.9E+05
Co-58	9.0E+04	13.0	6.3E+04	1.2E+05
Co-60	2.0E+05	28.9	1.2E+05	3.2E+05
Cr-51	8.4E+04	12.1	5.1E+04	1.3E+05
Cs-134	4.9E+02	0.1	3.0E+02	7.4E+02
Cs-137	4.2E+04	6.1	3.6E+04	4.8E+04
Eu-152	2.4E+02	<0.05	2.1E+02	2.6E+02
Eu-154	2.9E+02	<0.05	1.3E+02	5.4E+02
Eu-155	1.1E+02	<0.05	3.6E+01	2.7E+02
Fe-59	2.5E+04	3.6	1.5E+04	3.8E+04
Mn-54	8.1E+04	11.7	6.0E+04	1.1E+05
Nb-94	4.7E+01	<0.05	2.8E+01	7.5E+01
Nb-95	2.1E+03	0.3	1.6E+03	2.8E+03
Ni-59	1.6E+02	<0.05	9.7E+01	2.6E+02
Ni-63	2.5E+04	3.6	1.5E+04	3.9E+04
Pr-144	4.2E+04	6.1	3.2E+03	1.9E+05
Pu-238	1.0E+00	<0.05	4.6E-01	1.9E+00
Pu-239	4.8E-01	<0.05	2.1E-01	9.4E-01
Pu-240	1.0E-02	<0.05	9.0E-03	1.1E-02
Pu-241	1.5E+00	<0.05	1.4E+00	1.6E+00
Pu-242	1.0E-01	<0.05	9.0E-02	1.1E-01
Rh-106	6.8E+03	1.0	5.0E+03	9.0E+03
Ru-106	6.8E+03	1.0	5.0E+03	9.0E+03
Sb-125	2.9E+03	0.4	2.2E+03	3.9E+03
Sr-90	2.0E+04	2.8	1.9E+03	8.2E+04
Tc-99	3.0E-02	<0.05	1.8E-02	4.8E-02
U-234	4.8E+00	<0.05	3.8E+00	6.1E+00

Table 3-8b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
U-235	1.6E-01	<0.05	1.2E-01	2.0E-01
U-236	4.0E-03	<0.05	3.6E-03	4.4E-03
U-238	6.6E-01	<0.05	5.5E-01	7.9E-01
Y-90	1.9E+04	2.8	1.8E+03	8.2E+04
Zr-93	4.0E+00	<0.05	2.4E+00	6.4E+00
Zr-95	2.1E+03	0.3	1.5E+03	2.8E+03
Total	6.9E+05	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-9a. Inventory of nonradiological contaminants (listed by quantity) from the Naval Reactors Facility.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
—	Zirconium alloys	5.9E+06	4.7E+06	7.3E+06
7664393	Hydrofluoric acid	Unknown	NA[b]	NA
7439-92-1	Lead	Unknown	NA	NA
1332-21-4	Asbestos	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-9b. Inventory of nonradiological contaminants (listed alphabetically) from the Naval Reactors Facility.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
1332-21-4	Asbestos	Unknown	NA[b]	NA
7664393	Hydrofluoric acid	Unknown	NA	NA
7439-92-1	Lead	Unknown	NA	NA
—	Zirconium alloys	5.9E+06	4.7E+06	7.3E+06

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-10a. Inventory of radiological contaminants (listed by quantity) from the Naval Reactors Facility (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-60	1.1E+06	38.5	1.0E+06	1.2E+06
Fe-55	1.0E+06	36.7	9.9E+05	1.1E+06
Ni-63	2.2E+05	7.6	2.0E+05	2.3E+05
Sr-90	1.4E+05	4.7	9.2E+04	1.9E+05
Cs-137	1.4E+05	4.7	9.2E+04	1.9E+05
Sb-125	1.2E+05	4.3	1.1E+05	1.4E+05
Zr-95	7.3E+04	2.5	6.8E+04	7.8E+04
Sn-119m	2.7E+04	0.9	2.5E+04	3.0E+04
Co-58	2.0E+03	0.1	1.7E+03	2.4E+03
Total	2.9E+06	100.0		

Table 3-10b. Inventory of radiological contaminants (listed alphabetically) from the Naval Reactors Facility (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-58	2.0E+03	0.1	1.7E+03	2.4E+03
Co-60	1.1E+06	38.5	1.0E+06	1.2E+06
Cs-137	1.4E+05	4.7	9.2E+04	1.9E+05
Fe-55	1.0E+06	36.7	9.9E+05	1.1E+06
Ni-63	2.2E+05	7.6	2.0E+05	2.3E+05
Sb-125	1.2E+05	4.3	1.1E+05	1.4E+05
Sn-119m	2.7E+04	0.9	2.5E+04	3.0E+04
Sr-90	1.4E+05	4.7	9.2E+04	1.9E+05
Zr-95	7.3E+04	2.5	6.8E+04	7.8E+04
Total	2.9E+06	100.0		

Table 3-11a. Inventory of nonradiological contaminants (listed by quantity) from Argonne National Laboratory-West.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7439-92-1	Lead	1.4E+07	1.1E+07	1.7E+07
67-66-3	Chloroform	3.7E+01	3.6E+01	3.7E+01
—	Aqua regia	3.1E+01	3.0E+01	3.2E+01
56-23-5	Carbon tetrachloride	1.6E+01	1.5E+01	1.6E+01
7440-47-3	Chromium	Unknown	NA[b]	NA
7440-43-9	Cadmium	Unknown	NA	NA
1332-21-4	Asbestos	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-11b. Inventory of nonradiological contaminants (list alphabetically) from Argonne National Laboratory-West.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
—	Aqua regia	3.1E+01	3.0E+01	3.2E+01
1332-21-4	Asbestos	Unknown	NA[b]	NA
7440-43-9	Cadmium	Unknown	NA	NA
56-23-5	Carbon tetrachloride	1.6E+01	1.5E+01	1.6E+01
67-66-3	Chloroform	3.7E+01	3.6E+01	3.7E+01
7440-47-3	Chromium	Unknown	NA	NA
7439-92-1	Lead	1.4E+07	1.1E+07	1.7E+07

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-12a. Inventory of radiological contaminants (listed by quantity) from Argonne National Laboratory-West (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-60	3.3E+05	30.7	1.7E+05	5.9E+05
Sr-90	2.2E+05	20.7	1.8E+04	1.0E+06
Cs-137	1.4E+05	12.9	7.8E+04	2.3E+05
Cr-51	1.2E+05	11.4	8.7E+03	5.8E+05
Ce-144	1.0E+05	9.5	1.0E+04	4.3E+05
Mn-54	9.4E+04	8.6	6.7E+03	4.4E+05
Co-58	6.4E+04	5.8	4.7E+03	3.0E+05
Sb-124	1.8E+03	0.2	9.4E+00	1.3E+04
Cs-134	1.7E+03	0.2	1.9E+02	6.8E+03
Sb-125	1.2E+02	<0.05	7.8E-01	8.3E+02
Ce-141	1.9E+01	<0.05	1.7E+00	8.2E+01
Po-210	1.8E+01	<0.05	1.9E-01	1.2E+02
Fe-59	1.7E+01	<0.05	9.0E-02	1.2E+02
Pu-239	1.1E+01	<0.05	7.2E-02	7.9E+01
Ta-182	8.0E+00	<0.05	3.0E-01	4.4E+01
Nb-95	4.4E+00	<0.05	2.9E-01	2.1E+01
Be-10	4.3E+00	<0.05	2.2E-02	3.1E+01
U-234	3.4E+00	<0.05	3.0E+00	3.7E+00
Zr-95	1.4E+00	<0.05	9.2E-02	6.8E+00
U-238	1.2E+00	<0.05	1.2E+00	1.3E+00
U-235	2.7E-01	<0.05	2.6E-01	2.8E-01
Pu-238	2.2E-02	<0.05	5.9E-04	1.3E-01
Pu-240	8.0E-03	<0.05	6.0E-04	3.7E-02
Th-232	1.0E-05	<0.05	7.7E-06	1.3E-05
Am-241	1.8E-07	<0.05	4.8E-09	1.1E-06
Total	1.1E+06	100.0		

Table 3-12b. Inventory of radiological contaminants (listed alphabetically) from Argonne National Laboratory-West (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Am-241	1.8E-07	<0.05	4.8E-09	1.1E-06
Be-10	4.3E+00	<0.05	2.2E-02	3.1E+01
Ce-141	1.9E+01	<0.05	1.7E+00	8.2E+01
Ce-144	1.0E+05	9.5	1.0E+04	4.3E+05
Co-58	6.4E+04	5.8	4.7E+03	3.0E+05
Co-60	3.3E+05	30.7	1.7E+05	5.9E+05
Cr-51	1.2E+05	11.4	8.7E+03	5.8E+05
Cs-134	1.7E+03	0.2	1.9E+02	6.8E+03
Cs-137	1.4E+05	12.9	7.8E+04	2.3E+05
Fe-59	1.7E+01	<0.05	9.0E-02	1.2E+02
Mn-54	9.4E+04	8.6	6.7E+03	4.4E+05
Nb-95	4.4E+00	<0.05	2.9E-01	2.1E+01
Po-210	1.8E+01	<0.05	1.9E-01	1.2E+02
Pu-238	2.2E-02	<0.05	5.9E-04	1.3E-01
Pu-239	1.1E+01	<0.05	7.2E-02	7.9E+01
Pu-240	8.0E-03	<0.05	6.0E-04	3.7E-02
Sb-124	1.8E+03	0.2	9.4E+00	1.3E+04
Sb-125	1.2E+02	<0.05	7.8E-01	8.3E+02
Sr-90	2.2E+05	20.7	1.8E+04	1.0E+06
Ta-182	8.0E+00	<0.05	3.0E-01	4.4E+01
Th-232	1.0E-05	<0.05	7.7E-06	1.3E-05
U-234	3.4E+00	<0.05	3.0E+00	3.7E+00
U-235	2.7E-01	<0.05	2.6E-01	2.8E-01
U-238	1.2E+00	<0.05	1.2E+00	1.3E+00
Zr-95	1.4E+00	<0.05	9.2E-02	6.8E+00
Total	1.1E+06	100.0		

Table 3-13a. Inventory of nonradiological contaminants (listed by quantity) from the Rocky Flats Plant.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7631-99-4	Sodium nitrate	9.0E+08	5.9E+08	1.3E+09
7757-79-1	Potassium nitrate	4.5E+08	2.9E+08	6.6E+08
7439-92-1	Lead	1.9E+08	1.5E+08	2.4E+08
56-23-5	Carbon tetrachloride	1.2E+08	1.1E+08	1.4E+08
71-55-6	1,1,1-trichloroethane	1.1E+08	9.3E+07	1.2E+08
79-01-6	Trichloroethylene	1.0E+08	9.0E+07	1.2E+08
7757-82-6	Sodium sulfate	4.0E+07	2.6E+07	5.9E+07
7647-14-5	Sodium chloride	4.0E+07	2.6E+07	5.9E+07
127-18-4	Tetrachloroethylene	2.7E+07	2.3E+07	3.1E+07
7778-80-5	Potassium sulfate	2.0E+07	1.3E+07	2.9E+07
7447-40-7	Potassium chloride	2.0E+07	1.3E+07	2.9E+07
10101-89-0	Sodium phosphate	2.0E+07	1.3E+07	2.9E+07
75-09-2	Methylene chloride	1.4E+07	1.4E+07	1.5E+07
7778-77-0	Potassium phosphate	1.0E+07	6.5E+06	1.5E+07
76131	1,1,2-trichloro-1,2,2-trifluoroethane	9.1E+06	8.5E+06	9.8E+06
10588-01-9	Sodium dichromate	1.0E+06	6.5E+05	1.5E+06
7778-50-9	Potassium dichromate	5.7E+05	3.7E+05	8.4E+05
1330-20-7	Xylene	5.0E+05	4.5E+05	5.5E+05
67-56-1	Methyl alcohol	2.2E+05	2.0E+05	2.5E+05
71363	Butyl alcohol	9.9E+04	9.0E+04	1.1E+05
7440-43-9	Cadmium	6.6E+04	4.9E+04	8.7E+04
7440-41-7	Beryllium	9.0E-02	7.6E-02	1.0E-01
—	Organophosphates	Unknown	NA[b]	NA
—	Versenes	Unknown	NA	NA
—	Organic acids	Unknown	NA	NA
—	Nitrocellulose	Unknown	NA	NA
—	Dibutylethylcarbutol	Unknown	NA	NA
—	Alcohols	Unknown	NA	NA
7697-37-2	Nitric acid	Unknown	NA	NA

Table 3-13a. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7439-97-6	Mercury	Unknown	NA	NA
4165-60-0	Nitrobenzene	Unknown	NA	NA
1336363	PCB	Unknown	NA	NA
1309-48-4	Magnesium oxide	Unknown	NA	NA
1304-56-9	Beryllium oxide	Unknown	NA	NA
12057-24-8	Lithium oxide	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-13b. Inventory of nonradiological contaminants (listed alphabetically) from the Rocky Flats Plant.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
71-55-6	1,1,1-trichloroethane	1.1E+08	9.3E+07	1.2E+08
76131	1,1,2-trichloro-1,2,2-trifluoroethane	9.1E+06	8.5E+06	9.8E+06
—	Alcohols	Unknown	NA[b]	NA
7440-41-7	Beryllium	9.0E-02	7.6E-02	1.0E-01
1304-56-9	Beryllium oxide	Unknown	NA	NA
71363	Butyl alcohol	9.9E+04	9.0E+04	1.1E+05
7440-43-9	Cadmium	6.6E+04	4.9E+04	8.7E+04
56-23-5	Carbon tetrachloride	1.2E+08	1.1E+08	1.4E+08
—	Dibutylethylcarbutol	Unknown	NA	NA
7439-92-1	Lead	1.9E+08	1.5E+08	2.4E+08
12057-24-8	Lithium oxide	Unknown	NA	NA
1309-48-4	Magnesium oxide	Unknown	NA	NA
7439-97-6	Mercury	Unknown	NA	NA
67-56-1	Methyl alcohol	2.2E+05	2.0E+05	2.5E+05
75-09-2	Methylene chloride	1.4E+07	1.4E+07	1.5E+07
7697-37-2	Nitric acid	Unknown	NA	NA
4165-60-0	Nitrobenzene	Unknown	NA	NA
—	Nitrocellulose	Unknown	NA	NA
—	Organic acids	Unknown	NA	NA
—	Organophosphates	Unknown	NA	NA
1336363	PCB	Unknown	NA	NA
7447-40-7	Potassium chloride	2.0E+07	1.3E+07	2.9E+07
7778-50-9	Potassium dichromate	5.7E+05	3.7E+05	8.4E+05
7757-79-1	Potassium nitrate	4.5E+08	2.9E+08	6.6E+08
7778-77-0	Potassium phosphate	1.0E+07	6.5E+06	1.5E+07
7778-80-5	Potassium sulfate	2.0E+07	1.3E+07	2.9E+07
7647-14-5	Sodium chloride	4.0E+07	2.6E+07	5.9E+07
10588-01-9	Sodium dichromate	1.0E+06	6.5E+05	1.5E+06
7631-99-4	Sodium nitrate	9.0E+08	5.9E+08	1.3E+09

Table 3-13b. (continued).

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
10101-89-0	Sodium phosphate	2.0E+07	1.3E+07	2.9E+07
7757-82-6	Sodium sulfate	4.0E+07	2.6E+07	5.9E+07
127-18-4	Tetrachloroethylene	2.7E+07	2.3E+07	3.1E+07
79-01-6	Trichloroethylene	1.0E+08	9.0E+07	1.2E+08
—	Versenes	Unknown	NA	NA
1330-20-7	Xylene	5.0E+05	4.5E+05	5.5E+05

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-14a. Inventory of radiological contaminants (listed by quantity) from the Rocky Flats Plant (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Pu-241	3.9E+05	62.5	2.8E+05	5.3E+05
Am-241	1.5E+05	24.3	1.1E+05	2.0E+05
Pu-239	6.5E+04	10.4	4.7E+04	8.8E+04
Pu-240	1.4E+04	2.3	1.0E+04	2.0E+04
Pu-238	1.9E+03	0.3	1.4E+03	2.6E+03
Cs-137	2.1E+02	<0.05	7.4E+01	4.9E+02
Co-60	1.7E+02	<0.05	6.0E+01	4.0E+02
U-238	8.0E+01	<0.05	4.0E+01	1.5E+02
U-234	3.8E+01	<0.05	2.5E+01	5.6E+01
U-235	1.9E+00	<0.05	1.2E+00	2.9E+00
U-236	1.0E+00	<0.05	5.6E-01	1.8E+00
Pu-242	8.8E-01	<0.05	6.3E-01	1.2E+00
U-233	5.4E-01	<0.05	3.0E-01	9.0E-01
H-3	3.6E-01	<0.05	1.2E-01	8.3E-01
Ra-226	1.9E-01	<0.05	6.6E-02	4.4E-01
U-232	1.2E-02	<0.05	6.8E-03	2.1E-02
Total	6.2E+05	99.8[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-14b. Inventory of radiological contaminants (listed alphabetically) from the Rocky Flats Plant (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Am-241	1.5E+05	24.3	1.1E+05	2.0E+05
Co-60	1.7E+02	<0.05	6.0E+01	4.0E+02
Cs-137	2.1E+02	<0.05	7.4E+01	4.9E+02
H-3	3.6E-01	<0.05	1.2E-01	8.3E-01
Pu-238	1.9E+03	0.3	1.4E+03	2.6E+03
Pu-239	6.5E+04	10.4	4.7E+04	8.8E+04
Pu-240	1.4E+04	2.3	1.0E+04	2.0E+04
Pu-241	3.9E+05	62.5	2.8E+05	5.3E+05
Pu-242	8.8E-01	<0.05	6.3E-01	1.2E+00
Ra-226	1.9E-01	<0.05	6.6E-02	4.4E-01
U-232	1.2E-02	<0.05	6.8E-03	2.1E-02
U-233	5.4E-01	<0.05	3.0E-01	9.0E-01
U-234	3.8E+01	<0.05	2.5E+01	5.6E+01
U-235	1.9E+00	<0.05	1.2E+00	2.9E+00
U-236	1.0E+00	<0.05	5.6E-01	1.8E+00
U-238	8.0E+01	<0.05	4.0E+01	1.5E+02
Total	6.2E+05	99.8[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-15a. Inventory of nonradiological contaminants (listed by quantity) from the Central Facilities Area.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7439-92-1	Lead	1.8E+08	1.5E+08	2.3E+08
11135-81-2	Sodium potassium	1.7E+06	1.2E+06	2.4E+06
7440-67-7	Zirconium	1.3E+06	1.2E+06	1.5E+06
7697-37-2	Nitric acid	1.0E+06	6.8E+05	1.4E+06
7664393	Hydrofluoric acid	1.1E+05	7.3E+04	1.5E+05
7440-41-7	Beryllium	5.9E+04	2.3E+04	1.3E+05
7664-93-9	Sulfuric acid	1.5E+04	1.3E+04	1.6E+04
143-33-9	Sodium cyanide	9.4E+02	3.2E+02	2.2E+03
1310-73-2	Sodium hydroxide	1.5E+02	5.1E+01	3.4E+02
—	Cyanide	Unknown	NA[b]	NA
7439-97-6	Mercury	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-15b. Inventory of nonradiological contaminants (listed alphabetically) from the Central Facilities Area.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7440-41-7	Beryllium	5.9E+04	2.3E+04	1.3E+05
—	Cyanide	Unknown	NA[b]	NA
7664393	Hydrofluoric acid	1.1E+05	7.3E+04	1.5E+05
7439-92-1	Lead	1.8E+08	1.5E+08	2.3E+08
7439-97-6	Mercury	Unknown	NA	NA
7697-37-2	Nitric acid	1.0E+06	6.8E+05	1.4E+06
143-33-9	Sodium cyanide	9.4E+02	3.2E+02	2.2E+03
1310-73-2	Sodium hydroxide	1.5E+02	5.1E+01	3.4E+02
11135-81-2	Sodium potassium	1.7E+06	1.2E+06	2.4E+06
7664-93-9	Sulfuric acid	1.5E+04	1.3E+04	1.6E+04
7440-67-7	Zirconium	1.3E+06	1.2E+06	1.5E+06

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-16a. Inventory of nonradiological contaminants (listed by quantity) from offsite generators not otherwise specified.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7439-92-1	Lead	1.9E+07	1.6E+07	2.3E+07
7439-95-4	Magnesium	9.0E+06	7.4E+06	1.1E+07
7697-37-2	Nitric acid	7.0E+05	1.5E+05	2.1E+06
7790-86-5	Cerium chloride	5.1E+05	4.2E+05	6.2E+05
50-00-0	Formaldehyde	1.4E+05	1.3E+05	1.5E+05
7783-40-6	Magnesium fluoride	1.4E+05	1.3E+05	1.4E+05
120-12-7	Anthracene	2.0E+02	7.0E+01	4.6E+02
7631-99-4	Sodium nitrate	Unknown	NA[b]	NA
7580-67-8	Lithium hydride	Unknown	NA	NA
7440-41-7	Beryllium	Unknown	NA	NA
7440-23-5	Sodium	Unknown	NA	NA
7439-97-6	Mercury	Unknown	NA	NA
7439-96-5	Manganese	Unknown	NA	NA
71-43-2	Benzene	Unknown	NA	NA
67-56-1	Methyl alcohol	Unknown	NA	NA
64175	Ethyl alcohol	Unknown	NA	NA
56-49-5	3-methylcholanthrene	Unknown	NA	NA
56-23-5	Carbon tetrachloride	Unknown	NA	NA
55914	Diisopropylfluorophosphate	Unknown	NA	NA
1806-34-4	1,4-bis(5-phenyloxazol-2-YL)benzene	Unknown	NA	NA
1332-21-4	Asbestos	Unknown	NA	NA
1304-56-9	Beryllium oxide	Unknown	NA	NA
11135-81-2	Sodium potassium	Unknown	NA	NA
108-88-3	Toluene	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-16b. Inventory of nonradiological contaminants (listed alphabetically) from offsite generators not otherwise specified.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
1806-34-4	1,4-bis(5-phenyloxazol-2-YL)benzene	Unknown	NA[b]	NA
56-49-5	3-methylcholanthrene	Unknown	NA	NA
120-12-7	Anthracene	2.0E+02	7.0E+01	4.6E+02
1332-21-4	Asbestos	Unknown	NA	NA
71-43-2	Benzene	Unknown	NA	NA
7440-41-7	Beryllium	Unknown	NA	NA
1304-56-9	Beryllium oxide	Unknown	NA	NA
56-23-5	Carbon tetrachloride	Unknown	NA	NA
7790-86-5	Cerium chloride	5.1E+05	4.2E+05	6.2E+05
55914	Diisopropylfluorophosphate	Unknown	NA	NA
64175	Ethyl alcohol	Unknown	NA	NA
50-00-0	Formaldehyde	1.4E+05	1.3E+05	1.5E+05
7439-92-1	Lead	1.9E+07	1.6E+07	2.3E+07
7580-67-8	Lithium hydride	Unknown	NA	NA
7439-95-4	Magnesium	9.0E+06	7.4E+06	1.1E+07
7783-40-6	Magnesium fluoride	1.4E+05	1.3E+05	1.4E+05
7439-96-5	Manganese	Unknown	NA	NA
7439-97-6	Mercury	Unknown	NA	NA
67-56-1	Methyl alcohol	Unknown	NA	NA
7697-37-2	Nitric acid	7.0E+05	1.5E+05	2.1E+06
7440-23-5	Sodium	Unknown	NA	NA
7631-99-4	Sodium nitrate	Unknown	NA	NA
11135-81-2	Sodium potassium	Unknown	NA	NA
108-88-3	Toluene	Unknown	NA	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-17a. Inventory of nonradiological contaminants (listed by quantity) from the Power Excursion Reactor.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7439-92-1	Lead	2.1E+06	1.8E+06	2.5E+06
79-01-6	Trichloroethylene	4.1E+05	3.3E+05	5.0E+05
1330-20-7	Xylene	3.5E+05	2.4E+05	5.0E+05
71-55-6	1,1,1-trichloroethane	2.2E+05	1.6E+05	3.0E+05
108-88-3	Toluene	1.9E+05	1.3E+05	2.6E+05
67-64-1	Acetone	9.2E+04	7.6E+04	1.1E+05
78-93-3	2-butanone	3.2E+04	2.5E+04	4.0E+04
7440-43-9	Cadmium	1.5E+04	8.2E+03	2.6E+04
1332-21-4	Asbestos	1.1E+04	9.0E+03	1.4E+04
7440-22-4	Silver	5.9E+03	4.7E+03	7.3E+03
302012	Hydrazine	1.8E+03	1.3E+03	2.3E+03
7440-47-3	Chromium	4.5E+02	3.4E+02	5.9E+02
7440-36-0	Antimony	4.5E+02	1.6E+02	1.0E+03

a. CAS—Chemical Abstract Services.

Table 3-17b. Inventory of nonradiological contaminants (listed alphabetically) from the Power Excursion Reactor.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
71-55-6	1,1,1-trichloroethane	2.2E+05	1.6E+05	3.0E+05
78-93-3	2-butanone	3.2E+04	2.5E+04	4.0E+04
67-64-1	Acetone	9.2E+04	7.6E+04	1.1E+05
7440-36-0	Antimony	4.5E+02	1.6E+02	1.0E+03
1332-21-4	Asbestos	1.1E+04	9.0E+03	1.4E+04
7440-43-9	Cadmium	1.5E+04	8.2E+03	2.6E+04
7440-47-3	Chromium	4.5E+02	3.4E+02	5.9E+02
302012	Hydrazine	1.8E+03	1.3E+03	2.3E+03
7439-92-1	Lead	2.1E+06	1.8E+06	2.5E+06
7440-22-4	Silver	5.9E+03	4.7E+03	7.3E+03
108-88-3	Toluene	1.9E+05	1.3E+05	2.6E+05
79-01-6	Trichloroethylene	4.1E+05	3.3E+05	5.0E+05
1330-20-7	Xylene	3.5E+05	2.4E+05	5.0E+05

a. CAS—Chemical Abstract Services.

Table 3-18a. Inventory of nonradiological contaminants (listed by quantity) disposed of on Pad A.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7757-79-1	Potassium nitrate	1.4E+09	9.2E+08	2.0E+09
7631-99-4	Sodium nitrate	2.7E+08	1.8E+08	3.9E+08
7757-82-6	Sodium sulfate	1.2E+08	8.2E+07	1.7E+08
7647-14-5	Sodium chloride	1.2E+08	8.2E+07	1.7E+08
7778-80-5	Potassium sulfate	6.0E+07	4.1E+07	8.6E+07
7447-40-7	Potassium chloride	6.0E+07	4.1E+07	8.6E+07
10101-89-0	Sodium phosphate	6.0E+07	4.1E+07	8.6E+07
7778-77-0	Potassium phosphate	3.0E+07	2.1E+07	4.4E+07
10588-01-9	Sodium dichromate	3.1E+06	2.1E+06	4.4E+06
7778-50-9	Potassium dichromate	1.7E+06	1.1E+06	2.4E+06
7440-41-7	Beryllium	Unknown	NA[b]	NA

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-18b. Inventory of nonradiological contaminants (listed alphabetically) disposed of on Pad A.

CAS number[a]	Chemical	Best estimate (g)	Lower bound	Upper bound
7440-41-7	Beryllium	Unknown	NA[b]	NA
7447-40-7	Potassium chloride	6.0E+07	4.1E+07	8.6E+07
7778-50-9	Potassium dichromate	1.7E+06	1.1E+06	2.4E+06
7757-79-1	Potassium nitrate	1.4E+09	9.2E+08	2.0E+09
7778-77-0	Potassium phosphate	3.0E+07	2.1E+07	4.4E+07
7778-80-5	Potassium sulfate	6.0E+07	4.1E+07	8.6E+07
7647-14-5	Sodium chloride	1.2E+08	8.2E+07	1.7E+08
10588-01-9	Sodium dichromate	3.1E+06	2.1E+06	4.4E+06
7631-99-4	Sodium nitrate	2.7E+08	1.8E+08	3.9E+08
10101-89-0	Sodium phosphate	6.0E+07	4.1E+07	8.6E+07
7757-82-6	Sodium sulfate	1.2E+08	8.2E+07	1.7E+08

a. CAS—Chemical Abstract Services.

b. NA—not applicable.

Table 3-19a. Inventory of radiological contaminants (listed by quantity) from Argonne National Laboratory-East (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Sr-90	2.9E+02	61.2	5.8E+00	1.8E+03
Mn-54	1.1E+02	23.3	2.2E+00	6.9E+02
Co-60	5.8E+01	12.3	1.6E+01	1.6E+02
H-3	5.2E+00	1.1	1.0E-01	3.3E+01
Co-57	4.8E+00	1.0	9.6E-02	3.0E+01
U-238	1.3E+00	0.3	1.0E+00	1.7E+00
Ra-226	9.9E-01	0.2	7.7E-01	1.3E+00
Zn-65	6.2E-01	0.1	1.2E-02	3.9E+00
U-234	5.3E-01	0.1	4.1E-01	6.7E-01
Be-7	3.5E-01	0.1	7.1E-03	2.2E+00
Pu-240	2.4E-01	<0.05	4.7E-03	1.5E+00
Cd-109	1.9E-01	<0.05	3.9E-03	1.2E+00
Pu-239	1.8E-01	<0.05	3.6E-03	1.1E+00
Cr-51	1.2E-01	<0.05	2.4E-03	7.5E-01
Na-22	8.5E-02	<0.05	1.7E-03	5.4E-01
Fe-59	7.4E-02	<0.05	1.5E-03	4.7E-01
Zr-95	6.0E-02	<0.05	1.2E-03	3.8E-01
U-235	3.8E-02	<0.05	2.9E-02	4.8E-02
I-125	2.9E-02	<0.05	5.9E-04	1.8E-01
S-35	2.6E-02	<0.05	5.1E-04	1.6E-01
Y-88	2.5E-02	<0.05	5.0E-04	1.6E-01
Sc-46	2.5E-02	<0.05	5.0E-04	1.6E-01
Sc-44	2.5E-02	<0.05	5.0E-04	1.6E-01
Am-241	2.3E-02	<0.05	4.7E-04	1.5E-01
Ag-110	1.2E-02	<0.05	2.5E-04	7.9E-02
Eu-152	5.7E-03	<0.05	1.1E-04	3.6E-02
Cs-137	3.8E-03	<0.05	1.0E-03	1.0E-02
C-14	1.6E-03	<0.05	3.2E-05	1.0E-02
Ru-106	1.0E-03	<0.05	2.0E-05	6.3E-03

Table 3-19a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Mn-53	1.0E-03	<0.05	2.0E-05	6.3E-03
Cm-244	9.8E-04	<0.05	2.0E-05	6.2E-03
Eu-154	9.5E-04	<0.05	1.9E-05	6.0E-03
Np-237	8.5E-04	<0.05	1.7E-05	5.4E-03
Co-58	3.3E-04	<0.05	6.6E-06	2.1E-03
Th-232	3.1E-04	<0.05	2.4E-04	4.0E-04
Cs-134	3.0E-04	<0.05	6.1E-06	1.9E-03
Ni-63	2.5E-04	<0.05	6.7E-05	6.7E-04
U-233	4.2E-05	<0.05	3.2E-05	5.3E-05
Pu-238	3.0E-05	<0.05	6.1E-07	1.9E-04
Pb-212	2.0E-05	<0.05	4.0E-07	1.3E-04
Pu-242	1.4E-05	<0.05	2.9E-07	9.1E-05
Am-243	9.2E-06	<0.05	1.8E-07	5.8E-05
Pb-210	9.1E-06	<0.05	1.8E-07	5.7E-05
Ce-144	8.0E-06	<0.05	1.6E-07	5.0E-05
Tc-99	2.0E-06	<0.05	4.0E-08	1.3E-05
Ru-103	2.0E-06	<0.05	4.0E-08	1.3E-05
Ra-225	2.0E-06	<0.05	1.5E-06	2.5E-06
Rn-222	1.0E-06	<0.05	2.0E-08	6.3E-06
Cd-104	1.5E-07	<0.05	3.0E-09	9.5E-07
Total	4.7E+02	99.7[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-19b. Inventory of radiological contaminants (listed alphabetically) from Argonne National Laboratory-East (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ag-110	1.2E-02	<0.05	2.5E-04	7.9E-02
Am-241	2.3E-02	<0.05	4.7E-04	1.5E-01
Am-243	9.2E-06	<0.05	1.8E-07	5.8E-05
Be-7	3.5E-01	0.1	7.1E-03	2.2E+00
C-14	1.6E-03	<0.05	3.2E-05	1.0E-02
Cd-104	1.5E-07	<0.05	3.0E-09	9.5E-07
Cd-109	1.9E-01	<0.05	3.9E-03	1.2E+00
Ce-144	8.0E-06	<0.05	1.6E-07	5.0E-05
Cm-244	9.8E-04	<0.05	2.0E-05	6.2E-03
Co-57	4.8E+00	1.0	9.6E-02	3.0E+01
Co-58	3.3E-04	<0.05	6.6E-06	2.1E-03
Co-60	5.8E+01	12.3	1.6E+01	1.6E+02
Cr-51	1.2E-01	<0.05	2.4E-03	7.5E-01
Cs-134	3.0E-04	<0.05	6.1E-06	1.9E-03
Cs-137	3.8E-03	<0.05	1.0E-03	1.0E-02
Eu-152	5.7E-03	<0.05	1.1E-04	3.6E-02
Eu-154	9.5E-04	<0.05	1.9E-05	6.0E-03
Fe-59	7.4E-02	<0.05	1.5E-03	4.7E-01
H-3	5.2E+00	1.1	1.0E-01	3.3E+01
I-125	2.9E-02	<0.05	5.9E-04	1.8E-01
Mn-53	1.0E-03	<0.05	2.0E-05	6.3E-03
Mn-54	1.1E+02	23.3	2.2E+00	6.9E+02
Na-22	8.5E-02	<0.05	1.7E-03	5.4E-01
Ni-63	2.5E-04	<0.05	6.7E-05	6.7E-04
Np-237	8.5E-04	<0.05	1.7E-05	5.4E-03
Pb-210	9.1E-06	<0.05	1.8E-07	5.7E-05
Pb-212	2.0E-05	<0.05	4.0E-07	1.3E-04
Pu-238	3.0E-05	<0.05	6.1E-07	1.9E-04
Pu-239	1.8E-01	<0.05	3.6E-03	1.1E+00

Table 3-19b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Pu-240	2.4E-01	<0.05	4.7E-03	1.5E+00
Pu-242	1.4E-05	<0.05	2.9E-07	9.1E-05
Ra-225	2.0E-06	<0.05	1.5E-06	2.5E-06
Ra-226	9.9E-01	0.2	7.7E-01	1.3E+00
Rn-222	1.0E-06	<0.05	2.0E-08	6.3E-06
Ru-103	2.0E-06	<0.05	4.0E-08	1.3E-05
Ru-106	1.0E-03	<0.05	2.0E-05	6.3E-03
S-35	2.6E-02	<0.05	5.1E-04	1.6E-01
Sc-44	2.5E-02	<0.05	5.0E-04	1.6E-01
Sc-46	2.5E-02	<0.05	5.0E-04	1.6E-01
Sr-90	2.9E+02	61.2	5.8E+00	1.8E+03
Tc-99	2.0E-06	<0.05	4.0E-08	1.3E-05
Th-232	3.1E-04	<0.05	2.4E-04	4.0E-04
U-233	4.2E-05	<0.05	3.2E-05	5.3E-05
U-234	5.3E-01	0.1	4.1E-01	6.7E-01
U-235	3.8E-02	<0.05	2.9E-02	4.8E-02
U-238	1.3E+00	0.3	1.0E+00	1.7E+00
Y-88	2.5E-02	<0.05	5.0E-04	1.6E-01
Zn-65	6.2E-01	0.1	1.2E-02	3.9E+00
Zr-95	6.0E-02	<0.05	1.2E-03	3.8E-01
Total	4.7E+02	99.7[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-20a. Inventory of radiological contaminants (listed by quantity) from the Auxiliary Reactor Area (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Sr-90	3.4E+03	53.3	5.2E+02	1.2E+04
Cs-137	2.4E+03	36.9	1.5E+03	3.5E+03
Co-60	2.7E+02	4.2	1.5E+02	4.5E+02
Cr-51	1.6E+02	2.5	1.6E+00	1.1E+03
Ni-59	1.2E+02	1.8	5.5E-01	8.4E+02
Fe-59	8.0E+01	1.2	7.8E-01	5.6E+02
U-238	1.6E+00	<0.05	1.3E+00	2.1E+00
Ag-110	8.3E-01	<0.05	4.4E-03	6.0E+00
Nb-95	7.1E-01	<0.05	5.5E-03	5.0E+00
U-234	6.4E-01	<0.05	4.9E-01	8.1E-01
Zr-95	6.1E-01	<0.05	3.8E-03	4.4E+00
U-233	6.0E-01	<0.05	3.6E-01	9.5E-01
Ce-141	2.1E-01	<0.05	1.0E-03	1.5E+00
Eu-154	2.0E-01	<0.05	9.6E-04	1.4E+00
Eu-152	2.0E-01	<0.05	9.6E-04	1.4E+00
Cs-134	1.9E-01	<0.05	9.1E-04	1.4E+00
Ce-144	1.3E-01	<0.05	6.2E-04	9.5E-01
U-235	2.3E-02	<0.05	1.0E-02	4.4E-02
Pu-239	6.8E-03	<0.05	3.8E-04	3.4E-02
Am-241	1.0E-05	<0.05	4.8E-08	7.3E-05
Total	6.5E+03	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-20b. Inventory of radiological contaminants (listed alphabetically) from the Auxiliary Reactor Area (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ag-110	8.3E-01	<0.05	4.4E-03	6.0E+00
Am-241	1.0E-05	<0.05	4.8E-08	7.3E-05
Ce-141	2.1E-01	<0.05	1.0E-03	1.5E+00
Ce-144	1.3E-01	<0.05	6.2E-04	9.5E-01
Co-60	2.7E+02	4.2	1.5E+02	4.5E+02
Cr-51	1.6E+02	2.5	1.6E+00	1.1E+03
Cs-134	1.9E-01	<0.05	9.1E-04	1.4E+00
Cs-137	2.4E+03	36.9	1.5E+03	3.5E+03
Eu-152	2.0E-01	<0.05	9.6E-04	1.4E+00
Eu-154	2.0E-01	<0.05	9.6E-04	1.4E+00
Fe-59	8.0E+01	1.2	7.8E-01	5.6E+02
Nb-95	7.1E-01	<0.05	5.5E-03	5.0E+00
Ni-59	1.2E+02	1.8	5.5E-01	8.4E+02
Pu-239	6.8E-03	<0.05	3.8E-04	3.4E-02
Sr-90	3.4E+03	53.3	5.2E+02	1.2E+04
U-233	6.0E-01	<0.05	3.6E-01	9.5E-01
U-234	6.4E-01	<0.05	4.9E-01	8.1E-01
U-235	2.3E-02	<0.05	1.0E-02	4.4E-02
U-238	1.6E+00	<0.05	1.3E+00	2.1E+00
Zr-95	6.1E-01	<0.05	3.8E-03	4.4E+00
Total	6.5E+03	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-21a. Inventory of radiological contaminants (listed by quantity) from Battelle Northwest Laboratories (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
H-3	1.8E-01	93.5	8.5E-04	1.3E+00
Co-60	1.2E-02	6.5	1.1E-03	5.3E-02
C-14	5.0E-06	<0.05	2.4E-08	3.6E-05
Am-241	1.2E-06	<0.05	5.8E-09	8.7E-06
U-238	2.0E-09	<0.05	1.2E-09	3.2E-09
Total	1.9E-01	100.0		

Table 3-21b. Inventory of radiological contaminants (listed alphabetically) from Battelle Northwest Laboratories (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Am-241	1.2E-06	<0.05	5.8E-09	8.7E-06
C-14	5.0E-06	<0.05	2.4E-08	3.6E-05
Co-60	1.2E-02	6.5	1.1E-03	5.3E-02
H-3	1.8E-01	93.5	8.5E-04	1.3E+00
U-238	2.0E-09	<0.05	1.2E-09	3.2E-09
Total	1.9E-01	100.0		

Table 3-22a. Inventory of radiological contaminants (listed by quantity) from Central Facilities Area (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-60	1.7E+02	59.9	6.1E+01	3.9E+02
Sr-90	6.8E+01	23.4	4.5E+00	3.2E+02
Cs-137	4.7E+01	16.4	2.6E+01	7.9E+01
Fe-59	3.5E-01	0.1	1.9E-03	2.5E+00
U-238	3.5E-01	0.1	2.3E-01	5.2E-01
U-234	1.7E-01	0.1	1.0E-01	2.8E-01
Ra-226	3.8E-02	<0.05	3.4E-02	4.2E-02
U-235	2.0E-02	<0.05	1.3E-02	2.9E-02
Mn-54	2.9E-03	<0.05	3.2E-04	1.2E-02
Ru-103	1.2E-03	<0.05	1.4E-04	5.0E-03
Pu-240	1.0E-03	<0.05	1.1E-04	4.0E-03
P-32	1.0E-03	<0.05	5.1E-06	7.3E-03
Ba-133	5.4E-04	<0.05	2.8E-06	3.9E-03
I-131	1.4E-04	<0.05	1.6E-05	5.7E-04
Sr-85	1.0E-04	<0.05	1.1E-05	4.0E-04
Cs-134	3.3E-05	<0.05	3.6E-06	1.3E-04
Total	2.9E+02	100.0		

Table 3-22b. Inventory of radiological contaminants (listed alphabetically) from Central Facilities Area (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ba-133	5.4E-04	<0.05	2.8E-06	3.9E-03
Co-60	1.7E+02	59.9	6.1E+01	3.9E+02
Cs-134	3.3E-05	<0.05	3.6E-06	1.3E-04
Cs-137	4.7E+01	16.4	2.6E+01	7.9E+01
Fe-59	3.5E-01	0.1	1.9E-03	2.5E+00
I-131	1.4E-04	<0.05	1.6E-05	5.7E-04
Mn-54	2.9E-03	<0.05	3.2E-04	1.2E-02
P-32	1.0E-03	<0.05	5.1E-06	7.3E-03
Pu-240	1.0E-03	<0.05	1.1E-04	4.0E-03
Ra-226	3.8E-02	<0.05	3.4E-02	4.2E-02
Ru-103	1.2E-03	<0.05	1.4E-04	5.0E-03
Sr-85	1.0E-04	<0.05	1.1E-05	4.0E-04
Sr-90	6.8E+01	23.4	4.5E+00	3.2E+02
U-234	1.7E-01	0.1	1.0E-01	2.8E-01
U-235	2.0E-02	<0.05	1.3E-02	2.9E-02
U-238	3.5E-01	0.1	2.3E-01	5.2E-01
Total	2.9E+02	100.0		

Table 3-23a. Inventory of radiological contaminants (listed by quantity) from decontamination and decommissioning (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
H-3	3.3E+03	58.0	1.6E+01	2.4E+04
Co-60	1.6E+03	27.6	1.5E+02	6.7E+03
Ni-63	6.7E+02	11.8	6.0E+01	2.9E+03
Cs-137	6.2E+01	1.1	1.2E+01	2.0E+02
Fe-55	6.1E+01	1.1	5.5E+00	2.6E+02
Sr-90	1.3E+01	0.2	3.0E-01	8.4E+01
Ni-59	4.0E+00	0.1	1.9E-02	2.9E+01
Nb-94	2.0E+00	<0.05	9.6E-03	1.4E+01
Cs-134	8.1E-02	<0.05	7.9E-04	5.6E-01
Co-58	2.2E-02	<0.05	2.1E-04	1.5E-01
Pu-238	1.3E-03	<0.05	3.4E-05	8.0E-03
U-235	1.9E-04	<0.05	1.4E-04	2.6E-04
Eu-152	1.8E-05	<0.05	4.5E-07	1.1E-04
Eu-155	7.3E-06	<0.05	1.8E-07	4.4E-05
Am-241	5.8E-07	<0.05	1.5E-08	3.5E-06
Total	5.7E+03	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-23b. Inventory of radiological contaminants (listed alphabetically) from decontamination and decommissioning (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Am-241	5.8E-07	<0.05	1.5E-08	3.5E-06
Co-58	2.2E-02	<0.05	2.1E-04	1.5E-01
Co-60	1.6E+03	27.6	1.5E+02	6.7E+03
Cs-134	8.1E-02	<0.05	7.9E-04	5.6E-01
Cs-137	6.2E+01	1.1	1.2E+01	2.0E+02
Eu-152	1.8E-05	<0.05	4.5E-07	1.1E-04
Eu-155	7.3E-06	<0.05	1.8E-07	4.4E-05
Fe-55	6.1E+01	1.1	5.5E+00	2.6E+02
H-3	3.3E+03	58.0	1.6E+01	2.4E+04
Nb-94	2.0E+00	<0.05	9.6E-03	1.4E+01
Ni-59	4.0E+00	0.1	1.9E-02	2.9E+01
Ni-63	6.7E+02	11.8	6.0E+01	2.9E+03
Pu-238	1.3E-03	<0.05	3.4E-05	8.0E-03
Sr-90	1.3E+01	0.2	3.0E-01	8.4E+01
U-235	1.9E-04	<0.05	1.4E-04	2.6E-04
Total	5.7E+03	99.9[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-24a. Inventory of radiological contaminants (listed by quantity) from the Loss-of-Fluid Test Reactor (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-60	1.6E-03	50.0	2.1E-04	6.0E-03
Co-58	1.6E-03	50.0	8.5E-06	1.2E-02
Total	3.2E-03	100.0		

Table 3-24b. Inventory of radiological contaminants (listed alphabetically) from the Loss-of-Fluid Test Reactor (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-58	1.6E-03	50.0	8.5E-06	1.2E-02
Co-60	1.6E-03	50.0	2.1E-04	6.0E-03
Total	3.2E-03	100.0		

Table 3-25a. Inventory of radiological contaminants (listed by quantity) from offsite generators not otherwise specified (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Cs-137	2.2E+04	61.4	5.0E+03	6.6E+04
H-3	5.7E+03	15.6	5.6E+01	3.9E+04
Sr-90	2.4E+03	6.6	7.0E+01	1.4E+04
Co-60	2.0E+03	5.6	7.7E+02	4.4E+03
Fe-59	1.4E+03	3.8	3.7E+01	8.3E+03
Co-58	5.6E+02	1.5	8.4E+00	3.7E+03
Pu-239	5.0E+02	1.4	6.0E+00	3.4E+03
Pu-240	4.5E+02	1.2	4.4E+00	3.1E+03
Ni-59	3.5E+02	1.0	5.4E+00	2.3E+03
Zr-95	2.9E+02	0.8	2.8E+00	2.0E+03
Cr-51	1.8E+02	0.5	2.7E+00	1.2E+03
Ra-226	5.4E+01	0.1	4.0E+01	7.2E+01
Ir-192	5.4E+01	0.1	1.4E+00	3.2E+02
Po-210	5.2E+01	0.1	5.1E-01	3.6E+02
U-234	8.0E+00	<0.05	6.6E+00	9.7E+00
Tm-170	3.4E+00	<0.05	1.6E-02	2.4E+01
Sb-124	3.4E+00	<0.05	1.6E-02	2.4E+01
Ba-137m	3.4E+00	<0.05	1.6E-02	2.4E+01
U-238	2.7E+00	<0.05	2.2E+00	3.2E+00
Sc-46	1.5E+00	<0.05	1.5E-02	1.0E+01
Y-90	1.5E+00	<0.05	1.0E-02	1.1E+01
Kr-85	1.3E+00	<0.05	6.2E-03	9.5E+00
Th-232	1.3E+00	<0.05	1.0E+00	1.6E+00
Ru-106	1.2E+00	<0.05	1.7E-02	8.1E+00
Fe-55	1.0E+00	<0.05	2.3E-01	3.0E+00
Mo-99	1.0E+00	<0.05	1.5E-02	6.6E+00
Be-10	9.5E-01	<0.05	9.3E-03	6.6E+00
Ce-144	9.0E-01	<0.05	4.3E-03	6.6E+00
C-14	6.7E-01	<0.05	1.7E-02	4.0E+00

Table 3-25a. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
U-235	4.8E-01	<0.05	4.1E-01	5.6E-01
Y-91	3.1E-01	<0.05	3.1E-03	2.2E+00
Cl-36	3.1E-01	<0.05	3.1E-03	2.2E+00
Pm-147	2.3E-01	<0.05	2.5E-03	1.6E+00
Na-22	2.2E-01	<0.05	2.1E-03	1.5E+00
Cd-109	2.2E-01	<0.05	2.1E-03	1.5E+00
P-32	9.2E-02	<0.05	1.4E-03	6.0E-01
S-35	6.3E-02	<0.05	6.3E-04	4.3E-01
I-131	5.0E-02	<0.05	6.2E-04	3.4E-01
Sr-85	2.9E-02	<0.05	1.5E-04	2.1E-01
Zn-65	1.3E-02	<0.05	6.8E-05	9.2E-02
Hg-203	1.2E-02	<0.05	5.8E-05	8.7E-02
Cf-252	1.0E-02	<0.05	9.8E-05	6.9E-02
Yb-164	7.6E-03	<0.05	7.4E-05	5.3E-02
Er-169	7.6E-03	<0.05	7.4E-05	5.3E-02
Tl-204	6.7E-04	<0.05	3.2E-06	4.8E-03
Rb-86	6.7E-04	<0.05	3.2E-06	4.8E-03
Ca-45	6.7E-04	<0.05	3.2E-06	4.8E-03
Sr-89	Unknown	<0.05	NA[a]	NA
Total	3.6E+04			99.7[b]

a. NA—not applicable.

b. Total in table does not equal 100.0% due to round off.

Table 3-25b. Inventory of radiological contaminants (listed alphabetically) from offsite generators not otherwise specified (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Ba-137m	3.4E+00	<0.05	1.6E-02	2.4E+01
Be-10	9.5E-01	<0.05	9.3E-03	6.6E+00
C-14	6.7E-01	<0.05	1.7E-02	4.0E+00
Ca-45	6.7E-04	<0.05	3.2E-06	4.8E-03
Cd-109	2.2E-01	<0.05	2.1E-03	1.5E+00
Ce-144	9.0E-01	<0.05	4.3E-03	6.6E+00
Cf-252	1.0E-02	<0.05	9.8E-05	6.9E-02
Cl-36	3.1E-01	<0.05	3.1E-03	2.2E+00
Co-58	5.6E+02	1.5	8.4E+00	3.7E+03
Co-60	2.0E+03	5.6	7.7E+02	4.4E+03
Cr-51	1.8E+02	0.5	2.7E+00	1.2E+03
Cs-137	2.2E+04	61.4	5.0E+03	6.6E+04
Er-169	7.6E-03	<0.05	7.4E-05	5.3E-02
Fe-55	1.0E+00	<0.05	2.3E-01	3.0E+00
Fe-59	1.4E+03	3.8	3.7E+01	8.3E+03
H-3	5.7E+03	15.6	5.6E+01	3.9E+04
Hg-203	1.2E-02	<0.05	5.8E-05	8.7E-02
I-131	5.0E-02	<0.05	6.2E-04	3.4E-01
Ir-192	5.4E+01	0.1	1.4E+00	3.2E+02
Kr-85	1.3E+00	<0.05	6.2E-03	9.5E+00
Mo-99	1.0E+00	<0.05	1.5E-02	6.6E+00
Na-22	2.2E-01	<0.05	2.1E-03	1.5E+00
Ni-59	3.5E+02	1.0	5.4E+00	2.3E+03
P-32	9.2E-02	<0.05	1.4E-03	6.0E-01
Pm-147	2.3E-01	<0.05	2.5E-03	1.6E+00
Po-210	5.2E+01	0.1	5.1E-01	3.6E+02
Pu-239	5.0E+02	1.4	6.0E+00	3.4E+03
Pu-240	4.5E+02	1.2	4.4E+00	3.1E+03
Ra-226	5.4E+01	0.1	4.0E+01	7.2E+01

Table 3-25b. (continued).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Rb-86	6.7E-04	<0.05	3.2E-06	4.8E-03
Ru-106	1.2E+00	<0.05	1.7E-02	8.1E+00
S-35	6.3E-02	<0.05	6.3E-04	4.3E-01
Sb-124	3.4E+00	<0.05	1.6E-02	2.4E+01
Sc-46	1.5E+00	<0.05	1.5E-02	1.0E+01
Sr-85	2.9E-02	<0.05	1.5E-04	2.1E-01
Sr-89	Unknown	<0.05	NA[a]	NA
Sr-90	2.4E+03	6.6	7.0E+01	1.4E+04
Th-232	1.3E+00	<0.05	1.0E+00	1.6E+00
Tl-204	6.7E-04	<0.05	3.2E-06	4.8E-03
Tm-170	3.4E+00	<0.05	1.6E-02	2.4E+01
U-234	8.0E+00	<0.05	6.6E+00	9.7E+00
U-235	4.8E-01	<0.05	4.1E-01	5.6E-01
U-238	2.7E+00	<0.05	2.2E+00	3.2E+00
Y-90	1.5E+00	<0.05	1.0E-02	1.1E+01
Y-91	3.1E-01	<0.05	3.1E-03	2.2E+00
Yb-164	7.6E-03	<0.05	7.4E-05	5.3E-02
Zn-65	1.3E-02	<0.05	6.8E-05	9.2E-02
Zr-95	2.9E+02	0.8	2.8E+00	2.0E+03
Total	3.6E+04	99.7[b]		

a. NA—not applicable.

b. Total in table does not equal 100.0% due to round off.

Table 3-26a. Inventory of radiological contaminants (listed by quantity) from the Power Excursion Reactor (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Cs-137	9.7E+01	44.9	5.3E+01	1.6E+02
Be-10	3.8E+01	17.4	1.9E-01	2.7E+02
Sb-124	3.8E+01	17.4	1.9E-01	2.7E+02
Sr-90	2.3E+01	10.5	9.0E-01	1.2E+02
Co-60	2.1E+01	9.7	1.2E+01	3.3E+01
Ra-226	2.3E-01	0.1	1.4E-01	3.6E-01
U-238	1.2E-02	<0.05	1.0E-02	1.4E-02
U-235	3.7E-03	<0.05	3.2E-03	4.2E-03
Pu-239	5.0E-09	<0.05	2.0E-11	3.6E-08
Pu-238	5.0E-09	<0.05	2.0E-11	3.6E-08
Total	2.2E+02	100.0		

Table 3-26b. Inventory of radiological contaminants (listed alphabetically) from the Power Excursion Reactor (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Be-10	3.8E+01	17.4	1.9E-01	2.7E+02
Co-60	2.1E+01	9.7	1.2E+01	3.3E+01
Cs-137	9.7E+01	44.9	5.3E+01	1.6E+02
Pu-238	5.0E-09	<0.05	2.0E-11	3.6E-08
Pu-239	5.0E-09	<0.05	2.0E-11	3.6E-08
Ra-226	2.3E-01	0.1	1.4E-01	3.6E-01
Sb-124	3.8E+01	17.4	1.9E-01	2.7E+02
Sr-90	2.3E+01	10.5	9.0E-01	1.2E+02
U-235	3.7E-03	<0.05	3.2E-03	4.2E-03
U-238	1.2E-02	<0.05	1.0E-02	1.4E-02
Total	2.2E+02	100.0		

Table 3-27a. Inventory of radiological contaminants (listed by quantity) from the Radioactive Waste Management Complex (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Sr-90	4.8E+00	78.8	1.5E-01	2.8E+01
Cs-137	1.2E+00	20.0	4.1E-01	2.8E+00
Th-230	1.8E-02	0.3	1.4E-02	2.2E-02
U-238	1.8E-02	0.3	1.4E-02	2.2E-02
Ra-226	1.7E-02	0.3	1.4E-02	2.1E-02
U-234	1.7E-02	0.3	1.4E-02	2.1E-02
U-235	9.1E-04	<0.05	7.4E-04	1.1E-03
Co-60	4.1E-04	<0.05	1.4E-04	9.6E-04
Fe-59	3.9E-04	<0.05	1.2E-05	2.3E-03
Th-232	3.4E-04	<0.05	2.8E-04	4.1E-04
Total	6.1E+00	100.0		

Table 3-27b. Inventory of radiological contaminants (listed alphabetically) from the Radioactive Waste Management Complex (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-60	4.1E-04	<0.05	1.4E-04	9.6E-04
Cs-137	1.2E+00	20.0	4.1E-01	2.8E+00
Fe-59	3.9E-04	<0.05	1.2E-05	2.3E-03
Ra-226	1.7E-02	0.3	1.4E-02	2.1E-02
Sr-90	4.8E+00	78.8	1.5E-01	2.8E+01
Th-230	1.8E-02	0.3	1.4E-02	2.2E-02
Th-232	3.4E-04	<0.05	2.8E-04	4.1E-04
U-234	1.7E-02	0.3	1.4E-02	2.1E-02
U-235	9.1E-04	<0.05	7.4E-04	1.1E-03
U-238	1.8E-02	0.3	1.4E-02	2.2E-02
Total	6.1E+00	100.0		

Table 3-28a. Inventory of radiological contaminants (listed by quantity) disposed of on Pad A (activity at time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
U-238	2.5E+01	65.0	2.0E+01	3.0E+01
Pu-241	5.5E+00	14.2	4.5E+00	6.6E+00
U-234	4.7E+00	12.3	3.9E+00	5.6E+00
Co-60	1.8E+00	4.7	6.6E-01	4.0E+00
Pu-239	6.8E-01	1.8	4.7E-01	9.7E-01
U-235	3.3E-01	0.9	2.7E-01	4.0E-01
Pu-240	2.2E-01	0.6	6.4E-02	5.4E-01
Cs-137	2.1E-01	0.6	7.9E-02	4.7E-01
Pu-238	2.0E-02	<0.05	1.7E-02	2.5E-02
Th-232	2.8E-05	<0.05	2.3E-05	3.4E-05
Pu-242	1.2E-05	<0.05	1.0E-05	1.5E-05
Total	3.8E+01	100.1[a]		

a. Total in table does not equal 100.0% due to round off.

Table 3-28b. Inventory of radiological contaminants (listed alphabetically) disposed of on Pad A (activity at the time of disposal).

Radionuclide	Best estimate (Ci)	Percent of total (%)	Lower bound	Upper bound
Co-60	1.8E+00	4.7	6.6E-01	4.0E+00
Cs-137	2.1E-01	0.6	7.9E-02	4.7E-01
Pu-238	2.0E-02	<0.05	1.7E-02	2.5E-02
Pu-239	6.8E-01	1.8	4.7E-01	9.7E-01
Pu-240	2.2E-01	0.6	6.4E-02	5.4E-01
Pu-241	5.5E+00	14.2	4.5E+00	6.6E+00
Pu-242	1.2E-05	<0.05	1.0E-05	1.5E-05
Th-232	2.8E-05	<0.05	2.3E-05	3.4E-05
U-234	4.7E+00	12.3	3.9E+00	5.6E+00
U-235	3.3E-01	0.9	2.7E-01	4.0E-01
U-238	2.5E+01	65.0	2.0E+01	3.0E+01
Total	3.8E+01	100.1[a]		

a. Total in table does not equal 100.0% due to round off.

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4. EVALUATION OF INVENTORY ENTRIES FOR CONTAMINANTS WITH UNKNOWN QUANTITIES

4.1 Introduction

Section 3 presents the rolled-up results of the inventory compilation for radiological and nonradiological contaminants. Most of the entries for individual contaminants identified in individual waste streams had an associated quantity in which some confidence could be placed. Such entries were summed to produce the values in the Section 3 tables.

Several other contaminant entries were identified for which reliable estimates of the quantities were not possible. Even though there was generally strong evidence of the presence of the contaminant, insufficient information was available to the data gatherer to support a reliable estimate of the quantity. The contaminant quantities for such entries were listed as unknown in the Section 3 tables.

It is desirable to have a general idea of the magnitudes of the unknown quantities. Although the magnitudes of the unknowns cannot be known reliably, an inexact estimate or upper limit is useful for comparisons with the known quantities. Comparing the inexact estimates or upper limits of the unknown quantities with the best estimates of the known quantities gives a partial indication of the completeness of the inventory.

This section presents reasonable upper-limit estimates (not 95% confidence upper bounds on the best estimates), where possible, of nonradiological contaminants with quantities listed in CIDRA entries as unknown. These estimates are then compared with the best estimates of the known entries for the same contaminants.

For the unknown quantities of contaminants in the waste streams from the RFP, a somewhat different method was used. Section 4.2 explains this method.

Only CIDRA entries with unknown quantities of nonradiological contaminants were evaluated in detail. There are also a few entries in CIDRA with unknown quantities of radiological contaminants. However, several of these radionuclides have half-lives of less than 1 year; because they have been buried for more than 10 years, their activity is now negligible. The long-lived radionuclides Tc-99, Th-232, I-129, and Co-60 also exist in unknown quantities in some waste streams. However, because either the total volume of the waste stream is very small or the activity of their scaling radionuclide is small, the unknown activities can be discounted as negligible by comparison with other entries for the same radionuclide. Cesium-137 and C-14 also appear in unknown quantities, but the data sheets list them as being present in trace amounts. Thus, the unknown quantities of radiological contaminants are expected to be so small as not to justify further bounding analysis.

The results of the evaluation of the unknown quantities are not incorporated into CIDRA because of their lower reliability.

4.2 Approach

A CIDRA printout was generated that lists every inventory entry with an unknown quantity for any nonradiological contaminant in any waste stream.

The list was used to address two types of situations. In the first situation, all entries for a given contaminant indicate that the quantity is unknown. In the second situation, one or more entries list the quantity as unknown, whereas the same contaminant is listed with a known quantity in a different waste stream. The second situation was addressed because, with additional investigation, the unknown quantity could prove to be of comparable size or even larger than the known quantity.

The detailed data forms were reviewed for each unknown entry. As necessary, the preparer of the data form was contacted and any pertinent references cited on the data form were reviewed.

One additional type of situation was encountered. On a very few data forms, information was found in footnotes and descriptive fields that discussed contaminants not listed among the inventory entries in Part C because of the sparsity of details. With the addition of certain assumptions, such information could be used to estimate quantities of contaminants. This information was pursued in a similar manner to that discussed previously.

Because, by definition, no direct methods were available for estimating the quantities for the unknown entries, indirect methods, bounding estimates, and conservative assumptions were used to develop reasonable upper-limit estimates. For example, in many cases the volume of the waste shipment was known, and volumes of other items known to be present in the shipment were subtracted to obtain a reasonable upper-limit estimate of the unknown quantity of the contaminant.

For several contaminants, the upper-limit quantity in one stream was much larger than the amounts expected in other streams. An overall upper limit could be estimated based on knowledge of the one stream without having detailed knowledge of the amounts in the other streams.

For unknown quantities of contaminants in waste streams from the RFP, a somewhat different approach was used. Much of the waste from non-RFP generators tended to be shipment oriented. That is, the waste typically consisted of a relatively large number of individual, unique, one-time shipments, each of which was comparatively small in volume. Upper-limit estimates for unknown quantities of a contaminant in a given shipment could often be made based on the volume of each shipment. By contrast, the RFP waste tended to be process oriented. That is, the waste typically consisted of a relatively small number of types of waste, with very large volumes of each type. For example, thousands of nearly identical containers of first-stage sludge were shipped. The RFP waste was not amenable to the method of using shipment volumes and subtracting the volumes of known substances to obtain a reasonable upper limit for the unknown quantity of a contaminant. In addition, estimating an upper limit on the unknown quantity of a contaminant in one container of a given RFP waste stream, then multiplying by the very large number of containers in the waste stream, could lead to estimates of contaminant quantities that are unrealistically high. Therefore, for the RFP waste, the estimates for the unknown quantities of contaminants are generally best estimates rather than upper-limit estimates.

For some contaminants in some streams, no additional useful information was located to develop a reasonable upper limit or best estimate for the quantity. Such quantities remain wholly unknown.

The evaluation discussed in this section dealt only with contaminant quantities considered by the data gatherers to be unknown (i.e., no reliable estimates were possible). Therefore, the results presented here are less reliable than those for contaminant entries with known quantities. These results are useful only for rough comparisons.

Most of the results presented here for unknown quantities of contaminants are reasonable upper-limit quantities. (In the case of waste from the RFP, best estimates are generally presented.) The actual magnitudes of the unknown quantities of contaminants are probably much smaller. Thus, the nature of these comparisons generally presents the magnitude of the unknown quantities in the worst possible light (i.e., conservatively large). Exceptions to this situation occur in the case of some contaminants for which no estimates are possible for the (potentially large) quantities in certain streams. Examples are lead and asbestos.

4.3 Results

The detailed results of the evaluation of the unknown quantities are compiled in Appendix D. For each contaminant with one or more unknown entries, the designator is given for all waste streams containing unknown quantities of the contaminant. Next is a discussion of the attempt to estimate an upper-limit quantity (or, in the case of RFP waste, a best estimate). The last column of the table in Appendix D compiles the results for all unknown entries of that contaminant.

Table 4-1 compares the upper-limit estimates of the unknown quantities from Appendix D with the best estimates of the known quantities for the same contaminants. In some cases, comparisons could be made. If the two values were within a factor of two, one value was said to be "somewhat" smaller or larger than the other. If the difference was between a factor of two and a factor of five, the difference was said to be "considerable." If the difference was greater than a factor of five, one value was said to be "much" smaller or larger. (Qualitative comparisons were used because the lack of reliability of the estimates for the unknown quantities makes quantitative comparisons potentially misleading.) In some cases, comparisons were not possible.

4.4 Conclusions

As indicated in Table 4-1, one or more inventory entries with unknown quantities were identified for 36 nonradiological contaminants, considering Be/BeO as one entry. For 18 of these 36 contaminants, comparisons of the unknown quantities (upper limits in most cases) with the known quantities (best estimates) were possible. For 7 of the 18 contaminants, the unknown quantities are believed to be less than the known quantities. For the other 11 of the 18 contaminants, the unknown quantities could be larger than the known quantities. These 11 contaminants are asbestos, chloroform, copper, cyanide, ethyl alcohol, magnesium, mercury, methyl alcohol, organophosphates, terphenyl/diphenyl, and toluene.

For the remaining 18 contaminants, the conclusion was as follows. Evaluating the unknown quantities resulted in new estimates for 10 of the 18 contaminants because no known quantity was

Table 4-1. Comparisons of unknown quantities of contaminants with known quantities of the same contaminants in other waste streams.

Contaminant	Known quantity (g) (best estimate)	Unknown quantity (g) (reasonable upper limit[a])	Conclusion: size of unknown quantity (upper limit[a]) compared with known quantity (best estimate)[b]
1,4-bis(5-phenyloxazol-2-yl)benzene	None	2.0E+05	An upper-limit estimate for the unknown quantity is 2.0E+05 g
3-methyl-cholanthrene	None	E+05	An upper-limit estimate for the unknown quantity is E+05 g
Asbestos	1.2E+06	2.3E+06	Somewhat larger
Benzene	None	1.2E+05	An upper-limit estimate for the unknown quantity is 1.2E+05 g
Beryllium	1.5E+07 total beryllium as metal or oxide	8.0E+06	Somewhat smaller
Beryllium oxide		(combined with beryllium, above)	
Cadmium	1.6E+06	No information to support upper-limit estimate	No conclusion can be drawn
Carbon tetrachloride	1.2E+08	2.0E+05	Much smaller
Chloroform	3.7E+01	E+07	Much larger
Chromium	1.0E+03	No information to support upper-limit estimate	No conclusion can be drawn
Copper	1.1E+02 of copper in copper nitrate	4.5E+04	Much larger
Cyanide	9.4E+02 of sodium cyanide	2.9E+03	Considerably larger
Dibutylethylcarbutol	None	5.4E+06	A best estimate for the unknown quantity is 5.4E+06 g
Diisopropyl-fluorophosphate	None	<<E+05	An upper-limit estimate for the unknown quantity is <<E+05 g
Ether	None	No information to support upper-limit estimate	No conclusion can be drawn
Ethyl alcohol	2.2E+04	7.1E+07	Much larger
Hydrofluoric acid	7.6E+06	2.2E+06	Considerably smaller
Lead	5.8E+08	2.0E+07	Much smaller
Lithium hydride	None	There is no firm evidence that lithium hydride was disposed of in the SDA	There is no firm evidence that lithium hydride was disposed of in the SDA
Lithium oxide	None	No information to support best estimate	No conclusion can be drawn

Table 4-1. (continued).

Contaminant	Known quantity (g) (best estimate)	Unknown quantity (g) (reasonable upper limit[a])	Conclusion: size of unknown quantity (upper limit[a]) compared with known quantity (best estimate)[b]
Magnesium	9.0E+06, plus additional 1.4E+05 of magnesium fluoride	2.8E+05 magnesium metal plus 2.8E+08 of magnesium oxide	Much larger
Manganese	None	E+04	An upper-limit estimate for the unknown quantity is E+04 g
Mercury	4.7E+05 of mercury in mercury nitrate monohydrate	1.2E+06	Considerably larger
Methyl alcohol	2.2E+05	2.8E+05	Somewhat larger
Nickel	2.2E+03	No information to support upper-limit estimate	No conclusion can be drawn
Nitric acid	5.0E+07	2.3E+06	Much smaller
Nitrobenzene	None	No information to support best estimate; the quantity is unknown—trace	No conclusion can be drawn
Nitrocellulose	None	6.8E+06	A best estimate for the unknown quantity is 6.8E+06 g
Organic acids (assumed to be ascorbic acid)	None	7.1E+07	A best estimate for the unknown quantity is 7.1E+07 g
Organophosphates	1.0E+06 of tributylphosphate	5.4E+06, assumed to be tributylphosphate	Much larger
Polychlorinated biphenyls	None	2.4E+03	A best estimate for the unknown quantity is 2.4E+03 g
Sodium	6.8E+04	1E+02	Much smaller
Sodium nitrate	3.6E+09	4.5E+05	Much smaller
Sodium-potassium	1.7E+06	No information to support upper-limit estimate	No conclusion can be drawn
Terphenyl/diphenyl	4.5E+05 terphenyl, no diphenyl	5.9E+08 g for terphenyl; 1.8E+08 g for diphenyl	Much larger
Toluene	1.9E+05	2.0E+05	Somewhat larger

Table 4-1. (continued).

Contaminant	Known quantity (g) (best estimate)	Unknown quantity (g) (reasonable upper limit[a])	Conclusion: size of unknown quantity (upper limit[a]) compared with known quantity (best estimate)[b]
Versenes [assumed to be ethylenediaminetetraacetic acid (EDTA)]	None	7.1E+07	A best estimate for the unknown quantity is 7.1E+07 g

a. As explained in the text, for waste from non-RFP generators, the estimates of the unknown quantities of contaminants are generally upper-limit estimates; for waste from the RFP, the estimates are generally best estimates. The details given in Appendix D indicate which generators produced the various fractions of the quantities of each contaminant. If the RFP was the greatly dominant contributor of the unknown quantities of the contaminant, the estimate is called a best estimate. Otherwise, the estimate is called an upper-limit estimate.

b. If the two values were within a factor of two, one value was said to be "somewhat" smaller or larger than the other. If the difference was between a factor of two and a factor of five, the difference was said to be "considerable." If the difference was greater than a factor of five, one value was said to be "much" smaller or larger.

listed. (Alternatively, one could say that the known quantity was zero and that the unknown quantity, therefore, exceeded the known quantity.) For the final 8 of the 18 contaminants, no comparisons were possible because insufficient information was available to make even a reasonable upper-limit estimate.

Although the results presented here are not totally reliable, they do provide an essential perspective on how large the quantities of contaminants might be in the unknown entries, compared with those in the known entries. This information is also one qualitative measure of the level of confidence in the contaminant inventory.

5. DATA UNCERTAINTY: SOURCES AND METHODS FOR ESTIMATING

5.1 Purpose

Two primary objectives of this task were to (1) estimate the total quantity of each contaminant disposed of in the SDA during the years 1952 through 1983 and (2) attach uncertainty bounds to these total quantity estimates. Section 3 reports the results.

This section explains the approach to and results of the uncertainty-estimation process that led to the upper and lower bounds of the contaminant quantities. This section also discusses data uncertainties that led to corrections in best estimates because of biases.

Section 5.2 provides a brief, nontechnical summary of the approach. Section 5.3 addresses the applicable requirements. Section 5.4 discusses uncertainties and biases and how they were addressed.

5.2 Summary

Section 5 presents the statistical methods for obtaining best estimates of the contaminant quantities in waste buried in the SDA during the years 1952 through 1983 and the uncertainties in the best estimates. The equations that are developed allow the construction of upper and lower bounds on the quantity of a contaminant in the waste.

The analysis of historical documents and data uncovered a significant upward bias that can occur in estimating radioactivities in waste. This bias is in the G-M counter survey method used to assay much of the waste. The value of the upward bias is a factor of 2. Therefore, where appropriate, the best estimates were corrected for this bias. The corrections are presented in the following sections.

In addition to the bias, several sources of uncertainty exist in the best estimate that also must be estimated to construct upper and lower bounds on the actual quantity. The major sources identified and estimated include error in the G-M method bias correction, error in the G-M method, error because of using scaling factors when estimating radionuclide distributions, and random error. Depending on the situation, only a subset of these uncertainties is applicable.

Using standard error propagation techniques (NCRPM 1985), the applicable uncertainties are combined to produce an overall uncertainty in the best estimate, thus, allowing for construction of upper and lower bounds on the actual activity.

This bias does not apply to estimates of the quantities of nonradiological contaminants in the waste. Bounds on these quantities were established by more straightforward methods as described later in this section.

5.3 Requirements Concerning Uncertainty Estimates

According to the EPA's *Supplemental Guidance to RAGS: Calculating the Concentration Term* (EPA 1992), one of the most important inputs for a risk assessment is the concentrations of the

contaminants. EPA (1992) recommends that an average concentration be used. It also states that, because of the uncertainty associated with estimating the true average concentration at a site, the 95% upper confidence limit (UCL) of the arithmetic mean should be used. In the absence of data necessary for estimating UCLs, a value other than the 95% UCL can be used if the risk assessor can document that high coverage of the true population mean occurs, i.e., the value equals or exceeds the true population mean with high probability. While the guidance deals with contaminant concentrations, it can be applied equally well to contaminant quantities, which are the product of the HDT.

Many sources of uncertainty are inherent in quantifying the contaminant inventory of a waste site as complex as the SDA; some of them are quite large. It is not realistic to think that the total amount of each contaminant can be estimated statistically, especially in the absence of sampling, and that rigorous 95% confidence limits can be constructed. Therefore, the approach for estimating the contaminant inventory must be based on the second recommendation in EPA (1992). That is, a value other than the 95% UCL, but analogous to it, will be provided with reasonable justification that it provides coverage of the true total amount with high probability.

5.4 How Uncertainties and Biases Were Addressed

5.4.1 Background

The waste buried at the SDA during the years 1952 through 1983 originated from several generators over various time periods and consisted of many different types. Figure 5-1 depicts the steps in the waste handling process, from waste generation to disposal. The three boxes within the dashed oval are the steps that contribute to the uncertainty in the reported contaminant quantities in a shipment.

The step represented by the first box within the uncertainty oval is the measurement of radioactive waste volumes and radionuclide activities in the shipment. The uncertainty in the estimate is due to many sources of error in this measurement process. The measurement process depends on the type of waste being shipped and the waste generator.

The second box in the uncertainty oval pertains to the nonradioactive contaminants in the waste. Nonradiological contaminants were, at best, identified on shipping records as being part of a shipment to the SDA. A formal process for measuring and reporting nonradiological contaminants did not exist at that time, and quantities were generally not reported on shipping records. Therefore, estimating total quantities and uncertainties for the HDT was often based on sources other than the shipping records, e.g., process knowledge and interviews with personnel acquainted with the processes that produced specific waste streams. A major source of uncertainty is the incompleteness of the available information, which tends to underestimate the total quantities.

The third box in the uncertainty oval addresses recording the measurements on shipping records and transferring the information to the RWMIS database. Errors associated with transcription, summarization, interpretation, radionuclide distributions, and upper-limit reporting result in additional uncertainty in the reported total quantities of contaminants.

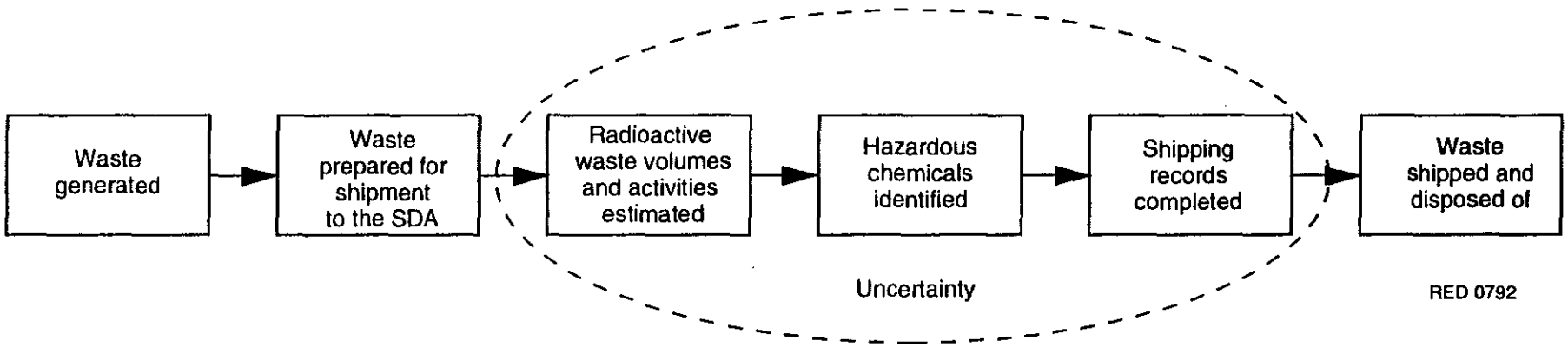

Figure 5-1. The process from waste generation to disposal.

As discussed in Section 2, a data form was filled out for each waste stream to record the knowledge gained in the information search. An important part of this process was identifying major sources of uncertainty. As mentioned previously, the contaminant-measurement process is dependent on the general type of waste. Furthermore, the generators used different processes and uncertainties differed in each step of the processes. The following subsections discuss the uncertainties.

5.4.2 Biases and Corrections for Radiological Data Originally Obtained by the Geiger-Müller Counter Survey Method

The minority of waste streams or waste shipments used sampling, other direct methods, or nuclear physics calculations to estimate radioactivity at the time of shipment. However, the majority of shipments used an indirect method at the time of shipment to estimate the radioactivity in a container of waste. The indirect method is a major source of uncertainty in estimates of radionuclide quantities for these generators. The specific method used since the 1950s is referred to here as the G-M counter survey method, or the G-M method. Another related source of uncertainty is that specific radionuclides are not identified in individual waste containers. These two sources of uncertainty are discussed in this section and in Section 5.4.3 in detail because of the large potential effect on the estimated radionuclide inventory.

The G-M method consists of taking radiation readings on each of the five exposed sides of a waste container using a calibrated G-M survey meter, averaging the readings, and multiplying by a constant number to convert the average radiation reading to the estimated radioactivity in curies. Several sources of uncertainty are inherent in this process: (a) the geometric position of the radiation source in the container, (b) the type of radiation from the particular radionuclides present in the container, (c) the density of the materials within the container (termed the "fill matrix"), and (d) the error in the survey meter itself.

Three documented studies (Simpson et al. 1982, Hartwell et al. 1987, and Hartwell and Thompson 1988) have explored the adequacy of the G-M method as applied to INEL waste containers. Although the studies involved only low-radiation-level containers, the results are believed to be generally accurate for higher-radiation-level containers.

The position of the source in the container appears to be a particularly large contributor to the uncertainty. According to Simpson et al. (1982), an upward bias of at least 50% (compared with more rigorous methods, such as gamma-ray spectrometry) was measured when a known MFP test source was located at the center of a mock-up waste box. (The G-M method was derived originally from theoretical considerations for steel waste dumpsters, but it was applied to many kinds of waste boxes.) When the source was located away from the center of the box, biases as large as 8,500% were measured for unusual situations. Simpson et al. (1982) concluded that the G-M method is highly susceptible to overestimating the actual curie content because of "hot spots" located near a container side and the small detector-to-source distance.

Simpson et al. (1982) also noted that results using the G-M method depended on the radionuclides present in the container, compared with the radionuclides used in developing and calibrating the method. For example, if the radionuclide in the container were Co-60 and if 0.7-MeV gammas had been assigned for conversion of the radiation readings to the estimated radioactivity, the effect could be overestimation by a factor of 2 (USHEW 1970).

Another significant contributor to the uncertainty is the density of the waste container fill matrix. This contributor includes both self-shielding within the source and shielding because of other materials within the container. Hartwell et al. (1987) investigated this effect and concluded the actual curie content is underestimated even at very slight attenuation. As the fill matrix density increases, the attenuation increases, and the underestimation becomes more severe. The conversion calculation from radiation reading to curies assumes that the container offers very slight attenuation. Thus, the conversion does not account for this problem. Tests conducted on various densities of fill matrix (Hartwell et al. 1987) indicated underestimates using the G-M method ranging from approximately -90% to -50% (i.e., factors of one-tenth to one-half) of the known actual value. Because the safety of the people handling the waste was a primary consideration, it is reasonable to assume that the fill matrix density was purposely increased to provide additional shielding protection. Interviews have confirmed this assumption, which further inflates an already significant negative bias.

Interviews with health physics personnel indicated that, during the early years, the random error in the survey meter was $\pm 20\%$. After approximately 1976, improvements in the calibration of the meters reduced this error to $\pm 10\%$.

Because of the highly variable (shipment-dependent) nature of the sources of the above uncertainty estimates, a statistically rigorous propagation to an overall uncertainty was not feasible. However, by combining professional judgment, reasonable assumptions, and standard statistical techniques, defendable bounds on actual quantities could be determined. These bounds are analogous to 95% confidence limits and represent "reasonable certainty" that they contain the true value. The following paragraphs describe the rationale used in arriving at estimates of the bias and the random error in the G-M method.

Uncertainty in the G-M method because of source position is a positive bias ranging from 50% to 8,500%, depending on the position of the source. The closer the source is to a face of the container, the more severe the bias. Typically, the contamination is not concentrated in a small volume of the container, but rather it is distributed throughout the container. A reasonable assumption is uniform distribution throughout the container. If we also assume that the bias increases (according to the inverse of the source-to-detector distance squared) from 50% to 8,500% as the source is moved from the center of the container to a face, the resulting average bias because of source position for a uniformly distributed source is approximately 1,050%, or 11.5 times the true value.

As stated previously, the bias because of density of the fill matrix ranges from -50% to -90%, depending on the density, based on measurements of mock-up containers with known sources and fill materials ranging from air to stacked paper (specific gravity approximately 0.8) (see Hartwell et al. 1987). The majority of the waste containers during the time period of interest would be expected to have effective fill densities no more than that of stacked paper. (This observation is based on a review of data for waste generated more recently and the fact that container packing density has increased over the years.)

The combined bias because of source position and fill density was evaluated as follows. Based on the data described above, the largest value that could be used for the combined bias is 8,500% (a factor of 86) for source location and -50% (a factor of 0.5) for fill density, which yields a product of 4,200% (a factor of 43). The smallest value that could be used for the combined bias is 50%

(a factor of 1.5) for source location and -90% (a factor of 0.1) for fill density, which yields a product of -85% (a factor of 0.15). However, these extreme values reflect highly unusual situations, such as a waste container in which a point source of radiation rests against one inner face of the container and nothing else except air is inside the container.

A more realistic set of limits on the bias was developed by assuming a uniformly distributed radiation source within the waste container. As stated above, the average bias because of source position in this case is 1,050% (a factor of 11.5). The same range of fill densities as above was retained. Thus, the largest realistic value that could be used for the combined bias is 1,050% (a factor of 11.5) for source location and -50% (a factor of 0.5) for fill density, which yields a product of 475% (a factor of 5.75). The smallest realistic value that could be used for the combined bias is 1,050% (a factor of 11.5) for source location and -90% (a factor of 0.1) for fill density, which yields a product of 15% (a factor of 1.15). A midpoint value for the combined bias is 1,050% (a factor of 11.5) for the source location and -70% (a factor of 0.3) for fill density, which yields a product of 245% (a factor of 3.45). This is the best estimate for the value of the bias. To be somewhat conservative, however, a combined bias of 100% (a factor of 2) was used for these two factors. In other words, ignoring variability because of error in the survey meter, the actual radioactivities are expected to be approximately one-half of the value of the reported measurements using this method.

The studies documented in Hartwell and Thompson (1988) and Simpson et al. (1982) include the measurements of numerous waste containers using the more accurate gamma-ray spectrometry method and the G-M method. In all cases, the G-M method resulted in measurements exceeding those of the gamma-ray spectrometry method by percentages ranging from 10% to 3,500%. This lends some confirmation to the conservative estimate of the positive bias of a factor of 2 and to the range of realistic combined biases derived above.

While the actual energy of the radiation from the radionuclides in a waste container is definitely a contributor to error in the reported activities, it was not included in the bias correction because a large portion of the inventory is near the assumed energy level of 0.7 MeV. Radionuclides of higher energy exist in substantial quantities as well, but their effect on the bias is to further overestimate the total quantities. To be conservative, this effect was ignored.

Thus, if the radioactivity in a waste stream was originally estimated using the G-M method, the reported estimates of total radionuclide quantities for specific years were divided by 2 to correct for these biases and to arrive at a best estimate. This correction is an approximation because of the large numbers and varieties of waste streams and radionuclides involved. However, use of the correction is believed to result in a more accurate inventory than use of the uncorrected G-M counter readings.

The random error because of the G-M survey meter was conservatively assumed to be $\pm 20\%$ for all radioactivity estimates believed to have been developed using the G-M method during the time period of interest. The total random error, including the uncertainty in the bias correction, is developed in Section 5.4.5.

As stated previously, for certain waste streams, the data gatherers used records of direct measurements, personal knowledge, interviews, and nuclear physics calculations to arrive at a sound

judgment on the uncertainty in their reported total quantities. In these cases, the data gatherers' uncertainty estimates were used to determine upper and lower bounds on the total quantities.

There are some exceptions to the approaches described above. These exceptions occurred when (a) the data gatherer lacked sufficient information to provide uncertainty estimates in the reported total quantities, and (b) the bias correction for the G-M method was not applicable. The bias correction is not applicable for radionuclides emitting weak gamma rays or no gamma rays.

If uncertainty information does not exist in the appropriate data fields for the bounds on radionuclide quantities, CIDRA automatically calculates upper and lower bounds (see Section 5.4.5) after correcting for the G-M method bias by dividing the reported estimate by 2. To ensure that these automatic calculations are not performed erroneously for radionuclides that emit very little or no gamma radiation, each waste stream was checked manually for these potential occurrences. Where there was any indication that the G-M method was not used for the radionuclides in question, estimates for the upper and lower bounds were provided to ensure that the G-M method correction was not applied.

The following paragraphs discuss some additional considerations that apply in developing the uncertainties for waste from NRF and ANL-W.

Because high-energy-emitting Co-60 was the principal radionuclide of interest at NRF, the survey meters were typically calibrated using high-energy radiation. This adds some uncertainty in the measurement when the container holds large quantities of radionuclides emitting low-energy radiation (e.g., Fe-55 and Ni-63). These uncertainties, however, are not considered to be any more significant than other assay uncertainties. Therefore, the bias and uncertainty estimates described in this section were also applied to most of the waste from NRF. The exception was the scrap core structural material shipped from ECF in scrap casks.

In a letter dated February 27, 1989 (Bartolomucci 1989), the manager of ECF Engineering at NRF informed EG&G Idaho that the past method for estimating radioactivity, or curie content, for scrap casks was in error. The letter provided revised curie content estimates, and these revised estimates were subsequently incorporated into the RWMIS database. Bartolomucci (1989) did not, however, assign uncertainty limits to the estimates.

Another letter issued by NRF (Nieslanik 1994) applied an accuracy of +10% and -30% to scrap cask activity calculations, taking into consideration incomplete content data on some cores when received, approximations that deleted radionuclides contributing less than 1% to the total activity, and assumptions that had to be made regarding radioactive flux and core life.

The method used by NRF to arrive at radioactivity estimates for the scrap cask shipments was based on knowledge of the metal alloys in the reactor core structural materials and reactor core radiation history. This information allowed NRF to calculate the extent of expected neutron activation of the core structural material. This activity was then decayed for the length of time from the end of reactor operation until the scrap was shipped from ECF to the SDA.

In summary, the NRF uncertainty estimate of +10% and -30% for the scrap cask estimates was used in this report; however, the bias and uncertainty estimates in this section related to the G-M method were applied to all the other waste from NRF.

Radioactivity estimates of ANL-W waste generated after 1970 were made at the time of shipment using a refined G-M counter method. The method factored in the type of waste container and other information. This method is considered more reliable than the typical G-M counter method, which was used by all generators listed previously. Therefore, upon the advice of ANL-W technical personnel, no bias correction was applied to ANL-W waste activity measurements made beginning in 1971. The random error was specified by ANL-W personnel to be ±25% for such measurements.

For all generators, the CIDRA database lists the radionuclide quantities (including the effects of the G-M correction, if any) as the "best estimates." The uncorrected quantities are also available from CIDRA and are called the "reported estimates."

5.4.3 Scaling Factor Uncertainties for Radiological Data

Another significant source of uncertainty is due to the use of scaling factors for estimating radionuclide distributions. In fact, based on the following analysis, it appears to be the dominant source of uncertainty in estimates of the total activity of many radionuclides.

A scaling factor is a fraction or percentage representing the activity of one radionuclide relative to the activity of another radionuclide or to the total activity of a group of radionuclides. Scaling factors were used to estimate the activities of several difficult-to-measure radionuclides in waste shipments to the SDA. For example, suppose the total activity in a waste shipment is 100 Ci and the scaling factor for Sr-90 (whose activity is difficult to measure outside a laboratory) is 0.15 (15%). Then the estimated activity of Sr-90 in the shipment is 15 Ci.

Scaling factors were developed by evaluating the data from analytical laboratories possessing the capabilities to analyze the activities of these difficult-to-measure radionuclides and relating the activities to those of easily analyzed radionuclides or total sample activities.

The uncertainty in the scaling factor must be estimated and incorporated into the overall uncertainty in the radionuclide activity. The following paragraphs provide an overview of the development of the uncertainty estimates for the scaling factors. Einerson and Smith (1995) provides the details. Section 5.4.5 incorporates the scaling factor uncertainty into the overall uncertainty.

Limited INEL data exist on scaling factors for the waste disposed of in the SDA. The most comprehensive data available for other locations exist in a report prepared for the Electric Power Research Institute (EPRI 1987). That report provides the results of an extensive data collection and analysis effort, including activities of several radionuclides from various waste types and reactor types. The data most closely resembling SDA waste came from samples originating in waste from pressurized water reactors of commercial nuclear utilities.

Two basic approaches are possible for estimating the uncertainty that arises from the use of scaling factors. The first approach is to identify all of the sources of uncertainty inherent in the

process of developing and using scaling factors (e.g., analytical error or error because of the G-M survey method). These uncertainties are then propagated to obtain an estimate of the overall uncertainty attributed to the use of scaling factors. The second method is strictly empirical. This approach involves using a large data set (such as that found in the EPRI report) containing the activities of several radionuclides for several waste streams. Then, by constructing scaling factors and estimating the distributional properties, the uncertainty is empirically developed.

Because a large data set that is somewhat representative of the SDA waste streams exists in the EPRI (1987) report, the empirical approach was used here. The three basic steps were to (1) choose subsets of the EPRI radionuclides thought to best represent the radionuclides present in the SDA waste, (2) estimate the scaling factor mean, standard deviation, and relative standard deviation (RSD) (the uncertainty) for each radionuclide in this subset, and (3) apply these uncertainty estimates to appropriate subsets of the radionuclides and waste streams for the SDA waste. A subset of radionuclides from the EPRI data was selected because the analysis of every radionuclide would have added only minimal information.

The subset of radionuclides analyzed from the EPRI data included C-14, Fe-55, Ni-63, Sr-90, Tc-99, I-129, Co-60, and Cs-137. These radionuclides were selected because they represent the difficult-to-measure radionuclides present in the SDA waste and the radionuclides to which their activities are compared. Therefore, they should demonstrate the range of scaling factor uncertainties inherent in the radionuclides present in the SDA waste.

The scaling factor for a radionuclide was taken to be the ratio of the activity for the radionuclide to the total activity in the waste. The total activity in a sample was defined here to be the sum of the eight radionuclides given above and is shown in Equation (5-1). It is recognized that, in actuality, several more radionuclides may constitute the total set. However, it seems reasonable to assume that the estimate of scaling factor uncertainty will not depend on the number of radionuclides used when calculating a "total" activity as long as the set of radionuclides used is representative and fairly comprehensive.

The total activity in a sample is shown in Equation (5-1):

$$t_j = \Sigma_i a_{ij} \qquad (5\text{-}1)$$

where

t_j = total activity for sample j

a_{ij} = activity of radionuclide i for sample j.

Then for each sample and each radionuclide used in this analysis, a scaling factor can be written as

$$w_{ij} = a_{ij}/t_j \qquad (5\text{-}2)$$

where

w_{ij} = scaling factor for radionuclide i and sample j.

The uncertainty referred to above is in terms of the RSD, which is defined as the standard deviation divided by the mean. Therefore, the next step in the analysis was to estimate the mean, standard deviation, and RSD of the scaling factors for each radionuclide across all samples for waste from pressurized water reactors in EPRI (1987). The results are presented in Table 5-1, along with the number of samples comprising the estimates.

Logical groupings of RSD values are apparent from the results in Table 5-1. The scaling factor RSDs for Fe-55, Ni-63, Co-60, and Cs-137 are 0.9, 1.0, 0.7, and 1.1, respectively. The scaling factor RSDs for C-14, Sr-90, I-129, and Tc-99 are 3.4, 4.8, 3.7, and 4.4, respectively. Based on these results, two values of the scaling factor RSDs, 1 and 5, were chosen for application to the uncertainty estimates for the radionuclides in the SDA waste that involved the use of scaling factors. These values of 1 and 5 were chosen based on simplicity and conservatism. While it would have been possible in theory to estimate a separate RSD for each of the approximately 100 radionuclides, the effort was not warranted considering the limited additional accuracy obtainable and the limited data available.

As described in Einerson and Smith (1995), the uncertainty in the scaling factors also depends on the particular waste stream in which the radionuclide exists because the method of estimating the activity of a given radionuclide sometimes varied from stream to stream. Thus, the radionuclides in the SDA waste can be placed into three groups corresponding to the three possibilities of scaling factor uncertainty: RSDs of 0, 1, and 5. An RSD of 0 occurs for those radionuclides for which scaling factors were not used in determining their activity.

Table 5-2 presents the scaling factor uncertainty used for each of the radionuclides when incorporating this uncertainty into the overall uncertainty of the total activities. Einerson and Smith (1995) presents the rules for applying scaling factor uncertainties, as well as some exceptions to Table 5-2 based on the method used to estimate the distribution for each waste stream.

Unless excluded by either or both considerations related to an RSD of 0 or an excluded waste stream, the scaling factor uncertainty was added to the other identified uncertainties whether or not the data gatherer had listed upper and lower bounds for the radioactivity entry on the datasheets.

Table 5-1. Scaling factor relative standard deviations for EPRI (1987) data.

Ratio	Number of samples	RSD
C-14/total	273	3.4
Fe-55/total	268	0.9
Ni-63/total	280	1.0
Sr-90/total	234	4.8
Tc-99/total	30	4.4
I-129/total	20	3.7
Co-60/total	333	0.7
Cs-137/total	241	1.1

Table 5-2. Scaling factor relative standard deviations for use in the historical data task uncertainty estimate.

Radionuclides	Scaling factor RSD used in uncertainty estimate
U, Th, Ra (all isotopes of)	0
Cs-137, Co-60, Fe-55, Ni-63	1
All other radionuclides	5

One exception to the scaling factor RSDs in Table 5-2 involves waste streams NRF-618-1H and NRF-618-6H. For these streams, the scaling factor RSD for Sr-90 was taken to be a value of 1 rather than 5. This exception was based on data collected by NRF.

5.4.4 Uncertainties for Nonradiological Contaminants

For nonradiological contaminants, the main source of uncertainty is the lack of information. For some waste streams, the data gatherers obtained good estimates and associated uncertainties of the total quantities of particular contaminants. In these instances, the data gatherers' estimates were used. These estimates are for a variety of contaminants from several waste streams and can be considered a representative subset of all the nonradiological contaminants identified. The upper bounds estimated by the data gatherers ranged from 1 to 3.6 times the estimated amount, with the majority being less than a factor of 2. When lacking uncertainty information, a factor of 2, based on the data gatherer's professional judgment, was conservatively used to construct an upper bound on the quantities disposed of.

5.4.5 Best Estimates and Bounds

Each waste stream from each waste generator was identified, and annual quantities of radiological and nonradiological contaminants in the streams were estimated. In addition to these estimates of annual quantities disposed of, bounds on these estimates were calculated. While it was not possible to calculate 95% confidence limits in the standard way because of the lack of sampling and appropriate data, it was possible to arrive at reasonable and defensible bounds based on the historical information acquired and on knowledge of the sources of uncertainty described in the preceding sections.

When possible, the bounds provided represent the data gatherers' indication that, with reasonable certainty, the true annual quantities buried are contained within them. In some cases, the data gatherers' indications are based on knowledge of the particular waste stream and the measurement methods used at the time. In other cases, heavier reliance was placed on professional judgment. When professional judgment could not be made, generic error bounds were constructed by propagation of known biases and uncertainties. "Reasonable certainty" can be considered analogous

to 95% confidence; while not statistically rigorous, it represents a legitimate attempt at quantifying a very difficult parameter.

With the assumption that the bounds estimated by the data gatherers (or through propagation) represent 95% confidence limits, the following discussion presents the method used to propagate the uncertainties so that uncertainty bounds could be constructed on the total amount of a contaminant disposed of at the SDA in all waste streams.

An individual contaminant may occur in a variety of forms and in a variety of waste streams. Therefore, it may or may not be useful to group all occurrences together when estimating contaminant quantities for use in a risk assessment. Groupings of contaminant occurrences will have to be performed based on the particular objectives of the data used in the risk assessment.

After a risk assessor determines a desired grouping, all occurrences in CIDRA for which the contaminant meets the grouping specification (e.g., a particular physical form of the contaminant) are flagged. An occurrence is a single row of Part C or Part D of the data form (see Appendix A). Each row corresponds to information for one contaminant from a single waste stream for a single year (or a range of years during which the generation rate was assumed constant). A single data form is restricted to describing only a single waste stream.

After the contaminants of interest have been selected, grouped, and flagged in the database, the next step is to estimate the quantities needed by the risk assessor. These include the best estimate of the total amount of a contaminant disposed of and its upper bound (analogous to a 95% UCL) for each uniquely flagged contaminant grouping.

The best estimate for the total amount of a contaminant grouping is the sum over all waste streams and all years for that contaminant grouping, as expressed by Equation (5-3):

$$T = \Sigma_i \Sigma_j T_{ij} \qquad (5\text{-}3)$$

where

T = best estimate of the total quantity of a particular contaminant grouping disposed of

T_{ij} = best estimate of the quantity of the particular contaminant grouping disposed of from waste stream i in year j.

To construct an upper bound on T requires s_{ij}, the standard deviations of T_{ij}. In cases where analysis data or professional judgment have been used to estimate U_{ij}, the upper bound on T_{ij}, the standard deviation of T_{ij} can be estimated as given in Equation (5-4).

$$s_{ij} = (U_{ij} - T_{ij})/2, \text{ when based on analysis data or professional judgment.} \qquad (5\text{-}4)$$

When such information is not available, s_{ij} is estimated based on the biases and random error involved. For radiological contaminants, the bias was shown earlier to range from a factor of 1.15 to a factor of 5.75. Thus, a bias correction (division by the bias) would range from 0.87 to 0.17 with a midpoint of 0.5, which is the correction factor used. It is assumed that this range is an approximate

95% confidence interval on the true bias. Given this assumption, an estimate of the uncertainty s_k (one standard deviation) in the bias correction is shown in Equation (5-5).

$$s_k = \frac{\text{range of 95\% confidence interval}}{4} = \frac{0.87 - 0.17}{4} = 0.17 \quad (5\text{-}5)$$

The estimate of the uncertainty, s_X, because of random error in the G-M survey meter is 20% of the reported quantity, as given in Equation (5-6).

$$s_{X_{ij}} = 0.2X_{ij} \quad (5\text{-}6)$$

where

X_{ij} = the reported quantity of a particular contaminant grouping disposed of from waste stream i in year j.

The estimate of the uncertainty because of the scaling factor, in terms of the RSD s_w/w, depends on the specific radionuclide and waste stream, as mentioned in Section 5.4.3 and discussed in detail in Einerson and Smith (1995). The three distinct cases are RSDs of 0, 1, and 5.

Combining these uncertainties, using the method of statistical differentials (Kotz and Johnson 1988), leads to a formula for estimating the standard deviation of T_{ij}, as shown in Equations (5-7) and (5-8).

$$T_{ij} = kX_{ij} \quad (5\text{-}7)$$

where

k = the bias correction, whose value is 0.5.

$$s_{ij} = \sqrt{(kX_{ij})^2 \left[\left(\frac{s_k}{k}\right)^2 + \left(\frac{s_{X_{ij}}}{X_{ij}}\right)^2 + \left(\frac{s_w}{w}\right)^2\right]} \quad (5\text{-}8)$$

$$= T_{ij}\sqrt{0.16 + \left(\frac{s_w}{w}\right)^2}, \text{ when analysis data or professional judgement are not available.}$$

For nonradiological contaminants, a conservative estimate of half the reported quantity, based on the discussion in Section 5.4.4, is used for s_{ij} when professional judgment cannot be made.

$s_{ij} = 0.5T_{ij}$, for nonradiological contaminants when professional judgment cannot be made. (5-9)

The standard deviation s of T can then be calculated as

$$s = (\Sigma_i \Sigma_j s_{ij}^2)^{1/2} \quad . \tag{5-10}$$

Data of this type typically follow a lognormal distribution (Gilbert 1987). Therefore, it is reasonable to assume that the total activity T of a radionuclide (or total quantity of a nonradiological contaminant) is lognormally distributed with mean α and standard deviation β, where α and β are estimated by T and s. Because of the relationship between the normal and lognormal distributions (Blackwood 1992), it follows that the natural logarithm of T is normally distributed with mean μ and standard deviation σ with

$$\alpha = e^{\mu + \frac{1}{2}\sigma^2} \tag{5-11}$$

$$\beta^2 = e^{2\mu + \sigma^2}\left(e^{\sigma^2} - 1\right) \quad . \tag{5-12}$$

Solving for μ and σ and using T and s as estimates of α and β gives:

$$\mu = \ln(T) - \frac{1}{2}\sigma^2 \tag{5-13}$$

$$\sigma^2 = \ln\left(\frac{T^2 + s^2}{T^2}\right) \quad . \tag{5-14}$$

An upper bound on the total quantity for a particular contaminant grouping U can now be calculated as shown in Equation (5-15).

$$U = e^{(\mu + 2\sigma)} \quad . \tag{5-15}$$

The construction of a lower bound L on T is analogous to the upper bound and is given in Equation (5-16).

$$L = e^{(\mu - 2\sigma)} \quad . \tag{5-16}$$

The above approach cannot be considered statistically rigorous. However, with the combination of professional judgment, reasonable assumptions, and conservative approximations, there is reasonable certainty (i.e., 95% confidence) that the upper bounds derived with this approach are not exceeded.

References for Section 5

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6. CONFIRMING THE COMPLETENESS OF THE RESULTS

This section compares the contaminant inventory against estimates given in previous reports and in existing databases, to the extent that such comparisons are possible and meaningful. In some cases, adjustments were necessary to compare values on the same basis. The inventory is also compared against the list of contaminants detected in environmental monitoring conducted at the RWMC. The results of all these comparisons help to confirm the credibility and substantial completeness of the inventory compiled in this task.

Although estimates of waste volume are included in CIDRA, no similar comparisons have been performed to confirm the accuracy of the volume estimates. The BRA will not use the volume estimates from CIDRA, so no special confirmation was considered necessary.

6.1 Comparison of Inventory with Estimates Given in Earlier Reports

Many earlier reports (see the references cited in Sections 2 and 3, for example) provide useful information on the inventories of contaminants buried in the SDA. The earlier reports were examined as part of the data-gathering for the HDT. However, the inventories in the earlier reports either (a) contain estimates for only a portion of the total inventory (e.g., only one disposal unit), (b) provide mostly or solely qualitative information, (c) deal with a somewhat different time period, or (d) were developed for a different purpose and made different assumptions to deal with the lack of definitive data in the original records. Therefore, only limited comparisons were possible between the total inventory developed in the HDT and the inventories in previous reports. Nevertheless, even the limited comparisons are useful to help confirm the credibility and substantial completeness of the current results.

6.1.1 Nonradiological Contaminants

Several reports provide estimates of the nonradiological contaminants disposed of in the SDA. Some of the reports provide estimates for waste disposed of in essentially the entire SDA; others concentrate on one particular disposal unit, such as Pad A, Pit 9, or the Acid Pit.

The CIDRA estimates are intended to be best estimates for waste buried in the entire SDA from 1952 through 1983. If contaminants were known to be present but no definitive information on the quantities was available, the best estimate was listed as unknown. Separately, attempts were made to provide an upper bound or inexact estimate for these unknown quantities, using various assumptions. The evaluation of these unknown quantities is provided in Section 4 and Appendix D.

The CIDRA inventory of nonradiological contaminants was compared against the inventory information listed in seven documents. Three of these documents contain information on waste that was disposed of in the entire SDA, two documents apply only to waste disposed of in Pit 9, one document applies only to waste placed on Pad A, and one document applies only to waste disposed of in the Acid Pit.

Cerven (1987) provides a compilation of nonradiological contaminants in the SDA. The data are based on RWMIS and on technical estimates and interviews involving personnel familiar with the waste generators or with RWMC operations. The compilation included disposal through 1987, rather than the 1983 cutoff used in this document, but it excluded some sludges, resins, and waste in the Acid Pit.

- The draft *Remedial Investigation/Feasibility Study Work Plan for the Subsurface Disposal Area Radioactive Waste Management Complex at the INEL* (EG&G Idaho 1989) provides estimates of the nonradiological contaminants disposed of in the SDA. It includes data from Cerven (1987), but it provides a more detailed analysis of the information. It also includes data from Garcia and Knight (1989a) and other documents.

Garcia and Knight (1989a) was used for SDA information because it was a source document for data on the estimated amounts of lead and mercury disposed of in the SDA. The majority of the document addresses estimates of Pit 9 contents. To prevent confusion on the applicability of the data, no Pit 9 data from Garcia and Knight were used in the present comparisons. Instead, Liekhus (1992) and Figueroa et al. (1992) were used for the Pit 9 information.

Halford et al. (1993) provides information for comparison of the nonradiological contaminants on Pad A. The report provides estimated chemical masses for the inorganic constituents in the RFP evaporator salts on Pad A based on a private communication. The report also provides analyses of one RFP salt drum retrieved from Pad A in January 1990, resuspended nitrate salt dust from the RFP drum loading area that was sampled in 1984, a 1978 sample of 36% salt solution from the RFP feed pond, and calculated concentrations from the shipping records covering 1972 through 1976.

Liekhus (1992) and Figueroa et al. (1992) provide detailed analysis of the nonradiological contaminants estimated to have been disposed of in Pit 9. The Pit 9 inventory has been the subject of considerable study as part of the CERCLA interim action activities of the Pit 9 project. In addition, Pit 9 is expected to contain a substantial fraction of the inventory of certain nonradiological contaminants in the entire SDA during the time period of interest. Therefore, comparisons against the Pit 9 inventory are useful.

The majority of Pit 9 waste came from the RFP. The Pit 9 inventory is based mainly on RWMIS, shipping records, and numerous assumptions and calculations in Liekhus (1992). Some of the Liekhus results were intentionally conservative, worst-case estimates based on calculations in the absence of definitive information in the waste records. The Liekhus estimates were intended to provide upper-limit inventories for use in the safety analysis report and the hazard classification of the Pit 9 project. Thus, because of the worst-case assumptions and the single disposal unit, the Pit 9 results are not strictly comparable with those in CIDRA, which include almost the entire SDA.

Jorgensen (1992) provides results and assessments of the characterization studies performed on the Acid Pit and a compilation of the disposal records for the waste disposed of in that unit. The compilation provides volumes and compositions of waste. It sometimes provides concentrations of the contaminants. For the comparisons presented in this report, some assumptions were necessary and calculations were performed on the Jorgensen results to convert them to estimated grams of the nonradiological contaminants disposed of in the Acid Pit.

Tables 6-1 and 6-2 compare the nonradiological organic (Table 6-1) and inorganic (Table 6-2) contaminants estimated in CIDRA and in the inexact estimates of the unknown quantities (from Section 4 and Appendix D) against estimates in the seven other reports discussed above.

An additional report, on organic contamination in the vadose zone underlying the SDA (Duncan et al. 1993), was also reviewed but is not included in Table 6-1. The inventory data in the report are the same quantities of organic compounds given in the Cerven (1987) and EG&G Idaho (1989) reports, which are included in Table 6-1.

The first conclusion from the comparisons is that the information in CIDRA and in the unknown quantities list includes many more contaminants than are listed in the seven other reports. This might be expected for the Pit 9 and Acid Pit data, because those reports address only one disposal unit. The combined CIDRA and unknown quantity list is longer than the contaminant list for the other SDA reports because of the increased efforts to obtain the information for this report.

The following paragraphs compare the combined values from CIDRA and the unknown quantities against the values in the other reports. Only the highlights of the comparisons are discussed, with most of the emphasis on explaining any entries for which the other reports listed larger quantities than those estimated in this report.

Ethylene glycol. The Cerven (1987) report furnished information on seven drums of ethylene glycol buried in a trench at the SDA between 1954 and 1970. The present search did not identify ethylene glycol in any of the waste streams.

Benzene and benzine. The Cerven (1987) report furnished some information on 0.1 m^3 of waste containing benzene. A review of the RWMIS potential hazardous materials listing did not show any benzene, but it did show 0.085 m^3 of benzine. It is assumed here that Cerven took this to be a typographic error and listed the material as benzene, and the quantity was rounded to 0.1 m^3. Therefore, the quantity of benzene in the Cerven report is listed in Table 6-1 as benzine. Benzene is estimated in this report as an unknown quantity at a mass of 1.2E+05 g. No other reports estimated any benzene in the SDA.

The quantity of benzine came from two RWMIS entries. One of these entries had a weight with it, but the other one did not. A density was calculated based on the one weight and volume, and that density was used to calculate the other weight. The derived weight (1.1E+04 g) is higher than the amount reported in CIDRA. The total weight shown in RWMIS is not from the benzine liquid. Therefore, it is expected that the CIDRA number is actually very close to the real quantity of benzine that is present in the RWMIS entries.

Carbon tetrachloride. The CIDRA number is slightly lower than the 1.5E+08 g that is shown in two other SDA reports. All of the numbers were derived from the Kudera (1987) report and would normally be the same. However, to provide the CIDRA estimate for the VOCs, the calculated quantities were assumed to be the upper bounds and the CIDRA best estimate was calculated to be three-fourths of the upper bound. This was done to provide some allowance for evaporation during the generation of the waste, storage of the waste before closure of the drum, and some possible venting of the drum before the actual covering with soil at the disposal site.

Table 6-1. Comparisons of nonradiological organic contaminant inventories in the CIDRA database and in the unknown quantities[a] against inventories in other reports.

	Subsurface Disposal Area				Pit 9		Acid Pit
Constituent	CIDRA best estimate (g)	Unknown quantities[a] (g)	Cerven (1987) (g)	EG&G Idaho (1989) (g)	Liekhus (1992) (g)	Figueroa et al. (1992) (g)	Jorgensen (1992) (g)
Organic Acids							
Ascorbic acid	—	7.1E+07	—	—	—	—	—
EDTA[b]	—	7.1E+07	—	—	—	2.3E+06	—
Alcohols							
Methanol	2.2E+05	2.8E+05	—	—	—	—	—
Ethanol	2.2E+04	7.1E+07	—	—	—	—	5.1E+00
Butanol	9.9E+04	—	—	—	—	—	—
Ethylene glycol	—	—	1.5E+06	—	—	—	—
Other Organics							
Acetone	1.1E+05	—	—	—	—	—	2.2E+00
Anthracene	2.0E+02	—	—	—	—	—	—
Benzene	—	1.2E+05	—	—	—	—	—
1,4-bis(5-phenyloxasol-2yl)benzene	—	2.0E+05	—	—	—	—	—
Benzine[c]	4.0E+03	—	1.1E+04	—	—	—	—
Butanone[d]	3.2E+04	—	—	—	—	—	—
Carbon tetrachloride	1.2E+08	2.0E+05	1.5E+08	1.5E+08	3.3E+07	5.2E+07	3.2E+01
Chloroform	3.7E+01	1.0E+07	—	—	—	—	—
Dibutylethylcarbutol	—	5.4E+06	—	—	—	—	—
Diisopropylfluorophosphate	—	<<E+05	—	—	—	—	—
Diphenyl	—	1.8E+08	—	—	—	—	—
Ether	—	Unknown	7.2E+05	—	—	—	—
Formaldehyde	1.4E+05	—	—	—	—	—	—
Freon[e]	9.1E+06	—	—	—	—	—	—
3-methyl-cholanthrene	—	1.0E+05	—	—	—	—	—

Table 6-1. (continued).

Constituent	Subsurface Disposal Area				Pit 9		Acid Pit
	CIDRA best estimate (g)	Unknown quantities[a] (g)	Cerven (1987) (g)	EG&G Idaho (1989) (g)	Liekhus (1992) (g)	Figueroa et al. (1992) (g)	Jorgensen (1992) (g)
Methylene chloride	1.4E+07	—	—	—	—	—	—
Methyl isobutyl ketone	8.9E+06	—	—	—	—	—	—
Nitrobenzene	—	Trace	—	—	—	—	—
Nitrocellulose	—	6.8E+06	—	—	—	—	—
Polychlorinated biphenyls[f]	—	2.4E+03	—	—	—	—	—
Terphenyl	4.5E+05	5.9E+08	—	—	—	—	—
Tetrachloroethylene	2.7E+07	—	—	4.1E+07	—	1.9E+07	—
Toluene	1.9E+05	2.0E+05	—	—	—	—	—
Tributylphosphate	1.0E+06	—	—	—	—	—	8.5E+01
Trichloroethane[g]	1.1E+08	—	—	2.5E+07	1.5E+07	1.5E+07	—
Trichloroethylene	1.0E+08	—	—	3.7E+07	—	1.7E+07	—
Trimethylpropane-triester	1.2E+06	—	—	—	—	—	—
Xylene	8.5E+05	—	—	—	—	—	—

a. The values listed for the unknown quantities are inexact estimates and, therefore, of lesser reliability than the values listed under CIDRA. They are not included in CIDRA.

b. EDTA or Versenes — ethylenediaminetetraacetic acid.

c. Benzine — a mixture of hydrocarbons, used as a motor fuel and in dry cleaning (*not* benzene).

d. Butanone — 2-butanone.

e. Freon — 1,1,2-trichloro-1,2,2-trifluoroethane.

f. Polychlorinated biphenyls — PCBs.

g. Trichloroethane — 1,1,1-trichloroethane.

Table 6-2. Comparisons of nonradiological inorganic contaminant inventories in the CIDRA database and in the unknown quantities[a] against inventories in other reports.

	Subsurface Disposal Area					Pad A	Pit 9		Acid Pit
Constituent	CIDRA best estimate (g)	Unknown quantities[a] (g)	Cerven (1987) (g)	EG&G Idaho (1989) (g)	Garcia and Knight (1989a) (g)	Halford (1993) (g)	Liekhus (1992) (g)	Figueroa et al. (1992) (g)	Jorgensen (1992) (g)
Inorganic Acids	—	—	3.9E+07	3.9E+07	—	—	—	—	—
Aqua regia	3.1E+01	—	—	—	—	—	—	—	—
Hydrochloric acid	—	—	—	—	—	—	—	—	2.5E+04
Hydrofluoric acid	7.6E+06	2.2E+06	—	—	—	—	—	—	1.5E+04
Nitric acid	5.0E+07	2.3E+06	—	—	—	—	—	—	2.2E+07
Sulfuric acid	1.2E+05	—	—	—	—	—	—	—	1.4E+04
Other Inorganics									
Aluminum nitrate	1.9E+08	—	—	—	—	—	—	—	1.8E+08
Ammonia	7.8E+05	—	—	—	—	—	—	—	1.6E+05
Antimony	4.5E+02	—	—	—	—	—	—	—	—
Asbestos	1.2E+06	2.3E+06	2.6E+07	2.6E+07	—	—	4.0E+05	4.0E+05	—
Beryllium[b]	1.5E+07	8.0E+06	—	—	—	—	2.0E+04	2.0E+04	—
Cadmium	1.6E+06	—	—	—	—	—	—	—	—
Calcium silicate	—	—	—	—	—	—	4.4E+07	4.4E+07	—
Caustic[c]	1.5E+02	—	—	1.0E+06	—	—	—	—	3.7E+04
Cerium chloride	5.1E+05	—	—	—	—	—	—	—	—
Chromium	1.0E+03	—	—	—	—	—	—	—	—
Copper	—	4.5E+04	—	—	—	—	—	—	—
Copper nitrate	3.3E+02	—	—	—	—	—	—	—	—
Cyanide[d]	9.4E+02	2.9E+03	—	—	—	—	—	—	2.0E+02
Hydrazine	1.8E+03	—	—	—	—	—	—	—	2.2E+03
Lead	5.8E+08	2.0E+07	1.9E+09	2.3E+08	3.6E+08	—	3.0E+06	3.0E+06	—
Lithium	—	—	—	—	—	—	1.0E+04	1.0E+04	—
Lithium hydride	—	Unknown	—	—	—	—	—	—	—
Lithium oxide	—	Trace	—	—	—	—	—	—	—
Magnesium	9.0E+06	2.8E+05	—	—	—	—	—	—	—
Magnesium fluoride	1.4E+05	—	—	—	—	—	—	—	—
Magnesium oxide	—	2.8E+08	—	—	—	—	—	—	—

Table 6-2. (continued).

Constituent	Subsurface Disposal Area					Pad A	Pit 9		Acid Pit
	CIDRA best estimate (g)	Unknown quantities[a] (g)	Cerven (1987) (g)	EG&G Idaho (1989) (g)	Garcia and Knight (1989a) (g)	Halford (1993) (g)	Liekhus (1992) (g)	Figueroa et al. (1992) (g)	Jorgensen (1992) (g)
Manganese	—	1.0E+04	—	—	—	—	—	—	—
Mercuric nitrate	8.1E+05	—	—	—	—	—	—	—	5.6E+05
Mercury	—	1.2E+06	—	—	1.1E+08	—	1.0E+05	1.0E+05	—
Nickel	2.2E+03	—	—	—	—	—	—	—	—
Potassium chloride	1.3E+08	—	—	—	—	5.1E+07	—	—	—
Potassium dichromate	1.7E+06	—	—	—	—	—	—	—	—
Potassium hydroxide	—	—	—	—	—	5.1E+07	—	—	—
Potassium nitrate	3.2E+09	—	—	—	—	1.4E+09	—	5.8E+07	—
Potassium phosphate	4.0E+07	—	—	—	—	—	—	—	—
Potassium sulfate	1.3E+08	—	—	—	—	5.1E+07	—	—	—
Silver	5.9E+03	—	—	—	—	—	—	—	—
Sodium	6.8E+04	1.0E+02	—	—	—	—	—	—	—
Sodium chloride	2.6E+08	—	—	—	—	1.0E+08	—	—	—
Sodium dichromate	3.1E+06	—	—	—	—	—	—	—	—
Sodium hydroxide	—	—	—	—	—	1.0E+08	—	—	—
Sodium nitrate	6.3E+09	4.5E+05	—	—	—	2.7E+09	—	1.2E+08	1.7E+06
Sodium phosphate	8.0E+07	—	—	—	—	—	—	—	—
Sodium sulfate	2.6E+08	—	—	—	—	1.0E+08	—	—	—
Sodium-potassium	1.7E+06	Small	—	—	—	—	—	—	—
Uranyl nitrate	2.2E+05	—	—	—	—	—	—	—	—
Zirconium	1.9E+07	—	2.0E+08	5.8E+08	—	—	1.5E+07	1.5E+07	—
Zirconium alloys	5.9E+06	—	—	—	—	—	—	—	—

a. The values listed for the unknown quantities are inexact estimates and, therefore, of lesser reliability than the values listed under CIDRA. They are not included in CIDRA.

b. Beryllium—beryllium as the metal or the oxide.

c. Caustic—sodium hydroxide.

d. Cyanide—sodium cyanide.

Ether. The RWMIS potential hazardous materials listing in the Cerven (1987) report contains a content code that was named, "Ether, Organics, Diphenyl." The total volume of the entries for this content code was 12.6 m^3, with a total weight of 2.9E+06 g. If one-fourth of the weight is due to ether, then the quantity would be 7.2E+05 g. The present search did not provide any quantitative values for the ether that was identified. It is possible that the entry given by Cerven was for the diphenyl listed above it in Table 6-1.

Tetrachloroethylene, trichloroethane, and trichloroethylene. The RI/FS Work Plan for the SDA (EG&G Idaho 1989) used the volume of "other organics" from the Kudera (1987) report and assumed that 20% of that volume was trichloroethane, one-third of the remaining volume was tetrachloroethylene, and another third of that volume was trichloroethylene.

The best estimate for CIDRA was made by using the same Kudera report and by assuming that there was no used oil present and the ratios of 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene in this "other organic" was the same as their ratios in the 1974 Harmful Materials Inventory at the RFP (ChemRisk 1992). Because this method only provided an estimate of the relative amounts of each of the VOCs in the volume of "other organics," the percentages of each were rounded to 45%, 45%, and 10% for making the best estimates.

Total inorganic acids. The data from EG&G Idaho (1989) actually come from the estimates of hazardous constituents in the SDA in the Cerven (1987) report. The data do not list any concentrations of particular acids; the entry is simply for 10,200 gal of acids. The total mass value was calculated assuming a density of 1 g/cm^3 of liquid. This number is a little higher than the total mass calculated for acids in the Acid Pit and a little lower than the total mass for all acids reported in CIDRA.

Asbestos. These data in EG&G Idaho (1989) also come from the Cerven (1987) report. The data state that 100 m^3 of asbestos was buried in the SDA. This was converted to grams by assuming a density of 16 lb/ft^3. It is probably a high number because it also assumes that the waste containers are completely full of asbestos. However, the CIDRA best estimate is probably low, but no data have been identified that justify raising the estimate.

Beryllium. The beryllium estimates in CIDRA and the unknown quantities are much higher than the estimates for waste buried in Pit 9. This is to be expected because Pit 9 is only one disposal unit. However, the Cerven (1987) and EG&G Idaho (1989) reports do not mention any beryllium or beryllium oxide. The RWMIS potential hazardous materials listing attached to the Cerven report does list beryllium, but it is not highlighted in the Cerven table of hazardous material constituents buried in the SDA. The total beryllium, excluding any neutron sources, in the RWMIS listings is 46 m^3. At a density of 1.85 g/cc, this calculates to 8.5E+07 g. If only one-tenth of the total volume were beryllium, this would be an estimate of 8.5E+06 g of beryllium. This estimate is similar to the best estimate provided in CIDRA. Differentiation between beryllium and beryllium oxide in the waste streams is not always possible. The unknown quantity estimate is a combination of beryllium metal and beryllium oxide estimates.

Calcium silicate. Calcium silicate was used at the RFP as an absorbent for organic liquids to convert them into sludge. The mass of this compound was not calculated for CIDRA because (a) the

compound was not identified on any regulatory list of hazardous substances and (b) no quantitative risk assessment can be performed because of the lack of EPA-approved toxicity data.

Caustic (sodium hydroxide). The quantities given in EG&G Idaho (1989) and for the Acid Pit are much higher than the quantity listed in CIDRA. EG&G Idaho (1989) lists caustic compounds as 26 m^3, which was converted here to 6,900 gal. It was assumed that this 6,900 gal was 1M (40 g/L) sodium hydroxide. The 26 m^3 came from the Cerven (1987) report, which describes the caustic compounds as sodium hydroxide in absorbent. This indicates that it was probably not 6,900 gal of 1M sodium hydroxide. However, it also means that providing a comprehensive and reliable estimate of the quantity of caustic (NaOH) disposed of in the SDA may not be possible.

The Acid Pit quantity was estimated from actual volumes disposed of; however, no concentrations were given. The estimate of the total grams in the Acid Pit was made assuming that the liquid was 2M (80 g/L) sodium hydroxide. It is difficult to provide a good estimate of caustic disposed of because it can react with acids or other compounds to form a third compound, such as sodium nitrate.

Lead. The quantity of lead listed in RWMIS as being buried in the SDA is 170 m^3. If the normal density of lead is used (11,300 kg/m^3), this calculates to the mass of 1.9E+09 g given in Cerven (1987). Garcia and Knight (1989a) used some RWMIS data and other assumptions to calculate a density of 2,134 kg/m^3 for the lead waste stream. Thus, the Garcia and Knight report shows a quantity of 3.6E+08 g of lead. Garcia and Knight proposed using the 1.9E+09 g as an upper limit and the 3.6E+08 g as a lower limit. The quantity in CIDRA (5.8E+08 g) is between the two suggested limits of Garcia and Knight.

Lithium and lithium oxide. The Liekhus (1992) Pit 9 report assumed that 16 pints of mercury was disposed of in the Acid Pit and that the lithium in lithium batteries is one-tenth of the amount of mercury. Actually, the lithium metal in the batteries is converted to an oxide as the batteries discharge; therefore, the lithium batteries disposed of would be expected to contain lithium oxide instead of lithium. Because there is no information on how many lithium batteries were disposed of at the SDA, the amount of lithium oxide could be estimated in CIDRA only as a trace.

Mercury and mercuric nitrate. The Liekhus (1992) Pit 9 report assumed that 16 pints of mercury was disposed of in the Acid Pit. The Cerven (1987) report found 8.5 m^3 of waste containing mercury in the RWMIS potential hazardous materials listings. The Garcia and Knight (1989a) report calculated (using a density of 13,500 kg/m^3) that a volume of 8.5 m^3 of mercury would equal 1.1E+08 g. This assumed that the entire volume of the waste was pure mercury. CIDRA listed the metallic mercury as unknown, and the estimate of this unknown is 1.2E+06 g. CIDRA also identified 4.7E+05 g of mercury that is present as mercuric nitrate monohydrate (8.1E+05 g). By examining the shipping records, the HDT study determined that one shipment of 120 ft^3 (3.4 m^3) of mercury listed in RWMIS actually consisted of soil contaminated with mercury (see Appendix D for details).

It appears, therefore, that the 1.1E+08 g of mercury (Garcia and Knight 1989a) is not a realistic estimate for the quantity buried in the SDA. It appears that the 1.2E+06 g quantity of mercury, which was calculated as an unknown quantity, is the best estimate that can be made at this time.

Sodium and potassium dichromates. An analysis of one drum of nitrate salts from Pad A (Halford et al. 1993) showed chromium at a concentration of 400 mg/kg. In the presence of high concentrations of nitrates at a pH of 9 to 10, it is expected that stable dichromates of sodium and potassium would be present. Because chromium can be a hazardous constituent of waste, the assumed quantities of these compounds in the nitrate salts was calculated.

Sodium and potassium hydroxides. These compounds were reported in the Pad A Halford et al. (1993) report. However, the same report presented a chemical analysis of a sample from one drum that showed a pH of 9 to 10. This pH indicates that only a small amount of hydroxides would be present in the waste. The analysis showed that, in addition to the nitrates, there were chlorides, sulfates, phosphates, fluorides, and nitrites. Therefore, the best estimate of the composition of these nitrate salts includes 4% chlorides, 4% sulfates, and 2% phosphates. No hydroxides were estimated in the nitrate salts on Pad A.

Zirconium. The search of the RWMIS potential hazardous materials listing by Cerven (1987) identified 30 m^3 of zirconium chips disposed of in the SDA. If it was assumed that all of this waste is pure zirconium at a density of 6.5 g/cm^3, there would be 2.0E+08 g of zirconium buried in the SDA. It is not expected that the entire volume would be pure zirconium; therefore, this is expected to be a maximum quantity.

EG&G Idaho (1989) lists a maximum quantity of zirconium buried in the SDA as 5.8E+08 g and a minimum quantity of 3.6E+07 g. This information came from Garcia et al. (1989). The evaluation of the metal content of Pit 9 by Garcia et al. was made using information in RWMIS. It was then assumed in EG&G Idaho (1989) that the rest of the SDA would have the same metal composition as Pit 9. It was also assumed that the maximum weight percent metal would be 80% of the total weight of the waste, and the minimum weight percent of the metal would be 5% of the total weight of the waste. The zirconium percentage was assumed to be 2.6% of the weight of the metal, as calculated for Pit 9.

The CIDRA best estimate for zirconium (1.9E+07 g) plus 5.9E+06 g of zirconium alloys is lower than the minimum quantity given in EG&G Idaho (1989) and, therefore, may be low. However, many assumptions were made in development of the zirconium estimates in the other reports, and the assumptions could prove to be unrealistic.

In summary, CIDRA provides estimates of many more nonradiological contaminants than does any other study performed on the SDA. Except for the estimates of asbestos, caustic, and zirconium, it appears that the CIDRA best estimates plus the unknown quantities fall in an expected range. For the asbestos, caustic, and zirconium quantities, consideration should be given to the objectives for use of the data. In some cases, further evaluation may be necessary.

6.1.2 Radiological Contaminants

The CIDRA data were compared against several other reports containing radionuclide inventories (see Table 6-3). For valid comparisons of the CIDRA data with radionuclide inventories in other reports, several aspects of the inventories must match. These aspects include the time period under consideration, the sources of the waste, the type of waste considered, and in which part of the

Table 6-3. Comparison of radiological inventories in the CIDRA database against those in other reports.

Radionuclide	CIDRA best estimate[a] 1952–1983 (Ci)	Litteer et al. (1993) 1952–1983 (Ci)	Figueroa et al. (1992) Pit 9 (Ci)	EG&G Idaho (1989) TRU waste only 1954–1970 (Ci)	Garcia and Knight (1989b) Pit 9 (Ci)
Co-60	2.8E+06	—	3.1E-01	9.9E+04	—
Sr-90	4.5E+05	—	4.2E+00	1.0E+03	—
Cs-137	7.0E+05	—	4.5E+00	1.0E+03	—
Ni-59	5.1E+03	—	—	1.5E+03	—
MAP	—	—	—	6.0E+03	—
MFP	—	—	—	5.0E+02	—
Unidentified beta-gamma	—	—	—	5.5E+03	—
Pu-238	2.5E+03	—	3.1E+01	5.7E+02	5.6E+02
Pu-239	6.6E+04	—	1.2E+03	2.1E+04	2.1E+04
Pu-240	1.5E+04	—	2.7E+02	4.9E+03	4.9E+03
Pu-241	4.0E+05	—	9.4E+03	1.8E+05	1.6E+05
Pu-242	9.9E-01	—	1.3E-02	2.0E-01	2.3E-01
Am-241	1.5E+05	—	2.1E+03	4.8E+04	5.1E+04
U-233	1.1E+00	—	—	5.0E-01	—
U-234	6.4E+01	—	—	—	6.1E+00
U-235	5.1E+00	—	—	3.0E-01	2.8E-01
U-238	1.1E+02	—	—	6.8E+01	6.8E+01
Total	1.2E+07	9.7E+06	1.3E+04	3.7E+05	2.4E+05

a. For CIDRA, the only radionuclides listed are those that were listed in the other reports. The CIDRA total, however, represents all of the radionuclides in the CIDRA inventory.

SDA the waste was buried. This study examined all waste buried at the SDA from all generators from 1952 through 1983. Figueroa et al. (1992) shows dramatically lower numbers for all radionuclides because the data in that report represent shipments primarily from only 1 year (1968), mostly from one source (the RFP), going to one disposal unit (Pit 9). Thus, the radioactivity inventory in Figueroa et al. (1992) can legitimately be orders of magnitude less than that in CIDRA.

The summary-to-date data in Litteer et al. (1993) include all waste buried in the RWMC through 1983 from all generators. The summary in that report offers only a total over all radionuclides. That total is approximately 2 million Ci less than the CIDRA total. This is to be expected because the HDT identified substantial radioactivity not included in RWMIS.

EG&G Idaho (1989) is like Figueroa et al. (1992) in that it takes a limited look at waste buried at the SDA because it was concerned with TRU waste. It refers to beta/gamma-emitting waste in the context of its having been mixed with TRU waste. The report offers inventories of some radionuclides that are close to the CIDRA values in some cases. For instance, the CIDRA value for Pu-239 is only about three times that of reported EG&G Idaho (1989). Throughout EG&G Idaho (1989), however, the values are smaller than those in CIDRA, as would be expected for a partial inventory.

The data in Garcia and Knight (1989b) likewise show lower activities than does CIDRA for all reported radionuclides, mostly because Garcia and Knight considered only data for waste that was buried in Pit 9 and originated at the RFP. In fact, the numbers in Garcia and Knight (1989b) are almost identical to those in EG&G Idaho (1989). This is not surprising because both of these reports take data from a single source. That source was a letter (Lee 1971) that transmitted data on RFP solid waste shipped to the INEL from 1954 through 1970.

Plansky and Hoiland (1992) contains data nearly identical to those found in RWMIS. A detailed comparison was not carried out because a comparison against RWMIS is made in Sections 6.2.3 and 6.2.4. The principal contribution made by Plansky and Hoiland was to provide a radionuclide distribution for the large activity listed previously in RWMIS under generic terms.

A comparison of CIDRA results for the radionuclides in waste from the RFP with the data recorded in these other reports (Table 6-4) shows a closer correspondence, reflecting the emphasis of these other reports exclusively on buried TRU waste and the fact that nearly all TRU waste at the SDA came from the RFP. CIDRA values are about two to three times those in EG&G Idaho (1989) for the more significant radionuclides (Pu-238, Pu-239, Pu-240, Pu-241, and Am-241). The CIDRA total is 2.5 times the EG&G Idaho (1989) total. These results are to be expected, given the increase in estimated activity of plutonium and americium brought about by this study and the fact that the other reports address only part of the waste. The Co-60, Cs-137, H-3, and Ra-226 listed under the CIDRA best estimate reflect a waste stream consisting of radiation sources. The stream is not identified in the shipping records and, therefore, was not identified in the other studies.

The data for RFP waste were also compared against data from the RFP that were discussed in Kudera (1994). That document compiled information from a 1964 study performed at the RFP. The RFP study estimated the amounts of plutonium discarded in various waste streams from 1954 through June 30, 1963. Many of the estimates were based on limited sampling and laboratory analyses. The

Table 6-4. Comparison of the CIDRA database radionuclide inventory for Rocky Flats Plant waste only against that in other reports.

Radionuclide	CIDRA best estimate 1952–1983 (Ci)	Litteer et al. (1993) 1952–1983 (Ci)	Figueroa et al. (1992) Pit 9 (Ci)	EG&G Idaho (1989) TRU waste only 1954–1970 (Ci)	Garcia and Knight (1989b) Pit 9 (Ci)
Am-241	1.5E+05	—	2.1E+03	4.8E+04	5.1E+04
Pu-238	1.9E+03	—	3.1E+01	5.7E+02	5.6E+02
Pu-239	6.5E+04	—	1.2E+03	2.1E+04	2.1E+04
Pu-240	1.4E+04	—	2.7E+02	4.9E+03	4.9E+03
Pu-241	3.9E+05	—	9.4E+03	1.8E+05	1.6E+05
Pu-242	8.8E-01	—	1.3E-02	2.0E-01	2.3E-01
U-232	1.2E-02	—	—	—	—
U-233	5.4E-01	—	—	5.0E-01	—
U-234	3.8E+01	—	—	—	—
U-235	1.9E+00	—	—	3.0E-01	2.8E-01
U-236	1.0E+00	—	—	—	—
U-238	8.0E+01	—	—	6.8E+01	6.8E+01
Co-60	1.7E+02	—	—	—	—
Cs-137	2.1E+02	—	—	—	—
H-3	3.6E-01	—	—	—	—
Ra-226	1.9E-01	—	—	—	—
Total	6.2E+05	2.5E+05	1.3E+04	2.5E+05	2.4E+05

estimated total of plutonium was 456.9 kg plus an unknown amount in boxed waste, which typically includes processing equipment, duct work, and piping. This value was compared against the quantity estimated for the HDT study in Appendix C, which used a completely different calculational approach. Based on the plutonium quantities for 1952 through 1962 plus one-half of the 1963 quantity, the Appendix C estimate is 431.7 kg. Thus, for the years indicated, the present estimate is within about 6% of an independent estimate, with the exception of the impact of the unknown quantity of plutonium in the boxed waste.

Thus, the limited comparisons that were possible against other reports containing radiological inventories for the SDA indicate that the inventory in CIDRA is substantially complete.

6.2 Comparison of Inventory with Inventories in Existing Databases

6.2.1 Introduction

This section compares the contaminant inventory developed in the HDT with corresponding inventories in existing databases. One objective was to confirm the substantial completeness and accuracy of the data collection for this task. A second objective was to identify and explain any major differences in inventory values between the databases and justify the new values that will be used in the BRA.

Only one database was identified against which to compare the complete contaminant inventory. That database is RWMIS, with the associated Qualifier Flag/Additional Contents database (see Section 2.3). Because RWMIS contains little information on nonradiological contaminants in the waste and no estimates of uncertainties, the comparisons involved only best estimates of radiological contaminants.

Because of the thousands of data involved in the radiological inventory, the comparisons reported here were made for general checking. The comparisons were not intended to be an exact accounting (which would not be useful because of the uncertainties in the data).

6.2.2 The Effect of RWMIS Data Groupings on the Comparisons

The nature of RWMIS affects the approach used here in the comparisons. RWMIS can provide inventories of the radionuclides in the waste based on two groupings of data. One RWMIS grouping involves rollups of the data that were provided on individual shipping records. RWMIS rollups of this type are referred to here as the RWMIS shipping record rollups. The advantage of these rollups is that they are radionuclide-specific. The disadvantage is that the rollups are incomplete for the period 1952 through 1970 because of missing shipping records.

The second RWMIS grouping involves the data summaries that have been prepared annually on the radioactivity in waste disposed of at the SDA. RWMIS data of this type are referred to here as RWMIS annual summaries. These data differ from the RWMIS shipping record rollups because they include estimates made in 1971 of the annual radioactivity in waste shipped to the SDA by each generator in all preceding years. (The 1971 estimates of the waste from 1952 through 1970 were made by waste management professionals in the form of an annual summary table, which was entered into RWMIS as a baseline. No documentation could be located on the basis for the 1971 estimates.) The advantage of these data is that they are substantially complete at the level of annual totals from each generator. The disadvantage of the data is that they do not include radionuclide distributions for all of the waste.

To incorporate this situation in the comparisons of CIDRA and RWMIS, two comparisons were made. One compares CIDRA data against the RWMIS shipping record rollups at the level of

individual radionuclide totals over all generators. The other compares CIDRA data against the RWMIS annual summary data at the level of total radioactivity from each major generator.

6.2.3 Comparisons at the Level of Individual Radionuclides, Summed Over All Generators

6.2.3.1 Approach. The RWMIS shipping record rollups were used for these comparisons against CIDRA. Figure 6-1 illustrates the approach. The strategy was to check for agreement first at the level of the total inventory of each radionuclide (over all waste generators). If, for a given radionuclide, the numbers were not reasonably close at that level, resolution was sought by comparisons at the level of the individual waste generators. Because CIDRA is organized by waste stream and RWMIS is organized by waste shipment, direct comparisons below the generator level were generally not feasible.

As the upper-right portion of Figure 6-1 shows, before the activities could be compared realistically, the RWMIS results had to be adjusted to replace the generic terms MAP, MFP, unidentified beta-gamma, and unidentified alpha with specific estimates by radionuclide. (Approximately 28% of the RWMIS radioactivity for 1952 through 1983 is listed in these generic terms.) The radionuclide distributions used in CIDRA for MAP, MFP, etc., vary by waste generator and sometimes even by waste stream for the same generator. *For purposes of this comparison only*, approximate breakdowns were developed as follows for each of the generic terms in RWMIS. For each generator, radionuclide distributions were identified that had been used in CIDRA, either for all waste streams or as a rough average (see Appendix E for the detailed distributions). These percentages were then multiplied by the RWMIS value, in curies, for each generic term for each generator. The resulting activities of each radionuclide were then added to the RWMIS values for the specific radionuclides. For example, the Co-60 activities deriving from the MAP value and from the unidentified beta-gamma value were added to the Co-60 activity that was listed separately in RWMIS. This process was performed for each affected radionuclide for each generator.

There is an additional complication. Section 5.4 noted that the radioactivity determinations for most waste containers were based on radiation surveys using G-M counters. The bias and random error of that method were discussed. A correction factor—multiplication by 0.5—was derived. CIDRA applies that correction factor to all best-estimate inventory entries for which uncertainties were not available, except as discussed in Section 5. Unfortunately, applying the correction factor makes it difficult to compare RWMIS and CIDRA as a completeness confirmation for CIDRA. For ease of comparison, the initial comparisons were made without the factor of 0.5 incorporated. The final comparisons reflect all of the inventory revisions made in CIDRA, as shown at the bottom of Figure 6-1.

6.2.3.2 Inventories as Listed in RWMIS and CIDRA. This section discusses how the inventory information was assembled for the comparisons. The columns of Table 6-5 indicate the results at various stages of the comparisons.

The first two columns of Table 6-5 list the total inventory for each radionuclide, as given in the RWMIS shipping record rollups. The radionuclides are listed in order of activity. The activities listed for the generic terms MFP, MAP, etc., are evident.

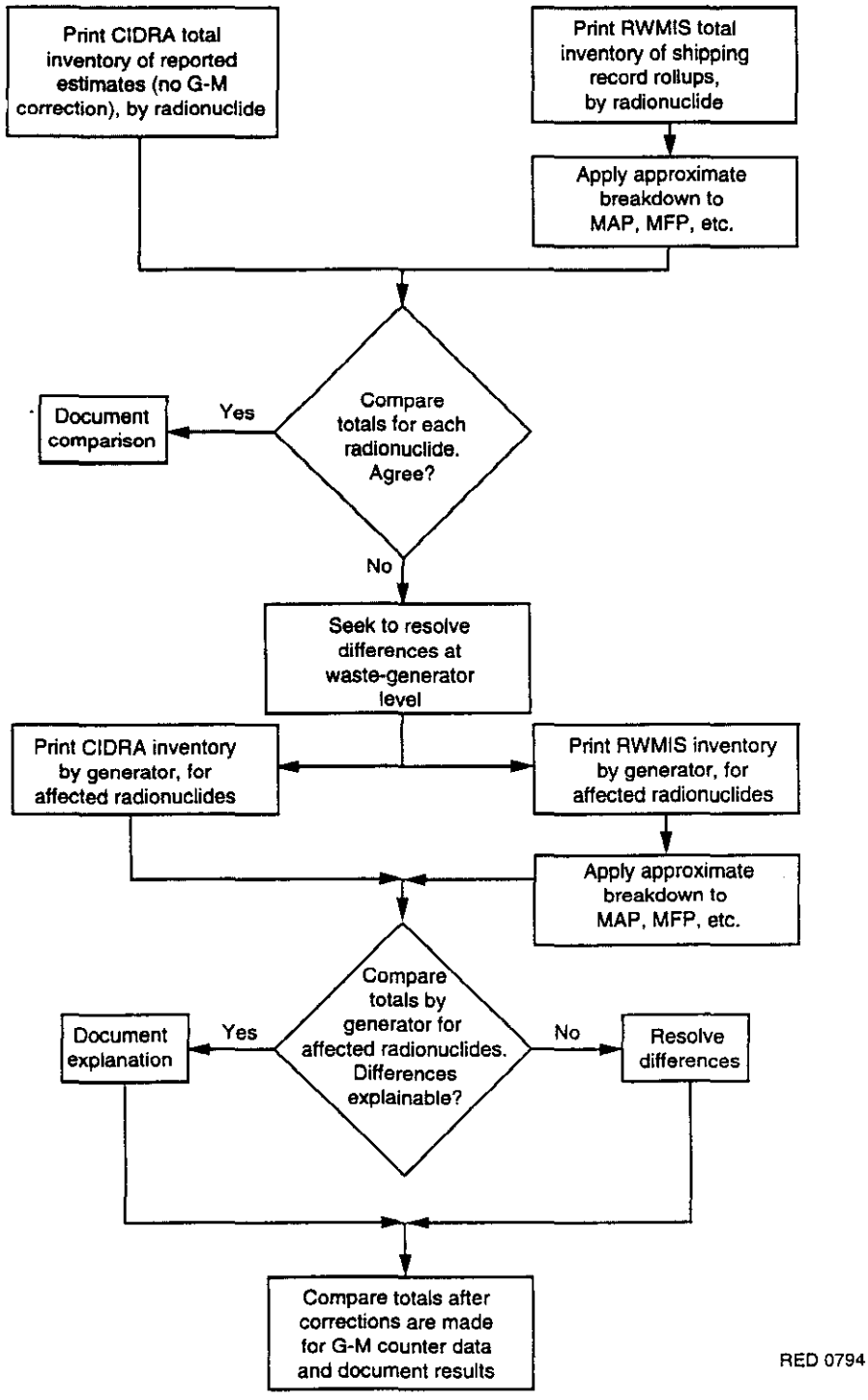

Figure 6-1. Approach for comparing the radionuclide inventory in the CIDRA database with that in the shipping record rollups of the RWMIS.

Table 6-5. Radionuclide inventories as given by RWMIS shipping record rollups and by CIDRA (with and without Geiger-Müller counter corrections): 1952—1983.

Radionuclide	RWMIS inventory (Ci)	RWMIS (with generic entries distributed) (Ci)	CIDRA reported estimates (no G-M corrections) (Ci)	CIDRA best estimate (with G-M corrections) (Ci)
Co-60	3.4E+06	4.1E+06	4.0E+06	2.8E+06
Cr-51	2.0E+06	2.0E+06	7.4E+05	7.3E+05
MFP	1.7E+06	0	0	0
MAP	8.2E+05	0	0	0
Co-58	6.6E+05	6.7E+05	1.6E+05	1.6E+05
Unidentified beta-gamma	5.3E+05	0	0	0
Mn-54	4.8E+05	4.9E+05	1.8E+05	1.8E+05
Zr-95	3.9E+05	4.1E+05	7.6E+04	7.6E+04
Fe-59	2.7E+05	2.7E+05	9.3E+04	9.1E+04
Fe-55	1.5E+05	3.3E+05	6.5E+06	3.8E+06
Sb-125	7.7E+04	1.2E+05	1.3E+05	1.3E+05
Ni-63	4.2E+04	4.2E+05	1.2E+06	7.4E+05
Zr-Nb-95	3.6E+04	0	0	0
Cs-137	3.3E+04	1.0E+06	1.2E+06	7.0E+05
Pu-241	3.3E+04	3.3E+04	4.1E+05	4.0E+05
Ce-141	2.8E+04	3.0E+04	1.5E+03	7.6E+02
Am-241	2.0E+04	2.0E+04	1.5E+05	1.5E+05
Sn-119m	2.0E+04	2.0E+04	2.7E+04	2.7E+04
Nb-95	1.6E+04	3.7E+04	2.7E+03	2.4E+03
Ce-144	1.2E+04	2.6E+05	1.7E+05	1.5E+05
Ru-103	9.6E+03	1.0E+04	7.2E+02	3.6E+02
H-3	9.5E+03	6.0E+04	1.3E+06	1.2E+06
Pr-144	8.8E+03	2.9E+04	4.2E+04	4.2E+04

Table 6-5. (continued).

Radionuclide	RWMIS inventory (Ci)	RWMIS (with generic entries distributed) (Ci)	CIDRA reported estimates (no G-M corrections) (Ci)	CIDRA best estimate (with G-M corrections) (Ci)
Ni-59	6.3E+03	9.1E+03	9.4E+03	5.1E+03
Sr-90	5.8E+03	3.4E+05	6.4E+05	4.5E+05
Pu-239	4.7E+03	4.7E+03	6.6E+04	6.6E+04
Y-90	3.3E+03	1.4E+04	1.9E+04	1.9E+04
Ru-106	2.6E+03	1.3E+04	6.8E+03	6.8E+03
Cs-134	1.8E+03	1.8E+03	2.6E+03	2.2E+03
Rh-106	1.8E+03	1.2E+04	6.8E+03	6.8E+03
Sr-Y-90	1.5E+03	0	0	0
Pu-240	1.5E+03	1.5E+03	1.5E+04	1.5E+04
U-235	7.1E+02	7.1E+02	5.2E+00	5.1E+00
Mn-56	5.8E+02	5.8E+02	2.7E+01	2.7E+01
Ce-Pr-144	5.6E+02	0	0	0
Pm-147	5.0E+02	5.0E+02	1.6E+02	8.1E+01
Eu-152	4.0E+02	4.0E+02	2.4E+02	2.4E+02
Zn-65	3.7E+02	3.7E+02	3.6E+02	3.6E+02
Eu-154	3.7E+02	3.7E+02	4.2E+03	3.0E+03
Pu-238	1.7E+02	1.7E+02	2.7E+03	2.5E+03
Eu-155	1.6E+02	3.1E+04	2.9E+04	1.5E+04
Ir-192	1.0E+02	1.0E+02	1.0E+02	5.4E+01
Be-10	9.0E+01	9.0E+01	4.3E+01	4.3E+01
La-140	8.7E+01	2.0E+03	1.5E+03	7.7E+02
Sc-46	8.7E+01	8.7E+01	5.3E+01	5.3E+01
Ru-Rh-106	8.4E+01	0	0	0

Table 6-5. (continued).

Radionuclide	RWMIS inventory (Ci)	RWMIS (with generic entries distributed) (Ci)	CIDRA reported estimates (no G-M corrections) (Ci)	CIDRA best estimate (with G-M corrections) (Ci)
Rb-86	7.7E+01	7.7E+01	1.4E+01	7.1E+00
Sb-124	7.6E+01	7.6E+01	1.8E+03	1.8E+03
Ba-140	6.7E+01	1.7E+03	1.3E+03	6.6E+02
Ra-226	3.0E+01	3.0E+01	6.9E+01	5.9E+01
Na-24	2.8E+01	2.8E+01	0	0
U-238	4.8E+01	4.8E+01	1.1E+02	1.1E+02
Po-210	1.8E+01	1.8E+01	8.0E+01	7.5E+01
I-131	1.4E+01	1.4E+01	1.5E+00	1.5E+00
Ba-La-140	1.1E+01	0	0	0
Ta-182	8.6E+00	8.6E+00	8.5E+00	8.5E+00
U-232	8.4E+00	8.4E+00	8.4E+00	8.4E+00
W-187	5.3E+00	5.3E+00	0	0
Co-57	4.8E+00	4.8E+00	4.8E+00	4.8E+00
Sr-89-90	3.9E+00	0	0	0
C-14	3.9E+00	8.5E+03	3.2E+04	1.6E+04
Sm-153	3.3E+00	3.3E+00	0	0
Ce-141-144	3.0E+00	0	0	0
Cd-109	2.9E+00	2.9E+00	4.1E-01	4.1E-01
Ag-110m	2.9E+00	2.9E+00	0	0
Unidentified alpha	2.8E+00	0	0	0
Nb-94	2.0E+00	2.0E+00	4.9E+01	4.9E+01
Sr-89	2.0E+00	1.2E+03	9.5E+02	4.7E+02
Hf-181	1.8E+00	1.8E+00	4.0E-01	3.6E-01

Table 6-5. (continued).

Radionuclide	RWMIS inventory (Ci)	RWMIS (with generic entries distributed) (Ci)	CIDRA reported estimates (no G-M corrections) (Ci)	CIDRA best estimate (with G-M corrections) (Ci)
Ag-110	1.7E+00	1.7E+00	1.7E+00	8.4E-01
Kr-85	1.4E+00	1.4E+00	1.3E+00	1.3E+00
Na-22	1.3E+00	1.3E+00	3.0E-01	3.0E-01
U-233	1.2E+00	1.2E+00	1.1E+00	1.1E+00
Mo-99	1.0E+00	1.0E+00	1.0E+00	1.0E+00
Pr-143	0	1.5E+03	1.2E+03	6.2E+02
Y-91	0	1.3E+03	1.0E+03	5.3E+02
Tc-99	2.5E-06	8.8E+02	5.2E+02	2.6E+02
Rh-103m	0	6.6E+02	5.4E+02	2.7E+02
Cm-242	0	7.3E-01	1.7E+02	9.1E+01
I-129	0	5.0E-02	1.9E-01	9.9E-02
Cm-244	9.8E-04	3.4E-01	1.4E+02	8.0E+01
U-234	1.8E-01	1.8E-01	6.8E+01	6.4E+01
Zr-93	0	0	4.0E+00	4.0E+00
Tm-170	0	0	3.4E+00	3.4E+00
Ba-137m	1.7E-01	1.7E-01	3.4E+00	3.4E+00
U-236	4.0E-03	4.0E-03	3.9E+00	2.5E+00
Np-237	6.0E-03	6.0E-03	4.6E+00	2.4E+00
Th-232	2.5E-01	2.5E-01	1.3E+00	1.3E+00
Cs-136	1.6E-01	1.6E-01	1.5E+00	7.7E-01
Total	1.1E+07	1.1E+07	1.7E+07	1.2E+07

Radionuclides were included in the comparison if their activity listed in RWMIS was at least 1 Ci. Additional radionuclides were included at the end of the list if their activity in the CIDRA database was at least 1 Ci, before correction for the bias in the G-M counter readings. In addition, I-129 was included because although its activity was very small, it is very long-lived and relatively mobile when released from confinement.

To compare the CIDRA and RWMIS entries, the generic terms had to be eliminated from the RWMIS entries. The activity represented by the generic terms was broken down as described in Section 6.2.3.1, leading to the values in the third column of Table 6-5. Also, dual radionuclide entries in RWMIS, such as Zr-Nb-95, were assigned as described in Appendix E. (Section 3.1.1 discusses the treatment of secular equilibrium in the CIDRA inventory and in the risk assessment.) The third column, therefore, represents the radionuclide inventory if RWMIS is used and the generic terms and dual radionuclide entries are broken down into their constituent radionuclides, following the general methods used in the HDT study.

The fourth column gives the CIDRA values for the same radionuclides. The data in this column do not reflect the corrections made for the bias in inventory information based on the G-M counter surveys of waste containers. Thus, the data in this column are not the final CIDRA data, but they are a version used only to check for completeness against the RWMIS values.

6.2.3.3 Comparisons of Results Before Applying Corrections to Activity Estimates Derived from Geiger-Müller Counter Survey Data. The third and fourth columns of Table 6-5 allow comparisons of the results from CIDRA with those from RWMIS. The generic radionuclide terms in RWMIS are distributed using a simplified version of the CIDRA results, but without the effect of the corrections to data originally obtained from the G-M counter surveys. The following paragraphs discuss the results for only the predominant radionuclides. For both databases, data rollups by generator were consulted in evaluating the results, but generally they are not presented here for brevity.

The nuclide-by-nuclide comparisons are discussed most easily by grouping the radionuclides according to fission products, activation products, and actinides. (Actinides include actinium and higher-numbered elements on the Periodic Table, such as plutonium, americium, and uranium.) Tritium (H-3) is a special case and is addressed first.

Tritium (H-3)—The CIDRA value is approximately 20 times larger than the RWMIS entry with the generic entries distributed. [Compared with the unmodified RWMIS inventory (i.e., without the generic entries distributed), the CIDRA H-3 entry is about 140 times larger.] This difference is to be expected. Section 2.4.2 explained that waste stream TRA-670-1H is the beryllium reflectors from ATR, MTR, and ETR. This stream contains nearly all of the CIDRA H-3 inventory. The H-3 activation product was not reported on the shipping records and is, therefore, not in RWMIS. Tritium is a pure beta-emitter, and its activity in a metallic matrix is very difficult to measure by conventional health physics instrumentation.

Fission Products—For the nine fission products that constitute nearly all of this type of activity, the CIDRA and RWMIS values are compared below. The order is the same as their ranking as reported estimates in CIDRA.

The *total* activities of these nine principal fission products in CIDRA and RWMIS are within about 20% (2.2 million Ci and 1.8 million Ci, respectively). This difference is less than the total random error for the estimated activity of the radionuclides in an individual waste shipment. The *distributions* of the fission products differ markedly, however, because most of the CIDRA values are based on nuclear physics calculations involving actual or assumed histories of nuclear reactor cores. Accordingly, the comparisons of some individual nuclides below involve differences considerably larger than 20%.

- **Cs-137.** The CIDRA value is 20% larger than the RWMIS value. The difference is less than the total random error for estimating the radioactivity in an individual waste shipment. Most of the Cs-137 is from TRA, NRF, and ANL-W.

- **Sr-90.** The CIDRA value is almost twice the RWMIS value. Most of the Sr-90 is from ANL-W, NRF, and TRA.

- **Ce-144.** The CIDRA value is about 35% smaller than the RWMIS value because of the assumed distribution of the MFP entries in RWMIS. Most of the Ce-144 is from ANL-W.

- **Sb-125.** The CIDRA value is 8% larger than the RWMIS value. The difference is less than the total random error for estimating the radioactivity in an individual waste shipment. Most of the Sb-125 is from NRF.

- **Pr-144.** The CIDRA value is about 45% larger than the RWMIS value. The Pr-144 is from CPP.

- **Eu-155.** The CIDRA value is about 6% smaller than the CIDRA value. The difference is less than the total random error for estimating the radioactivity in an individual waste shipment. Most of the Eu-155 is from TRA.

- **Sn-119m.** The CIDRA value is 35% larger than the RWMIS value. The Sn-119m is from NRF.

- **Y-90.** The CIDRA value is about 35% larger than the CIDRA value. As explained in Section 3.1, Y-90 is a short-lived decay product of Sr-90. Secular equilibrium is established quickly between the two radionuclides. Some preparers of waste information included the Y-90; some did not. The lack of full reporting of Y-90 is not important to the BRA; the calculations of radioactive decay to be performed in conjunction with the BRA will reflect equilibrium and the appropriate activity of Y-90.

- **Ce-141.** The CIDRA value of 1,500 Ci is about 1/20 of the RWMIS value of 30,000 Ci. In RWMIS, 28,000 Ci of the 30,000 Ci is from TRA. In CIDRA, TRA reported only 3 Ci of Ce-141; most of the 1,500 Ci in CIDRA is from TAN. With a half-life of only 32.5 days, the 30,000 Ci of Ce-144 was reduced to approximately 30 Ci within 325 days after reporting and has now decayed to < 1 Ci in activity. The large difference in reported activities between RWMIS and CIDRA is probably due to a difference in the convention regarding the reporting of very short-lived radionuclides. The difference is of no consequence for the BRA.

Iodine-129 is not one of the top nine fission products in CIDRA in terms of activity. However, I-129 is important to the BRA because of its very long half-life (15.7 million years) and its potential for a comparatively high mobility in subsurface transport. The CIDRA value for I-129 is 0.19 Ci, almost entirely from TRA. The activity was estimated by means of the nuclear physics calculations described in Section 2.4.2. The RWMIS value is 0 before distributing the MFP and unidentified beta-gamma emitters and 0.05 Ci after. Iodine-129 is seldom reported in waste shipments because it is very difficult to measure (EPRI 1987).

For the principal fission products and for the fission products as a whole, the comparison against the data in RWMIS confirmed that the CIDRA inventory of fission products is substantially complete. The only principal fission products for which the CIDRA values are substantially smaller than the RWMIS values are Ce-144 and Ce-141. The half-lives of these two radionuclides are only 284.6 and 32.5 days, respectively.

Activation Products. For the nine activation products that constitute nearly all of this type of activity, the CIDRA and RWMIS values are compared below. The order is the same as their ranking as reported estimates in CIDRA.

The total activity for these nine principal activation products in CIDRA is about 50% higher than the corresponding total in RWMIS (13.0 million versus 8.7 million Ci). Again, the distributions differ markedly because most of the CIDRA values are based on nuclear physics calculations involving actual or assumed operating histories of nuclear reactor cores. Accordingly, the comparisons of some individual nuclides below involve differences larger than 50%.

- **Fe-55.** The CIDRA value is almost 20 times larger than the RWMIS value. Most of the Fe-55 is from TRA. The reason for the large increase in the estimated activity of Fe-55 is given in Tables 2-8 and 2-10 and is repeated here. Laboratory data (e.g., EPRI 1987) show that Fe-55 is a predominant contributor to the activity in certain types of LLW. Iron-55 emits no gamma radiation, so it does not contribute to the activity detected by the G-M method. This is why the scaling factors used here for those types of waste total more than unity.

- **Co-60.** The CIDRA value is about 2% smaller than the RWMIS value. The difference is less than the total random error for estimating the radioactivity in an individual waste shipment. Most of the Co-60 is from TRA and NRF.

- **Ni-63.** The CIDRA value is almost 3 times larger than the RWMIS value. Most of the Ni-63 is from TRA. The reason for the large increase in the estimated activity of Ni-63 is the same as that for Fe-55.

- **Cr-51.** The CIDRA value about one-third of the RWMIS value. Most of the Cr-51 is from TRA.

- **Mn-54.** The CIDRA value is about one-third of the RWMIS value. Most of the Mn-54 is from ANL-W and CPP.

- **Co-58.** The CIDRA value is about one-fourth of the RWMIS value. Most of the Co-58 is from CPP and ANL-W.

- **Fe-59.** The CIDRA value is about one-third of the RWMIS value. Most of the Fe-59 is from TRA and CPP.

- **Zr-95.** The CIDRA value is about one-fifth of the RWMIS value. Most of the Zr-95 is from NRF.

- **C-14.** The CIDRA value is 32,000 Ci, virtually all of which is from TRA. The RWMIS value before distributing the generic entries is only 3.9 Ci; virtually all of the C-14 came from offsite and none was reported from TRA. The simple method for distributing the generic entries increases the RWMIS value to 8,500 Ci. Carbon-14 is very difficult to measure in waste shipments; evidently, nuclear physics calculations were not performed to support the TRA data submittal to RWMIS.

Technetium-99 and Nb-94 are not among the top nine activation products in CIDRA in terms of activity. However, they are important to the BRA because of their very long half-lives (5,730 years for C-14 and 20,000 years for Nb-94) and their potential for comparatively high mobilities in subsurface transport. Their activities are discussed below.

The CIDRA value for Tc-99 is 520 Ci, almost all of which is from TRA. The RWMIS value before distributing the generic entries is <1 Ci. The simple method for distributing the generic entries increases the RWMIS value to 880 Ci. The reason why Tc-99 was underreported on the shipping records is the same as that stated for C-14.

The CIDRA value for Nb-94 is 49 Ci, with 47 Ci generated by CPP and 2 Ci generated by D&D activities. The RWMIS value is only the 2 Ci from D&D. The reason why Nb-94 was underreported on the shipping records is the same as that stated for C-14.

Among the principal activation products, the CIDRA inventory is substantially less than that in RWMIS only for Cr-51, Mn-54, Co-58, Fe-59, and Zr-95. The half-lives of these radionuclides are all less than 1 year. Thus, the CIDRA values are either much larger than or similar to the RWMIS values for all principal activation products with half-lives greater than 1 year. As a result, for the principal activation products and for the activation products as a whole, the comparison against the data in RWMIS confirmed that the CIDRA inventory of activation products is substantially complete.

Actinides. For the 11 actinides that constitute nearly all of this type of activity, the CIDRA and RWMIS values are compared below. The sequence departs slightly from their ranking as reported estimates in CIDRA so that closely related radionuclides could be discussed consecutively.

The total activity for these 11 principal actinides in CIDRA is much higher than the corresponding total in RWMIS (640,000 versus 60,000 Ci). The difference in the total is due almost entirely to the new, increased estimates of activity in the RFP waste (which is almost exclusively from actinides) and to the incompleteness of the early RWMIS records.

- **Pu-241.** The CIDRA value is approximately 12 times the RWMIS value. The Pu-241 is almost entirely from RFP.

- **Am-241.** The CIDRA value is approximately 7-1/2 times the RWMIS value. The Am-241 is almost entirely from RFP.

- **Pu-239.** The CIDRA value is approximately 14 times the RWMIS value. The Pu-239 is almost entirely from RFP.

- **Pu-240.** The CIDRA value is approximately 10 times the RWMIS value. The Pu-240 is almost entirely from RFP.

- **Pu-238.** The CIDRA value is approximately 16 times the RWMIS value. The Pu-238 is almost entirely from RFP.

- **U-238.** The CIDRA value is more than twice the RWMIS value. Most of the U-238 came from RFP and was disposed of either in the pits and trenches or on Pad A.

- **U-234.** The CIDRA value is 68 Ci, mostly from RFP. RWMIS lists < 1 Ci of U-234. The reason for the large difference is that the uranium-234 in CIDRA was estimated based on nuclear physics calculations. U-234 exists in all uranium, in a concentration that depends on the enrichment, but the U-234 was seldom reported on shipping records.

- **U-235.** The CIDRA value is much smaller than the RWMIS value (5.2 Ci versus 710 Ci). The difference is almost entirely due to an error in a single shipping record that was entered into RWMIS. The record related to NRF waste shipped in 1965. The radionuclide entry on that particular shipping record should have read "700 Ci of mixed fission products with a trace of U-235" instead of "700 Ci of U-235." The discrepancy is discussed in detail in Nieslanik (1994). Deleting this erroneous entry from RWMIS would result in the CIDRA and RWMIS values for U-235 agreeing to within about 5 Ci.

- **Cm-242.** The CIDRA value is 170 Ci, almost entirely from TRA. RWMIS does not list any Cm-242. The reason for the large difference is that the Cm-242 in CIDRA was estimated based on nuclear physics calculations.

- **Cm-244.** The CIDRA value is 140 Ci, almost entirely from TRA. RWMIS lists < 1 Ci. The reason for the large difference is that the Cm-244 in CIDRA was estimated based on nuclear physics calculations.

- **Ra-226.** The CIDRA value is 69 Ci, mostly from the miscellaneous offsite generators. The RWMIS value is 30 Ci.

Neptunium-237 is not among the top 11 activation products in CIDRA in terms of activity. However, Np-237 is important to the BRA because of its very long half-life (2.14 million years). The CIDRA value is 4.6 Ci, almost all from TRA. The RWMIS value is 0.006 Ci. The reason for the difference is that the Np-237 in CIDRA was estimated based on nuclear physics calculations.

Thus, the CIDRA entries for the actinides are all larger than the corresponding RWMIS values, except for the erroneous RWMIS record for U-235.

Total Inventory—The total activity in CIDRA (without the G-M corrections) is 17 million Ci; the total inventory in RWMIS is 11 million Ci. The relative value of these two totals indicates that CIDRA is not missing any large inventory entries.

Conclusion—For the principal, longer-lived nuclides (i.e., half-lives beyond 1 year) in each segment of the inventory—fission products, activation products, and actinides—the total activity in CIDRA is similar to or larger than that in RWMIS. In addition, the total inventory in CIDRA is substantially larger than that in RWMIS. Therefore, the results of these comparisons of CIDRA values (without the G-M correction) against RWMIS values (with the generic activity terms distributed) confirm that the HDT has not overlooked any substantial radioactivity in the waste.

6.2.3.4 Comparisons of Results After Applying the CIDRA Corrections for Geiger-Müller Counter Survey Data. The third and fifth columns of Table 6-5 allow comparisons of CIDRA and RWMIS results, including the effect of the corrected data from G-M counter surveys. Because of the corrections made to some of the values taken from the records, this comparison is less useful than the preceding one in identifying possible oversights in CIDRA. However, the comparison is useful to show the overall change in contaminant inventory. The following paragraphs discuss the impacts of the corrections in reference to the comparisons against RWMIS.

The correction to the data derived from G-M counter surveys reduces the activities of certain radionuclides in the CIDRA inventory. This reduction arises in the following way. For individual waste streams from generators other than the RFP, the reduction ranges from no change to a factor of two. If the uncertainty in contaminant quantity was specified by the data gatherer, based on consideration of how the estimates or measurements were made originally, the G-M correction is not applied. If no uncertainty was specified (because the standard G-M counter method was believed to have been used), all activities in the waste stream were divided by two.

If all waste streams contributing to the inventory of a given radionuclide were subject to the factor of two reduction, then the total inventory of that radionuclide (last column of Table 6-5) reflects a reduction by a factor of two, compared with the entry in the preceding column. For example, such is the case for Ru-103. On the other hand, if none of the contributory streams were subject to the correction, then the entries in the last two columns are identical. For example, the Pu-239 comes almost entirely from RFP waste streams, in which a calculational method was used rather than the G-M counter survey method. The entries for Pu-239 in the last two columns are, therefore, identical. For most radionuclides, the amount of the correction falls between these two extremes.

For radionuclides not affected by the G-M counter correction, such as Pu-239, the discussion in the previous comparison against RWMIS still applies. For radionuclides strongly affected by the correction, the CIDRA quantity is reduced by as much as a factor of two, and the comparison against RWMIS is similarly affected.

Applying the G-M counter correction reduces the total activity in CIDRA from 17 million to 12 million Ci, approximately 9% larger than RWMIS.

6.2.4 Comparisons at the Level of Individual Generators, Summed Over All Radionuclides

6.2.4.1 Approach. The RWMIS annual summaries were used for most of the comparisons at the level of individual generators. The results from the RWMIS shipping record rollups are also useful for comparison.

The methods used for these comparisons were basically the same as those described in Section 6.2.3. The principal difference is that the total radioactivity in the waste from each major generator in 1952 through 1983 is given.

Again, it is stressed that the comparisons presented here are for the purpose of confirming the general completeness of CIDRA. The comparisons are not intended to drive the totals from CIDRA to match those in RWMIS because CIDRA contains significantly improved information that is not found in RWMIS.

6.2.4.2 Comparisons. Table 6-6 provides the results of these comparisons. For confirming the completeness of CIDRA and for understanding the nature of the data-gathering process, the column containing the CIDRA reported estimates (no G-M correction) is compared with the two columns to the left of it. The last column is shown only for perspective. The comparisons are discussed in terms of approximate numbers because of rounding all totals to two significant figures.

- **TAN.** The CIDRA value of 70,000 Ci for the total radioactivity in TAN waste lies between the two RWMIS values of 63,000 and 100,000 Ci. The differences relate primarily to assumptions made about the activity in the waste from 1956 through 1962. Waste generated in these years involved almost one-half of the radioactivity in TAN waste; in addition, these years were during the period when the shipping records were incomplete. As expected, the RWMIS shipping records rollup is the smallest of the three values for TAN. The TAN lead data gatherer for CIDRA used judgment based on knowledge of the operations at TAN during each year to assign the annual values of radioactivity listed in Table 2-4. The annual summaries for TAN that were entered into RWMIS in 1971 evidently were still larger than those in Table 2-4. The persons who entered those data in 1971 evidently assigned a higher fraction of the total NRTS radioactivity to TAN than did the CIDRA data gatherer.

- **TRA.** The CIDRA value of 11 million Ci for the total radioactivity in TRA waste is larger than the RWMIS values of 3.9 million and 4.6 million Ci. (Interestingly, the RWMIS shipping record rollup gives a larger value than do the RWMIS annual summaries.) Part of the difference is due to stream TRA-670-1H, the beryllium reflectors. The H-3 in this stream, which amounts to an estimated 1,049,500 Ci, is not included in the RWMIS records. The remainder of the difference is due primarily to the use of activity scaling factors that sum to greater than unity, as explained in Tables 2-8 and 2-10.

- **ICPP.** The CIDRA value of 690,000 Ci is somewhat larger than the two RWMIS values of 610,000 Ci. For several waste streams, the ICPP lead data gatherer for CIDRA obtained radioactivity data from other information sources that added to the values given in RWMIS. One example is a waste stream generated in 1959 involving contaminated soil, a stream that is not in RWMIS because of the gaps in the shipping records.

Table 6-6. Radioactivity totals as given by RWMIS annual summaries and shipping record rollups, and by CIDRA (with and without Geiger-Müller counter corrections).

Major generator	RWMIS annual summaries (Ci)	RWMIS shipping record rollups (Ci)	CIDRA reported estimates (no G-M corrections) (Ci)	CIDRA best estimate (with G-M corrections) (Ci)
TAN	1.0E+05	6.3E+04	7.0E+04	3.5E+04
TRA	3.9E+06	4.6E+06	1.1E+07	6.6E+06
ICPP	6.1E+05	6.1E+05	6.9E+05	6.9E+05
NRF	3.7E+06	4.2E+06	3.2E+06	2.9E+06
ANL-W	1.1E+06	1.1E+06	1.1E+06	1.1E+06
RFP	2.6E+05	5.7E+04	6.2E+05	6.2E+05
Other[a]	1.1E+05	5.5E+04	5.3E+04	4.9E+04
Total	9.7E+06	1.1E+07	1.7E+07	1.2E+07

a. Includes the 38 Ci on Pad A from all generators.

- **NRF.** The CIDRA value of 3.2 million Ci is somewhat smaller than the RWMIS values of 3.7 million and 4.2 million Ci. The difference of about 15% to 20% is considered to be within the uncertainty of the inventory approaches used.

- **ANL-W.** The CIDRA value of 1.1 million Ci matches the RWMIS values.

- **RFP.** The CIDRA value of 620,000 Ci for the total radioactivity in RFP waste is much larger than the RWMIS values of 57,000 and 260,000 Ci. As discussed in Section 2.4.6 and Appendix C, the improved method for estimating the inventory of contaminants in waste from the RFP did not involve the use of RWMIS (except for shipments of depleted uranium in 1971–1972, which were very small in radioactivity). The method involved the use of plantwide inventory balances at the RFP. The much higher values that appear in CIDRA are not surprising and are considered to be the most reliable estimates available.

- **Other.** The CIDRA value of 53,000 Ci for the total radioactivity in waste from the other generators is nearly identical to the value of 55,000 Ci in the RWMIS shipping record rollup. The value of 110,000 Ci found in the RWMIS annual summaries is inappropriate

for comparison. It includes 61,000 Ci that was attributed in 1971 to the RWMC itself as a waste generator, because the 61,000 Ci was generated by unknown onsite generators. That is, in using the RWMIS annual summaries, the 61,000 Ci ascribed to the RWMC should probably be apportioned over TAN, TRA, ICPP, NRF, and ANL-W. Subtracting the 61,000 Ci from the other generator category would reduce the RWMIS annual summaries value to 51,000 Ci, which is slightly smaller than the 53,000 Ci in CIDRA and the 55,000 Ci in the RWMIS shipping record rollup.

In summary, the generator-by-generator comparisons provide expected results considering the nature of the present inventory compilation and the uncertainties involved.

6.3 Comparison of the Inventory with Contaminants Detected in Environmental Monitoring

6.3.1 Purpose

It is useful to compare the estimated inventory of contaminants in CIDRA with the list of contaminants whose presence is detected at the RWMC by means of environmental monitoring. Potential gaps in the inventory may, thereby, be identified.

The following sections include (a) the approach used to analyze contaminant monitoring results, (b) a summary of routine environmental monitoring activities and of special studies not part of the routine monitoring, (c) a brief summary of the monitoring results in terms of contaminants detected, years, and environmental media, and (d) comparisons of contaminants detected against the contaminant inventory in CIDRA for the historical and recent periods. [Because the environmental monitoring may detect contaminants disposed of during either the historical period (1952 through 1983) or the recent period (1984 through 2003), the comparison was performed simultaneously for the inventory of both periods.] The documents from which the monitoring summaries were produced are listed in the bibliography in Appendix F.

6.3.2 Approach

Pertinent monitoring data for the RWMC were obtained from two primary sources: (a) annual summary reports for routine monitoring and (b) documentation for special environmental studies. Routine monitoring results for the environmental monitoring program have been summarized annually since 1976. Concentrations are measured for radiological and nonradiological contaminants in air, soil, water, geologic media, and biotic media. These data were examined and summarized for the years 1976 through 1993. Existing databases and documents were consulted to identify special studies conducted on the SDA that resulted in reported environmental concentrations for radiological or nonradiological contaminants. Routine monitoring and special study results were evaluated by contaminant and medium and were summarized. The monitoring results were compared with the list of contaminants in the CIDRA inventory. The results of the comparison were interpreted with respect to the completeness of the list of contaminants in the inventory.

6.3.3 Environmental Monitoring Program

A comprehensive monitoring program is conducted at the RWMC and other areas of the INEL. The program provides for routine monitoring and data interpretation of radioactive and nonradioactive contaminants in the environment associated with the RWMC and SDA (Wilhelmsen et al. 1994).

Routine monitoring activities conducted as part of the program for the RWMC and SDA are summarized in Table 6-7. The program includes measuring the concentrations of radioactive contaminants in air, water, soil, and biota (vegetation and small mammals), as well as monitoring of ambient radiation (Wilhelmsen et al. 1994). Monitoring conducted by RESL and groundwater monitoring activities conducted by the U.S. Geological Survey (USGS) are incorporated into the program and included in the annual summary reports. Nonradiological contaminants—metals and organics in liquid effluents and drinking water—are also assessed.

6.3.4 Special Studies

A number of special or one-time environmental studies for radiological and nonradiological contaminants have been performed at the RWMC and SDA. Data collected as part of the RWMC Subsurface Investigations Program, USGS studies, and other contaminant investigative studies were reviewed and summarized. Investigations included subsurface drilling, soil vapor monitoring, and groundwater monitoring. Data from the studies included in this HDT date back as far as the mid-1970s.

6.3.5 Summary of Monitoring Results

The results of routine monitoring and special studies for radiological and nonradiological contaminants in the SDA are summarized in Appendix F.

6.3.6 Comparison of Contaminants Detected in Monitoring Activities Against Contaminants Identified in the Waste Inventory

Table 6-8 compares the results from environmental monitoring against the results of the inventory compilation for the historical and recent periods. The table lists the contaminants detected in routine monitoring or in special studies, the presence of each contaminant in the waste inventory, the media in which the contaminants were detected, the years in which they were detected, and brief conclusions concerning the comparisons (i.e., monitoring reliability and the qualitative amount of the contaminant in historical and recent periods). The table lists radiological contaminants first, followed by nonradiological contaminants.

6.3.6.1 Radiological Contaminants. No radiological contaminants that were reliably detected during monitoring were missing from the waste inventory.

The following radiological contaminants were detected in reliable data from the monitoring and were identified in the waste inventory: Am-241, Co-60, Cs-134, Cs-137, H-3, Pu-238, Pu-239/240, Sb-125, Sr-90, U-234, U-235, and U-238.

Table 6-7. Routine environmental monitoring activities performed at the Subsurface Disposal Area (compiled from Wilhelmsen et al. 1994).

Activity	Facility	Description	Frequency of analysis	Type of analysis
RADIOLOGICAL CONTAMINANTS				
Ambient air monitoring	SDA	Eight low-volume air samples operated at 0.14 m^3/min (includes one control and one replicate)	Semimonthly Semimonthly Monthly Quarterly	Gross alpha Gross beta Gamma spectrometry Radiochemistry[a]
Soil sampling	SDA	Five locations in each of five major areas (plus one control area)	Triennially	Gamma spectrometry Radiochemistry[a]
Subsurface water (sampled by the USGS)	SDA	2-L samples from each of six wells (five wells to the aquifer, one well to perched water)	65-m (perched water) well annually 183-m (aquifer) wells quarterly Production well quarterly	Gamma spectroscopy, chlorides (i.e., Cl-35), H-3, Sr-90, Co-60, Cs-137, Pu-238, Pu-239/240, and Am-241
Surface water sampling	SDA	4-L surface runoff samples from SDA and control location	Quarterly, but depends on precipitation	Gross alpha Gross beta Gamma spectrometry Radiochemistry[a,b,c]
Biotic surveillance	SDA and TSA	Small mammals—three composites in each of five major areas (plus one control area)[c]	Annually, but species sampled varies each year depending on availability	Gamma spectrometry Radiochemistry[a]
		Vegetation—three composites in each of five major areas (plus one control area)[c]	Annually, but species sampled varies each year depending on availability	Gamma spectrometry Radiochemistry[a]
		Small mammal burrow excavations (soil)—three composites from each of five major areas	Annually	Gamma spectrometry Radiochemistry[a]
NONRADIOLOGICAL CONTAMINANTS				
Subsurface water (sampled by the USGS)	SDA	Drinking water	Production well monthly	Organics Specific conductance Chloride, sodium, nitrate

a. Analysis for Am-241, Pu-238, Pu-239/240, U-235, U-238, and Sr-90.

b. Samples for radiochemical analyses usually taken during second quarter only.

c. Exact number of samples may vary because of availability.

Table 6-8. Comparison of results of environmental monitoring against results of the inventory compilation.

Contaminant	Contaminant present in inventory? (historical period 1952–1983)	Contaminant present in inventory? (recent period 1984–1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
RADIOLOGICAL					
Ac-228	No	No	Aquifer	1979	Not identified in waste for either period; monitoring detections not reliable
Ag-110	Yes	Yes	Air Surface water Soil	1980 1977 1979, 80	Minute quantities identified in waste for both time periods; monitoring detections not reliable
Am-241	Yes	Yes	Aquifer Surface water Subsurface sediment Surficial sediment Soil Biota—vegetation Biotic—soil Biotic—tissue Air	1976, 81, 82, 84, 87 1977, 83–85, 90–93 1975–77, 85–88, 89 1989 1977–81, 84, 86, 88, 91, 92 1984, 86, 87, 90–93 1984–86, 90 1987, 89 1978–81, 84–93	Very large and small quantities identified in waste for historical period and for recent period, respectively; detected frequently in monitoring program
Ba-140	Yes	Yes	Air	1980	Small and minute quantities identified in waste for historical period and for recent period, respectively; monitoring detections not reliable
Ce-141	Yes	Yes	Aquifer Surface water Soil Air	1983 1977, 81 1979–81 1978–81, 83–84	Small and minute quantities identified in waste for historical period and for recent period, respectively; monitoring detections not reliable
Ce-144	Yes	Yes	Subsurface sediment Surface water Soil Air	1975–78 1976–79 1978–81 1978–81, 83–84	Very large and moderate quantities identified in waste for historical period and for recent period, respectively; monitoring detections not reliable

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952-1983)	Contaminant present in inventory? (recent period 1984-1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Co-58	Yes	Yes	Soil	1978-81	Very large quantities identified in waste for both time periods; most monitoring detections not reliable
			Air	1978-81, 83, 85	
Co-60	Yes	Yes	Aquifer	1980, 87	Very large quantities identified in waste for both time periods; detected frequently in monitoring program
			Perched water	1976-77	
			Subsurface sediment	1976-88, 89	
			Surface water	1977	
			Surficial sediment	1989	
			Soil	1977-81, 86	
			Biota—vegetation	1983	
			Biotic—soil	1984	
			Biotic—tissue	1987, 91, 92	
			Air	1978-81, 83, 86	
Cr-51	Yes	Yes	Surface water	1977	Very large and large quantities identified in waste for historical and recent periods, respectively; monitoring detections not reliable
			Soil	1978-81	
			Air	1978-81, 83	
Cs-134	Yes	Yes	Surface water	1977, 79, 81	Moderate and small quantities identified in waste for historical and recent periods, respectively; detected occasionally in monitoring program
			Soil	1978-81	
			Biota—vegetation	1987	
			Air	1978-81, 85	
Cs-137	Yes	Yes	Aquifer	1976, 77, 80, 86, 87	Very large and moderate quantities identified in waste for historical and recent periods, respectively; detected frequently in monitoring program
			Perched water	1976, 77	
			Subsurface sediment	1975-88, 89	
			Surface water	1976, 77, 79-81, 83-86, 88, 90, 93	
			Surficial sediment	1989	
			Soil	1977-81, 84, 88, 89, 92	
			Biota—vegetation	1983, 84, 87	
			Biotic—soil	1984, 86, 90	
			Biotic—tissue	1987, 91, 92	
			Air	1978-81, 84-85, 87, 91	

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952-1983)	Contaminant present in inventory? (recent period 1984-1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Eu-152	Yes	Yes	Surface water Soil Biotic—tissue Air	1976, 78-79 1978-81 1987 1978-81	Small and minute quantities identified in waste for historical and recent periods, respectively; most monitoring detections not reliable
Eu-154	Yes	Yes	Subsurface sediment Surface water Surficial sediment Soil Biotic—tissue Air	1985 1976, 79 1989 1978-81, 89 1987 1978-81	Moderate and minute quantities identified in waste for historical and recent periods, respectively; most monitoring detections not reliable
Eu-155	Yes	Yes	Soil Air	1981 1981	Large and minute quantities identified in waste for historical and recent periods, respectively; monitoring detections not reliable
Fe-59	Yes	Yes	Aquifer Soil Air	1976 1979-81 1978-81	Large quantities identified in waste for both time periods; monitoring detections not reliable
H-3	Yes	Yes	Aquifer Perched water	1977-93 1976-77, 92, 93	Very large quantities identified in waste for both time periods; detected frequently in monitoring program
Hf-181	Yes	Yes	Soil Air	1978-81 1978-81	Minute and moderate quantities identified in waste for historical and recent periods, respectively; monitoring detections not reliable
Hg-203	Yes	No	Soil Air	1980-81 1978-81	Minute and no quantities identified in waste for historical period and recent period, respectively; monitoring detections not reliable
I-131	Yes	Yes	Air	1980	Minute quantities identified in waste for both time periods; monitoring detections not reliable

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952-1983)	Contaminant present in inventory? (recent period 1984-1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Mn-54	Yes	Yes	Aquifer Soil Air	1977 1979-81 1978-81, 83	Very large quantities identified in waste for both time periods; monitoring detections not reliable
Nb-95	Yes	Yes	Surface water Soil Air	1977 1978-81 1978-81	Moderate quantities identified in waste for both time periods; monitoring detections not reliable
Pb-212	Yes	No	Aquifer	1978	Minute and no quantities identified in waste for historical period and recent period, respectively; monitoring detections not reliable
Pu-238	Yes	Yes	Aquifer Perched water Subsurface sediment Surface water Surficial sediment Soil Soil water Biota—vegetation Biotic—tissue Air	1981, 83, 87 1976, 77, 89 1975-89 1983 1989 1979-81, 88, 89, 91, 92 1989 1984, 86-87, 90 1987, 89 1980, 86-88	Large and small quantities identified in waste for historical period and recent period, respectively; detected frequently in monitoring program
Pu-239/240	Yes	Yes	Aquifer, perched Subsurface sediment Surface water Surficial sediment Soil Soil water Biota—vegetation Biotic—soil Biotic—tissue Air	1976, 85-89 1975-78, 85-88, 89 1983-85 1989 1976-77, 79-81, 86, 88, 89, 91-93 1989 1986-87, 90 1984, 86-90 1987, 89 1980, 84-88, 90-93	Very large and small quantities identified in waste for historical period and recent period, respectively; detected frequently in monitoring program

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952–1983)	Contaminant present in inventory? (recent period 1984–1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Ru-103	Yes	Yes	Surface water Soil Air	1977, 81 1978–81 1978–80, 83	Small and minute quantities identified in waste for the historical and recent periods, respectively; monitoring detections not reliable
Ru-106	Yes	Yes	Surface water Soil Biota—vegetation Air	1976–77, 79 1979, 81 1978 1978–81	Moderate and small quantities identified in waste for the historical and recent periods, respectively; monitoring detections not reliable
Sb-124	Yes	Yes	Soil Air	1979–81 1979–81	Moderate and minute quantities identified in waste for the historical and recent periods, respectively; monitoring detections not reliable
Sb-125	Yes	Yes	Surface water Soil Biota—vegetation Biotic—tissue Air	1978–81 1978–81 1987 1987 1978–81, 84	Very large and moderate quantities identified in waste for the historical and recent periods, respectively; detected occasionally in monitoring program, but early detections not reliable
Sc-46	Yes	Yes	Soil Air	1979–81 1978–81	Minute quantities identified in waste for both time periods; monitoring detections not reliable
Sr-90	Yes	Yes	Aquifer, perched Subsurface sediment Surface water Surficial sediment Soil Biota—vegetation Biotic—tissue Biotic—soil Air	1976, 78–80, 85–88 1975–88, 89 1987 1989 1988, 89, 91, 92 1983, 84, 86, 87, 90, 92, 93 1987, 89 1984 1986–88, 93	Very large and small quantities identified in waste for the historical and recent periods, respectively; detected frequently in monitoring program

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952–1983)	Contaminant present in inventory? (recent period 1984–1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Ta-182	Yes	Yes	Soil Air	1979–81 1979–81	Minute and large quantities identified in waste for the historical and recent periods, respectively; monitoring detections not reliable
U-234	Yes	Yes	Soil Biota—vegetation Biotic—tissue	1986, 92 1985, 87 1987	Small quantities identified in waste for both time periods; detected occasionally in monitoring program
U-235	Yes	Yes	Soil Biota—vegetation Biotic—tissue	1983 1987 1987, 89	Small quantities identified in waste for both time periods; detected rarely in monitoring program
U-237	No	No	Air	1980	Not identified in waste for either time period; monitoring detections not reliable
U-238	Yes	Yes	Soil Biota—vegetation Biotic—tissue	1983–84, 92 1987 1987, 89	Moderate and small quantities identified in waste for the historical and recent periods, respectively; detected rarely in monitoring program
Y-91	Yes	No	Soil Air	1979–80 1979–80	Small and no quantities identified in waste for historical period and recent period, respectively; monitoring detections not reliable
Zn-65	Yes	Yes	Soil Air	1979–81 1978–81	Small and moderate quantities identified in waste for the historical and recent periods, respectively; monitoring detections not reliable
Zr-95	Yes	Yes	Soil Air Surface water	1979–81 1978–81 1977	Large and moderate quantities identified in waste for the historical and recent periods, respectively; monitoring detections not reliable

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952–1983)	Contaminant present in inventory? (recent period 1984–1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
NONRADIOLOGICAL					
Organics[e]					
1,1,1-trichloroethane	Yes	No	Aquifer, perched Soil borehole (vapor) Soil/soil gas Air	1987–93 1987, 88 1987 1991, 94	Very large quantity identified in waste for the historical period; detected frequently in monitoring program
1,1,2-trichloro-trifluoroethane	Yes	No	Perched water Soil borehole (vapor) Soil/soil gas Air	1987–90 1987 1987 1989	Large quantity in waste for the historical period; detected frequently in monitoring program
1,1-dichloroethylene	No	No	Aquifer, perched	1987–93	Not specifically identified in inventory; detected frequently in monitoring program
1,1-dichloroethane	No	No	Aquifer, perched	1987–93	Not specifically identified in inventory; detected frequently in monitoring program
2-butanone	Yes	No	Air	1994	Moderate quantity identified in the waste for the historical period; previous instruments were not capable of measuring low concentrations of 2-butanone
Acetone	Yes	No	Sedimentary interbed Air	1987 1994	Large quantity identified in waste for the historical period; detected rarely in monitoring program
Carbon tetrachloride	Yes	No	Aquifer, perched Borehole (vapor) Soil/soil gas Air	1987–93 1987–88 1987, 92 1987, 89	Very large quantity identified in waste for the historical period; detected frequently in monitoring program
Chloroform	Yes	No	Aquifer, perched Soil/borehole (vapor) Sedimentary interbed Air	1987–93 1987–88, 92 1987 1989, 94	Very large (unknown) quantity identified in waste for the historical period; detected frequently in monitoring program

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952–1983)	Contaminant present in inventory? (recent period 1984–1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Organics (continued)					
Dichlorodifluoromethane	No	No	Aquifer, perched Air	1987–93 1994	Not specifically identified in inventory; detected frequently in monitoring program
Methylene chloride	Yes	No	Sedimentary interbed Perched water Air	1987 1993 1991, 94	Very large quantity in waste for the historical period; detected rarely in monitoring program
Phenol	No	No	Aquifer	1991	Not specifically identified in inventory; detected rarely in monitoring program
Tetrachloroethylene	Yes	No	Aquifer, perched Soil/borehole (vapor) Soil/soil vapor Air	1987–93 1987, 92 1987 1994	Very large quantity identified in waste for the historical period; detected frequently in monitoring program
Toluene	Yes	No	Aquifer, perched Soil/borehole (vapor) Air	1987–93 1987, 92 1994	Large quantity identified in waste for the historical period; detected frequently in monitoring program
Trichloroethylene	Yes	No	Air Aquifer, perched Soil/borehole (vapor) Sedimentary interbed	1987, 89 1987–93 1987, 92 1987	Very large quantity identified in historical waste; detected frequently in monitoring program
Metals					
Antimony	Yes	No	Perched	1988, 93	Small quantity identified in waste for the historical period; detected rarely in monitoring program
Arsenic	No	Yes	Aquifer, perched	1987–88, 93	Only small quantity identified in waste for recent period; detected rarely in monitoring program

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952–1983)	Contaminant present in inventory? (recent period 1984–1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Metals (continued)					
Barium	No	No	Perched water Sedimentary interbed	1988, 93 1987	Not identified in waste; detected rarely in monitoring program
Beryllium	Yes	Yes	Perched water Subsurface soil Sedimentary interbed	1988, 93 1991 1987	Very large and large quantities in inventory for the historical and recent periods, respectively; detected occasionally
Boron	No	No	Surface soil	1982	Not identified in inventory; not on lists of hazardous substances; detected rarely
Cadmium	Yes	Yes	Perched water Surface soil	1988, 93 1982	Large and small quantities of waste identified in historical and recent period, respectively; detected rarely
Chromium	Yes	Yes	Surface water Aquifer, perched Soil Sedimentary interbed	1986 1985–87, 93 1982 1987	Moderate and small quantities of waste identified in historical and recent period, respectively; detected occasionally
Cobalt	No	No	Perched water	1988, 93	Not identified as a nonradiological contaminant in waste; detected rarely in monitoring program
Copper	Yes	Yes	Perched water Soil Sedimentary interbed	1988, 93 1982 1987	Small and moderate quantities of waste identified in historical and recent period, respectively; detected occasionally
Lead	Yes	Yes	Perched water Surface soil	1988, 93 1982	Very large quantities identified in inventory for both periods; detected rarely
Mercury	Yes	Yes	Perched water Subsurface soil[f] Sedimentary interbed Soil vapor	1988, 93 1991[f] 1987 1990	Large and small quantities of waste identified in historical and recent period, respectively; detected occasionally in environmental monitoring; detected in direct sampling of the Acid Pit

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952–1983)	Contaminant present in inventory? (recent period 1984–1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Metals (continued)					
Nickel	Yes	No	Perched water Sedimentary interbed	1988, 93 1987	Moderate quantity identified in waste for historical period; detected rarely in monitoring program
Selenium	No	No	Sedimentary interbed Subsurface water, perched	1987 1987, 88 1993	Not identified in waste; detected rarely in monitoring program
Silver	Yes	No	Perched water Sedimentary interbed	1988, 93 1987	Moderate quantity identified in waste for historical period; detected rarely in monitoring program
Thallium	No	No	Perched water Sedimentary interbed	1988, 93 1987	Not identified in waste; detected rarely in monitoring program
Tin	No	No	Perched water Sedimentary interbed	1988 1987	Not identified as a nonradiological contaminant in waste; detected rarely in monitoring program
Vanadium	No	No	Perched water Sedimentary interbed	1988, 93 1987	Not identified in waste; detected rarely in monitoring program
Zinc	No	No	Perched water Surface soil Sedimentary interbed	1988, 93 1982 1987	Identified in waste inventory only in radioactive form (<1 g mass); detected rarely
Other					
Chloride	Yes	No	Aquifer, perched Surface soil	1979, 82–93 1982	Very large quantity identified in waste for historical period; detected frequently in monitoring program
Cyanide	Yes	No	Perched water Sedimentary interbed	1988 1987	Small quantity identified in waste for historical period; detected rarely in monitoring program

Table 6-8. (continued).

Contaminant	Contaminant present in inventory? (historical period 1952-1983)	Contaminant present in inventory? (recent period 1984-1993)	Environmental media in which detected[a]	Years detected[b]	Conclusion[c,d]
Other (continued)					
Nitrate	Yes	No	Aquifer, perched Surface water Soil	1982-83, 85, 87, 93 1980-82 1980-83	Very large quantity identified in waste for historical period; detected frequently in monitoring program
Sodium ion	Yes	No	Aquifer, perched Surface water	1979, 82-93 1983-86	Very large quantity identified in waste for historical period; detected frequently in monitoring program
Sulfate	Yes	No	Perched water	1985, 88, 93	Very large quantity identified in waste for historical period; detected occasionally in monitoring program
Sulfide	No	No	Sedimentary interbed	1987	Not identified in waste; detected rarely in monitoring program

a. Subsurface water includes samples from five wells that sample aquifer water and from one well that samples perched water. Separate entries are indicated where possible.

b. Data obtained by EG&G Idaho, Inc. routine monitoring before approximately 1983 are considered to be of lower reliability because, in many cases, no control samples were collected or the control samples were from inappropriate locations. In many cases, contaminants detected in these early samples may have originated in the airborne or waterborne emissions from other INEL facilities rather than from the SDA.

c. The following method was used to express quantitative inventory values using a set of qualitative terms. The expression E+03, for example, covers entries between E+03 and 9.9E+03. Radiological contaminants—Alpha-emitters: Very large=E+04 and greater, Large=E+03, Moderate=E+02, Small=E+01 and less; Beta/gamma-emitters: Very large=E+05 and greater, Large=E+04, Moderate=E+03, Small=E+02, Minute=E+01 and less. Nonradiological contaminants—Very large=E+07 and greater; Large=E+05, E+06; Moderate=E+03, E+04; and Small=E+02 and less.

d. The frequency of detection is expressed in a qualitative hierarchy of terms: frequently, occasionally, rarely. The determination of the appropriate term is based on technical judgment after considering (a) the number of years in which the contaminant was detected and (b) the number of years in which the contaminant was monitored.

e. During 1984 through 1993, no organic contaminants were disposed of in the SDA.

f. Mercury was sampled for in one SDA trench in 1990 but was not detected. Mercury was sampled for and detected in the Acid Pit.

As stated previously, contaminants detected in monitoring at the SDA might not have migrated from the buried waste. This could be the case, for example, with contaminants that are detected only in the aquifer. As another example, U-234, U-235, and U-238 are detected from time to time at the SDA. However, these radionuclides also occur naturally. Only a carefully constructed set of control samples will discriminate as to the likely origin of these three detected radionuclides, between the naturally occurring source and the source within the buried waste. It is beyond the scope of this document to provide definitive determinations on the source of the contaminants detected in the monitoring. The purpose of the present comparison is a simple check to help ensure that the inventory has not omitted any contaminants whose possible presence in the buried waste is manifest by environmental monitoring data.

The following radiological contaminants were detected only in the years before improved routine monitoring began, about 1984 (as discussed in Appendix F, these detections are questionable): Ac-228, Ag-110, Ba-140, Ce-141, Ce-144, Cr-51, Eu-155, Fe-59, Hf-181, Hg-203, I-131, Mn-54, Nb-95, Pb-212, Ru-103, Ru-106, Sb-124, Sc-46, Ta-182, U-237, Y-91, Zn-65, and Zr-95. There are no known, reliable monitoring data suggesting the migration of these contaminants at the SDA. This conclusion is not surprising because many of these contaminants have extremely low mobilities (being trapped in metal matrices), have very short half-lives, and are present in relatively small amounts.

The historical inventory contains a large activity of Pu-241, and this radionuclide is not monitored. The reason is that Pu-241, a beta-emitter, is less radiotoxic than the alpha-emitting plutonium and americium radionuclides that are monitored (Pu-238, Pu-239/240, and Am-241). Plutonium-241 is more difficult to measure and is also much shorter-lived than the other radionuclides mentioned.

6.3.6.2 Nonradiological Contaminants. Routine monitoring for nonradiological contaminants at the RWMC began in the mid- to late 1980s. All of the data for nonradiological contaminants are considered sufficiently reliable for use in these comparisons.

Ten of the fourteen organic contaminants that were detected in the monitoring are listed in the historical inventory. Those not specifically listed in the inventory are 1,1-dichloroethylene, 1,1-dichloroethane, dichlorodifluoromethane, and phenol. (However, phenol was detected only rarely—it was detected in the aquifer once in 1991.) The frequent detections were in both aquifer water and perched water. Any contaminants detected only in the aquifer could have originated at other upgradient INEL facilities. However, any contaminants detected in perched water could have originated in the buried waste.

Several possible explanations exist as to why some of the organic contaminants were detected in the monitoring but not identified specifically in either this inventory or other inventory reports. First, the waste information on which the inventory is based could simply be incomplete. Second, the contaminants could have been secondary species in a waste stream wherein only the primary species were identified. Third, the contaminants detected in the monitoring could be degradation products originating from a contaminant that is listed in the inventory. Three of the organics are very similar in molecular structure to organic compounds that have been identified in the inventory in large quantities; 1,1-dichloroethylene is similar to trichloroethylene, 1,1-dichloroethane is similar to

1,1,1-trichloroethane, and dichlorodifluoromethane is similar to 1,1,2-trichloro-1,2,2-trifluoroethane. Therefore, there is a strong possibility that these are impurities or degradation products of substances that are listed in the inventory. It is beyond the scope of this comparison to distinguish definitively among these possible explanations for the fact that three organics were detected more often than rarely in the monitoring but not identified specifically in the inventory. The conclusion is that nearly all of the organic contaminants detected in the monitoring were identified in the inventory for the historical period.

Among the metals, only beryllium, chromium, copper, and mercury have been detected more than once or twice in the monitoring. All of these metals were identified in the inventory, in quantities ranging from small to very large for both the historical and recent periods. Several other metals have been detected once or twice in the monitoring: cadmium, lead, zinc, antimony, arsenic, cobalt, barium, nickel, selenium, silver, thallium, tin, boron, and vanadium. The measured concentrations approximate natural background levels in many cases. Some of these metals have been identified in the inventory for both the historical and recent periods. The conclusion is that the entire inventory includes all toxic metals that have been detected in the environment on more than rare occasions and at concentrations well above natural background.

The last class of nonradiological contaminants monitored is certain inorganic species. Sodium ion, chlorides, sulfates, and nitrates are detected occasionally to frequently by monitoring; they are listed in the inventory for the historical period in various forms and in very large quantities. Sulfides were detected once in the monitoring, but they were not identified in the inventory for either time period. Again, these detected contaminants could have originated from naturally occurring sources or from the waste. Cyanide has been detected on two occasions and is identified in the inventory for the historical period in a small quantity.

6.3.6.3 Conclusions. No radiological contaminants that were reliably detected in the monitoring are missing from the waste inventory.

For the nonradiological contaminants, other than rare detections or detections at concentrations near natural background levels, no metals or other inorganics on the list of hazardous substances were detected in the environmental monitoring but not listed in the inventory for one of the two time periods. Ten of the fourteen organic contaminants that were detected in the monitoring are listed in the inventory for the historical period. The other four organic contaminants may be degradation products or impurities of contaminants that were identified in the inventory for the historical period or may have originated from other INEL sources.

6.4 Contaminant Profile Data Sheets

Appendix G presents the contaminant inventory in a simple yet informative form, on contaminant profile data sheets. The data sheets provide a quick reference summary for most of the principal contaminants. Data sheets were prepared for contaminants that were among those present in the largest quantities.

Each contaminant profile data sheet briefly lists typical contaminant physical and chemical forms and properties, common uses, general presence in the environment, toxicology, the amount disposed of at the SDA, and the results of environmental monitoring at the SDA. For radiological contaminants, the radiological properties and radiotoxicity are also included.

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7. OBSERVATIONS AND CONCLUSIONS

Based on the results and knowledge gained in compiling the inventory, the following observations and conclusions are presented:

- The combined use of many types of information sources—process knowledge, operating records, technical calculations, reports, interviews, shipping records, the RWMIS database, and others—was essential to achieve the present degree of completeness of the inventory.

- For radiological contaminants, the inventory information that could be located and that is compiled in the new CIDRA database is believed to be substantially complete.

- For nonradiological contaminants, the inventory information that could be located and that is compiled in CIDRA is also believed to be substantially complete. During the time period of interest, strong emphasis was not placed on documenting the nonradiological hazards in the waste because the current requirements for reporting hazardous chemicals did not exist. However, process information gathered from a multitude of sources has resulted in closing most of the gaps in the shipping records.

- A substantial effort was devoted to breaking down the generic radioactivity terms MAP, MFP, unidentified alpha-emitters, and unidentified beta/gamma-emitters for each generator so that a specific distribution of radionuclides would be available for the risk assessment.

- The predominant (by mass) nonradiological contaminants identified in the waste were as follows: metals—lead, zirconium and its alloys, beryllium, magnesium, sodium-potassium, cadmium, and mercury compounds; organics—carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, and methylene chloride; acids; nitrates and other salts; and asbestos.

- The predominant (by radioactivity at the time of disposal) radiological contaminants identified in the waste were Fe-55, Co-60, H-3, Ni-63, Cr-51, Cs-137, Sr-90, Pu-241, Mn-54, Co-58, Ce-144, and Am-241.

- To confirm its completeness, the compiled inventory of radiological contaminants was compared against the corresponding inventory in the RWMIS database. For the principal radionuclides, the agreement with RWMIS was generally within the total random error of the usual activity-measurement method except for two instances in which the present task developed major new information:

  - The estimated H-3 activity is approximately 20 times larger than the RWMIS value, due primarily to the identification of a major TRA waste stream with approximately 1 million Ci of H-3 entrapped in beryllium.

  - The estimated activities of plutonium and americium radionuclides increased typically by a factor of 10 over the RWMIS values. This result stemmed from an extensive effort to obtain new information on the RFP waste, based on a plantwide inventory balance at the RFP.

- As an additional confirmation of its completeness, the compiled inventory of radiological and nonradiological contaminants was compared against the inventories in previous reports. The list of contaminants in the new inventory is considerably longer than those in previous inventories. For nearly all contaminants, the new inventory values are similar to or larger than those in previous inventories. Possible exceptions are asbestos, sodium hydroxide, and zirconium, but the methods of estimating quantities of the contaminants vary from study to study.

- As a final confirmation of its completeness, the present inventory of contaminants was compared against the list of contaminants detected in environmental monitoring at the RWMC. No radiological contaminants were reliably detected in the monitoring that had not been identified in the inventory. The only nonradiological contaminants detected more than rarely in the environmental monitoring that were not identified in the inventory were three organic compounds: 1,1-dichloroethylene, 1,1-dichloroethane, and dichlorodifluoromethane. These three contaminants may be degradation products or impurities associated with closely related contaminants that were identified in the inventory. Detected contaminants also could have originated from sources other than the subject waste, e.g., in effluents from other INEL facilities or from other waste at the RWMC.

- A large quantity of information was assembled and entered into CIDRA on the physical and chemical forms of the waste streams and of the contaminants, as well as on the packaging of the waste streams.

- Even though the information now residing in CIDRA has been through multiple checks and reviews, the possibility exists for oversights and discrepancies. As new information is discovered, the database will be revised as necessary.

Appendix A

Data Collection Forms

Appendix A

Data Collection Forms

This appendix presents two items related to collecting information on the contaminant inventories.

The first item is a blank, five-page data collection form. One data form was completed for each identified waste stream disposed of in the Subsurface Disposal Area (SDA). Continuation pages were added to the form as necessary. The Contaminant Inventory Database for Risk Assessment (CIDRA) database was modeled after this form. Completed forms for all identified waste streams are stored in CIDRA and constitute Appendix B of this report.

The second item is a list of the general physical forms for waste buried in the SDA. The list can be used in the database compilation of the inventory to rollup all waste streams having a similar physical form, regardless of the generator or building that produced the waste.

DATA INPUT FOR HISTORICAL DATA TASK FOR RWMC SUBSURFACE DISPOSAL AREA

PART A - GENERAL INFORMATION

1. Preparer _____

2. Date prepared _____

3. Generator _____
(area or contractor - use code from attached list)

4. Particular facility _____
(building number - use code from attached list)

5. Number of the waste stream from this facility
_____

6. Waste stream _____
_____
_____
_____
_____

7. Type of radioactive waste (check box)
☐ TRU or suspect TRU
☐ LLW
☐ non-radioactive

8. Actual years disposed of at SDA
Starting year _____ Ending year _____

9. Waste stream volume
Amount _____ Units _____
Check box: ☐ annual or ☐ total over all years
Check box: ☐ container volume or ☐ waste volume

10. Comments (specify number of pertinent question) _____
_____
_____
_____
_____
_____
_____

PART B - WASTE STREAM CHARACTERISTICS

1. General physical form (see attached list)

☐ other (specify) _____

2. Details on physical form (particularly confinement related)

3. Chemical form _____

4. Inner packaging: ☐ plastic bag ☐ plastic liner ☐ metal liner
☐ none ☐ other (specify) _____

5. Waste container type (see attached list)

6. Other characteristics of interest _____

7. Comments (specify number of pertinent question) _____

PART C - NONRADIOLOGICAL CONTAMINANTS

For each contaminant, complete at least one line on the following table. If any entries for that contaminant vary by year, fill out additional lines as needed to cover the varying entries for different years. For example, if the annual quantity disposed was x kg for 1952–56 and y kg for 1957–84, use two lines to handle this situation.

Contaminant and CAS Registry Number	Physical Form	Chemical Form	(A)Annual/ (T)Total Quantity	Units	Begin Year	End Year	Samples? Y/N*	Minimum Value or No. of Samples*	Maximum Value or Std. Dev.*	Basis for Uncertainty

* If sample data are available, mark Y in the column titled "Samples?" and provide number of samples in the next column and standard deviation in the next column. If not, mark N and give the minimum value and maximum value.

Additional information or explanations (indicate pertinent contaminant)_____

_____

_____

_____

_____

PART D - RADIOLOGICAL CONTAMINANTS

Radionuclide	Physical Form	Chemical Form	(A)Annual/ (T)Total Quantity	Units	Begin Year	End Year	Samples? Y/N*	Minimum Value or No. of Samples*	Maximum Value or Std. Dev.*	Basis for Uncertainty

* If sample data are available, mark Y in the column titled "Samples?" and provide number of samples in the next column and standard deviation in the next column. If not, Mark N and give minimum value and maximum value.

Additional information or explanations (indicate pertinent contaminant). _____

_____

_____

_____

_____

_____

PART E - SOURCES OF INFORMATION AND UNCERTAINTIES

1. Type of source of information (check box)

☐ RWMIS ☐ other database
☐ sample analysis data
☐ operating records ☐ interview
☐ expert judgment ☐ reports
☐ other (specify) _____

2. Details concerning source [names, report no., dates, etc.]

_____
_____
_____
_____
_____
_____

3. Do the estimates of contaminant quantities in Part C and D represent: (check box)

☐ best estimate
☐ worst case
☐ other (specify) _____

4. If other than best estimate, explain why _____

_____
_____
_____

5. Do the data conflict with RWMIS?

☐ no
☐ yes

6. If yes, explain why _____

_____
_____

7. Major unknowns in inventories of contaminants _____

_____
_____
_____
_____
_____

8. Key assumptions used to deal with the unknowns _____

_____
_____
_____
_____
_____
_____

CONTINUATION PAGE

Continuation of Part _____, Column or Question Number or Title _____

GENERAL PHYSICAL FORMS FOR
WASTE BURIED IN THE SUBSURFACE DISPOSAL AREA

Number	Form
1	Irradiated fuel rods from experiments
2	Irradiated fuel from experiments
3	Unirradiated fuel from experiments
4	Irradiated end boxes
5	Other core, reactor vessel, and loop components
6	Ventilation systems
7	Lead
8	Beryllium
9	Zirconium
10	Other scrap metals
11	Sludge
12	Resin
13	Vermiculite and other sorbents
14	Evaporated salts
15	Other liquid setups
16	Graphite
17	Reactive metals
21	Combustibles (paper, cloth, wood, etc.)
22	High-efficiency particulate air filters
23	Other filters
24	Biological waste
31	Radiation sources
41	Concrete, brick, asphalt
42	Glass
43	Soil
44	Plastics
45	Rubber
46	Soot, ash
47	Asbestos
51	Liquids
52	Unknown
53	Other

Appendix B

Complete Printout of the Contaminant Inventory and Other Information from the CIDRA Database (Provided in Volumes 2 through 5)

Appendix C

The Inventory of Plutonium, Americium, and Uranium from the Rocky Flats Plant Buried at the Subsurface Disposal Area from 1954–1972

Appendix C

The Inventory of Plutonium, Americium, and Uranium from the Rocky Flats Plant Buried at the Subsurface Disposal Area from 1954–1972

J. J. Einerson
D. E. Kudera
T. H. Smith

INTRODUCTION

The Idaho National Engineering Laboratory (INEL) historical data task (HDT) was established to develop a detailed inventory of waste buried in the INEL Subsurface Disposal Area (SDA) from 1952 through 1983. The inventory will be used for performing a risk assessment under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to help determine the most appropriate remedial action, if any, for the SDA.

Waste received from the Rocky Flats Plant (RFP) constitutes part of the SDA inventory and was buried in the SDA from 1954 to 1972. The last plutonium and americium from the RFP was buried in 1970; only uranium was buried in 1971 and 1972.

The plutonium, americium, and uranium quantities that have been estimated to be buried at the SDA historically came from a 1971 letter from Lee to Soule (Lee 1971); these estimates have been used in a variety of subsequent INEL documents. However, RFP personnel do not believe that these quantities represent the best estimates. Therefore, INEL personnel have concluded that inventories provided in Lee (1971) are not adequate for conducting the SDA risk assessment. The previous RFP inventory estimate was inadequate because waste analysis technology was limited in the early years of operation.

The numbers used for the RFP portion of the SDA inventory in the risk assessment should reflect the *best current thinking of both RFP and INEL personnel*. Therefore, the HDT addresses the question of the best estimates for the RFP shipments to the SDA.

A briefing for INEL personnel was conducted at the RFP on August 24, 1993. Based on information presented by RFP personnel at that briefing and on subsequent INEL calculations using that information, best estimates and upper bounds were developed for the amounts of plutonium, enriched uranium, and americium in the RFP waste buried at the SDA.

The results of those calculations are documented here. The details of the pertinent information received from the RFP and of the INEL calculations are not presented here. For perspective, a brief summary of available information on RFP waste buried in the SDA follows.

AVAILABILITY OF INFORMATION ON RFP WASTE

The existing primary sources of information at the INEL concerning 1954 through 1972 RFP waste are a letter from the Lee to Soule (Lee 1971) and miscellaneous shipping records. There are indications that these information sources are not accurate. One indication is that individual drums have been found at the INEL containing plutonium levels above those identified in the shipping documents. RFP personnel also have stated that plutonium quantities in INEL records are significantly lower than the actual amount.

The only officially recorded removals of plutonium from the processing stream at the RFP were through War Reserve scheduled shipments, approved special orders, and authorized measured discards. The removals by War Reserve schedule and special orders are quite accurate. The removals through measured discard were almost entirely in the form of solidified liquid waste.

The volume of the liquid waste was measured and the liquid was sampled and analyzed for its radionuclide content before solidification. Measuring and sampling these liquids was a difficult problem, and the RFP records show that the credit taken for measured discards has been inadequate. The fact that more plutonium was discarded in this waste than credit was taken for is substantiated by the fact that the sludges accumulated during waste treatment have shown a plutonium content of over twice the weight taken as measured discards.

Discard values or levels for solid waste shipped offsite were not established. Even if these levels had been established, it would have been difficult to determine the amount of accountable material because the only control was by measuring the gamma radiation level, which is not an accurate method for measuring plutonium, americium, and uranium in solid waste. In the early 1960s, extensive research and development work took place at the RFP to improve drum counting methods. The use of drum counters began in 1964. However, for the first few years, shipping personnel did not use the results of the drum counters because they mistrusted the results. In addition, no authorized measurement methods were available for boxes through the early 1970s. A Geiger-Müller (G-M) gamma survey was performed on the boxes to try to ensure that large amounts of radionuclides were not being shipped. Acceptable techniques for measuring the radionuclide content of boxes were not available at the RFP before 1978.

Because of the significant limitations in measuring plutonium in most of the RFP waste buried at the SDA, further analysis of the shipping records was not considered productive. INEL personnel have long been aware that RFP personnel have been seeking to improve their knowledge of the disposition of the plutonium since at least 1964, and that RFP personnel have reached some conclusions about the disposition of the plutonium.

The RFP approach to investigating the disposition was based on a plantwide plutonium balance. Table C-1 summarizes the results of this RFP investigation, which provides the best estimates and INEL-calculated upper bounds for the total amount of plutonium, Am-241, and enriched uranium that was shipped from the RFP to the INEL and buried in the SDA from 1954 through 1972. Table C-2 presents the annual best estimates of plutonium, Am-241, and enriched uranium shipped from the RFP to the INEL for burial.

Table C-1. Summary of best estimates and upper bounds of Rocky Flats Plant waste buried at the Subsurface Disposal Area.

Radionuclide	Best estimate (kg)	Upper bound (kg)
Plutonium	1,102	1,455
Am-241	44	58
Enriched uranium	386	603

Table C-2. Annual best estimates of plutonium, Am-241, and enriched uranium shipped to the Idaho National Engineering Laboratory and buried in the Subsurface Disposal Area from 1954 through 1972.

Year	Plutonium best estimates (kg)	Am-241 best estimates (kg)	Enriched uranium best estimates (kg)
1954	1.6	0.1	3.1
1955	8.0	0.3	8.2
1956	16.1	0.6	10.7
1957	23.3	0.9	21.9
1958	54.1	2.2	71.8
1959	59.4	2.4	8.8
			(6.4)
1960	70.3	2.8	94.1
1961	64.3	2.6	47.7
1962	83.7	3.3	55.4
1963	101.8	4.1	11.2
1964	87.3	3.5	51.5
1965	125.5	5.0	8.6
			(-13.1)
1966	153.2	6.1	2.8
			(-11.1)
1967	72.0	2.9	8.4
	(58.9)	(2.4)	
1968	68.1	2.7	1.3
	(25.5)	(1.0)	(-14.7)
1969	74.0	3.0	10.0
1970	94.2	3.8	31.8
			(23.5)
1971	None	None	0.7
1972	None	None	2.7
			(0.6)

NOTE: For plutonium and Am-241 for 1967 and 1968 and enriched uranium for 1959, 1965, 1966, 1968, 1970, and 1972, the numbers in parentheses are the annual quantities used for the cumulative best estimate. The top numbers are annual best estimates. The differences are assumed to be because of recovery of backlogged material or material from the cleanout of equipment.

SUMMARY

Table C-1 provides the best estimates and upper bounds for the amounts of plutonium (material type Pu-52),[a] Am-241, and enriched uranium (material type U-38)[b] shipped to the INEL from the RFP and buried in the SDA during the years 1954 through 1972.

Table C-2 provides the annual best estimates for the amounts of plutonium, Am-241, and enriched uranium shipped to the INEL from the RFP and buried in the SDA during the years 1954 through 1972. Plutonium and americium were not buried in the SDA after 1970.

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a. Material type Pu-52 is the U.S. Department of Energy (DOE) designation for plutonium whose radionuclide mixture is considered weapons grade. The mixture breakdown is 0.0001 Pu-238, 0.9389 Pu-239, 0.0575 Pu-240, 0.0034 Pu-241, and 0.0002 Pu-242 by mass (EG&G Idaho 1985).

b. Material type U-38 is the DOE designation for enriched uranium whose radionuclide mixture is 0.0093 U-234, 0.9308 U-235, 0.0034 U-236, and 0.0565 U-238 by mass (EG&G Idaho 1985).

REFERENCES FOR APPENDIX C

EG&G Idaho, (EG&G Idaho, Inc.) 1985, *Solid Waste Management Information System (SWIMS) Users Manual*, April 1985.

Lee, W. H., 1971, letter to H. F. Soule, "Rocky Flats Solid Waste Shipped to NRTS," June 10, 1971.

Appendix D

Detailed Evaluation of Inventory Entries for Contaminants with Unknown Quantities

Appendix D

Detailed Evaluation of Inventory Entries for Contaminants with Unknown Quantities

This appendix evaluates the inventory entries for nonradiological contaminants with unknown quantities. Resolution of the inventory entries for radiological contaminants with unknown entries is discussed in Section 4. This appendix also provides an estimate of the volumes of Rocky Flats Plant (RFP) waste streams.

Evaluation of Unknown Quantities of Nonradiological Contaminants

Table D-1 presents the detailed results for the evaluation of the unknown quantities of nonradiological contaminants. For each contaminant with one or more entries giving the quantity as unknown, the designator is given for all waste streams containing unknown quantities of the contaminant. Next is a discussion of the attempt to estimate an upper-limit quantity (or, in the case of the RFP waste, a best estimate). The last column of the table compiles the results for all unknown entries of that contaminant.

The results of the evaluation of the unknown quantities of contaminants are not incorporated into the Contaminant Inventory Database for Risk Assessment (CIDRA) database because of their lower reliability.

Estimate of the Volumes of RFO-DOW-1H to RFO-DOW-14H Waste Streams

The total volumes of the various RFP waste streams buried in the Subsurface Disposal Area (SDA) are unknown. The available information did not provide an estimate of the annual volume or total volume for RFP buried waste streams RFO-DOW-1H through RFO-DOW-14H. Lee (1971) provides a total volume of waste that was shipped from the RFP to the Radioactive Waste Management Complex (RWMC) each year from 1954 to 1970. There is no indication, however, of the volumes of each type of waste, (i.e., each waste stream). The volume of these waste streams may be important for some future calculations. Therefore, an estimate of these volumes is made here.

The extrapolations to calculate the radionuclides and hazardous constituents present in each of the first 14 waste streams were based mostly on available information on RFP stored waste (Clements 1982). Therefore, the estimate of the volumes was made using the number of drums and boxes of each applicable content code received from 1971 through 1981 from the Clements (1982) report on stored waste. It was assumed that each drum is a 55-gal drum and that each box is $4 \times 4 \times 7$ ft. The numbers of drums and boxes and the total volume for each waste stream are shown in Table D-2. The relative volume percent of each waste stream was calculated from these numbers and is also shown in Table D-2. However, the total volume shipped from the RFP each year from Lee (1971) must be corrected for the amounts of organic sludge (RFO-DOW-15H) and evaporator salts (RFO-DOW-17H) that were buried. This total yearly volume (1954 through 1970) correction is shown in Table D-3. The corrected total yearly volumes are then multiplied by the volume percents for each waste stream (Table D-2) to obtain the annual volume of each of the first 14 buried waste streams for the years 1954 through 1970. These estimates are shown in Table D-4.

Table D-1. Results of the search to estimate upper-limit[a] quantities for nonradiological contaminants whose quantities are listed as unknown.

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
1,4-bis(5-phenyloxazol-2-yl)benzene	OFF-WSU-1H	Most of the waste in the 2.15-m^3 stream is paper, glassware, animal carcasses, and aqueous and organic solutions. The contaminant is believed to be <10% of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.22 m^3, or about 2.0E+05 g, at a specific gravity of about 0.9.	Detailed data form; Clements (1980)	An upper-limit estimate is 2.0E+05 g
3-methyl-cholanthrene	OFF-UOW-1H	Most of the waste in the 12.97-m^3 stream is paper, laboratory clothing, glassware, and animal carcasses. Small amounts of various laboratory chemicals are included. The contaminant is believed to be a small fraction (<1%) of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.13 m^3, or about E+05 g.	Detailed data form; Clements (1980)	An upper-limit estimate is E+05 g
Alcohols (assumed to be ethyl alcohol)	RFO-DOW-2H	See the evaluation of Versenes.	Clements (1982)	
Asbestos	ANL-765-1H	The detailed data form contains no information useful for estimating the quantity of asbestos other than the total stream volume of 1,815 m^3.	Detailed data form	A best estimate is 2.3E+06 g
	ANL-EBRI-1H	The detailed data form indicates that 511 ft^3 of asbestos was contained in the waste for September 1959. The quantities of asbestos during the remaining 5 years in which this stream was generated are not stated. Thus, all that is known is a lower limit of 511 ft^3 × 16 lb/ft^3 × 0.15 asbestos contents × 454 g/lb = 5.6E+05 g asbestos.	Detailed data form	
	D&D-OMR-1H	Only an inexact estimate can be made. The reference report states that the volume of metallic waste is 40,000 ft^3 (the external volume of the containers in which the waste was shipped). Photos suggest that about one-fourth of this volume is piping (the remainder being one-half tanks and one-fourth heat exchangers, pumps, etc.) If one-third of the piping is insulated, the *container* volume for such waste was about 40,000/12 = 3,300 ft^3, or 26 4 × 4 × 8-ft boxes. If there are 10 8-ft segments of insulated piping in each box, the total length would be 80 × 26 ft = 2,080 ft. Based on an estimate for TRA pipe insulation, assume the insulation volume is 1/3 × 2,080 ft = 700 ft^3. Based on assumptions used for the known quantity of asbestos in stream TRA-603-10H, assume 700 ft^3 × 16 lb/ft^3 × 0.15 asbestos (remainder of insulation material was magnesia and hydrated magnesium carbonate) × 454 g/lb = 7.6E+05 g asbestos.	Detailed data form; Hine (1980)	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit* quantity for each stream	Source(s) of information	Reasonable upper limit* on total unknown quantity over all streams shown
Asbestos (continued)	D&D-SPT-1H	The reference report indicates 18 m^3 of waste containers of piping. However, the photos suggest that little insulation is present. Assume the quantity of asbestos is small compared with that in other streams (<E+05 g).	Detailed data form; Smith (1979)	
	D&D-TAN-1H	The waste from two TAN D&D tasks is in this stream. The reference report for the TAN PM-2A task mentions asbestos only in connection with a 289-ft^3 tank. Very little piping is involved. Assuming cubical tank dimensions, 2-in. insulation thickness, and other assumptions as in stream D&D-OMR-1H, 6 sides × 6.6 ft × 6.6 ft × 1/6-ft-thick × 16 lb/ft^3 × 0.15 asbestos × 454 g/lb = 4.8E+04 g asbestos. The other D&D task (TAN/TSF-3 pad) involved no asbestos.	Detailed data form; Smith (1983) and Smith and Wisler (1984)	
	NRF-617-2H	This stream composites all of the lead and asbestos from NRF from 1955 through 1983. The volume of the stream is unknown, and the volumes of the two contaminants are unknown. There is no way to estimate reasonable upper limits for the quantities of lead and asbestos. The quantities could be large.	Detailed data form	
	OFF-LRL-1H	The reference report mentions asbestos only in connection with the Lawrence Berkeley Laboratory portion (263 m^3) of the stream. The asbestos millboard that is mentioned is assumed here to be a small fraction (1%) of the volume of the highly mixed waste stream. Assuming that the board has a density of 80 lb/ft^3 and is 25% asbestos, the mass of asbestos of 0.01 × 263 m^3 × 35.31 × 80 × 0.25 × 454 = 8.4E+05 g asbestos.	Detailed data form; Clements (1980)	
	OFF-LRL-2H	See discussion for stream OFF-LRL-1H. Stream OFF-LRL-2H is from Lawrence Livermore Laboratory. The reference does not mention asbestos in waste shipments from Lawrence Livermore. For simplicity, the data forms for the two shipments listed identical contaminants for the unknowns.	Detailed data form; Clements (1980)	
Benzene	OFF-UOW-1H	Most of the waste in the 12.97-m^3 stream is paper, laboratory clothing, glassware, and animal carcasses. Small amounts of various laboratory chemicals are included. The contaminant is believed to be a small fraction (<1%) of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.13 m^3, or 1.2E+05 g at a specific gravity of 0.9.	Detailed data form; Clements (1980)	An upper-limit estimate is 1.2E+05 g

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Beryllium	CFA-639-1H	The detailed data form states that the stream is 7 m^3 of paper, wood, and metal scrap with some beryllium, in two wooden boxes. Based on the varied composition of the waste, the quantity of beryllium is estimated to be very small compared with that in other streams (< < E+06 g).	Detailed data form	An upper-limit estimate for beryllium and beryllium oxide is a total of 8.0E+06 g
	CFA-654-1H	The detailed data form states that the stream includes scrap metals (steel, lead, beryllium, zirconium), sludge, and combustibles. The total volume is 50 m^3. The amount of lead is 800 lb. Based on the varied composition of the waste, the quantity of beryllium is estimated to be very small compared with that in other streams (< < E+06 g).	Detailed data form	
	OFF-ATI-1H	The reference report mentions 19 55-gal drums containing beryllium or beryllium oxide, as well as a plutonium-beryllium neutron source. Other waste is also contaminated with beryllium. A rough estimate, believed to be conservative, is developed by assuming that the 19 drums contained only beryllium scrap, and then doubling the result to allow for beryllium in other containers. The weights of waste containers received at the RWMC that are packed with metal scrap do not correspond to 100% dense packing of the metal, but rather range from 10% to 20% of theoretical density. Conservatively assuming 30% of theoretical density leads to a beryllium mass of 19 drums × 7.4 ft^3/drum × 0.3 × 115 lb/ft^3 × 454 g/lb = 2.2E+06 g. Doubling this amount gives 4.4 E+06 g.	Detailed data form; Clements (1980)	
	RFO-DOW-15H	Beryllium was machined and made into shapes at the RFP. Machining and/or degreasing solvents used in beryllium operations could have been included in this organic sludge stream. There is no indication of the amounts of beryllium-contaminated organics (or the concentrations of beryllium) included in this stream. The only current information is from the cited report, which states that degreasing solvents generated by Building 444 operations are contaminated with beryllium. It is assumed here that the beryllium is 10% of the amount of the plutonium. The total amount of plutonium disposed of in this stream is 2.9 kg. Thus, the beryllium is estimated to be 2.9E+02 g.	Clements (1982)	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Beryllium (continued)	TAN-607-3H	The detailed data form contains no information useful for estimating the quantity of beryllium. The volume of the waste stream is 653 m^3. The quantity of beryllium would be a small fraction of that volume, but the fraction is unknown.	Detailed data form	
	TAN-633-2H	The detailed data form contains no information useful for estimating the quantity of beryllium. The volume of the waste stream is unknown. The quantity of beryllium is expected to be much smaller than that in other streams because this stream consists of metallurgical samples and test specimens.	Detailed data form	
	TAN-640-1	The beryllium in this stream was present as part of a radium-beryllium radiation source. The activity of the source was 1 Ci of Ra-226, so the mass of Ra-226 was approximately 1 g. The mass of beryllium was probably less than E+02 g.	Detailed data form	
	PDA-RFO-1A	The beryllium foundry operation generated Be and BeO contaminated wastes in the form of paperwipes, plastic, graphite molds and crucibles, small tools, and casting sculls (casting residue). It was estimated by foundry personnel that the casting process alone would generate 20 to 20 lb/day of Be and BeO sculls. The overall average production rate was estimated at 125 day/yr. Thus, the estimated average rate of sculls generated each year would be 2,500 to 3,750 lb. The sculls may be in solid (Be metal) or powder (BeO) forms. In addition to sculls, impure or damaged castings that could not be salvaged were periodically included with other foundry wastes. A beryllium casting may weigh up to 125 lb. Between September 1972 and April 1978, depleted uranium and beryllium wastes were placed on Pad A. At 3,750 lb/yr for approximately 5.5 years, it is estimated that this unknown quantity on Pad A could be 1.7E+06 grams of beryllium, as the metal or the oxide.	Clements (1985)	
Beryllium oxide	OFF-ATI-1H	See above entry for beryllium in stream OFF-ATI-1H.	Detailed data form; Clements (1980)	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Beryllium oxide (continued)	RFO-DOW-3H	It has been stated that the first-stage sludge may contain low concentrations of beryllium. Samples of combined first- and second-stage sludges (after 1979) may contain up to 1,000 ppm of beryllium. Because this sludge was formed by precipitation with caustic, it is assumed that the beryllium would be present as the oxide. It is assumed that the mass of a filled drum is about 400 lb. Assume that 700 drums/yr contained 1,000 ppm beryllium. Multiplying 1,000 ppm × 350 lb/drum × 700 drums × 17 yr × 454 g/lb = about 1.9E+06 g of beryllium oxide.	Clements (1981) and Clements (1982)	
	TAN-607-2H	The detailed data form contains no information useful for estimating the quantity of beryllium oxide. The volume of the waste stream is unknown.	Detailed data form	
Cadmium	ANL-752-3H	The detailed data form contains no information useful for estimating the quantity of cadmium, other than the total stream volume of 23.1 m^3 and the fact that much of the volume was concrete used to stabilize the evaporator bottoms.	Detailed data form	There is no information to support an upper-limit estimate
Carbon tetrachloride	OFF-UOW-1H	Most of the waste in the 12.97-m^3 stream is paper, laboratory clothing, glassware, and animal carcasses. Small amounts of various laboratory chemicals are included. The contaminant is believed to be a small fraction (<1%) of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.13 m^3, or 2.0E+05 g at a specific gravity of 1.6.	Detailed data form; Clements (1980)	An upper-limit estimate is 2.0E+05 g
Chloroform	None identified	Chloroform was not identified in any RFP waste streams and is, therefore, not listed as an unknown in any RFP stream. However, it has been detected frequently in environmental monitoring at the RWMC and was used at the RFP. If chloroform were present in large quantities in RFP waste, it would have been discarded as part of the organic sludge waste stream because it is an organic compound. Uses of chloroform at the RFP included analyses of the gallium content of plutonium samples, as a glue used by carpenters to join plexiglas, and for dissolving plastics. The first date of use of chloroform at the RFP has not been identified. An estimate is as follows. A 1974 harmful materials inventory indicated a chloroform inventory of	ChemRisk (1992a) and ChemRisk (1992b)	A best estimate is E+07 g

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Chloroform (continued)		5,513 L (8.9 tons). It has been conservatively estimated in ChemRisk (1992a) that the airborne emissions of chloroform from the RFP were 1.5 to 15 tons/yr from 1952–1974. The report estimated an airborne emission rate of methylene chloride (used for stripping paint) of 5 to 15 tons/yr from 1952–1954. Because the two compounds are similar chemically and were not used in major plant processes, and the airborne emission rates have been estimated to be similar, it will be assumed that the total amount of RFP chloroform buried is the same as the amount of methylene chloride buried, about E+07 g.		
Chromium	ANL-752-3H	The detailed data form contains no information useful for estimating the quantity of chromium, other than the total stream volume of 23.1 m^3 and the fact that much of the volume was concrete used to stabilize the evaporator bottoms.	Detailed data form	There is no information to support an upper-limit estimate
	TAN-633-4H	The chromium was present in the form of an unknown amount of nichrome cladding and structural material. The amount cannot be estimated, but it is expected to be small because this stream consists of metallurgical samples and test specimens.	Detailed data form	
Copper	D&D-TAN-1H	The indications are that copper was present in the waste only in the form of copper wiring. One 128-ft^3 box of waste contained galvanized steel, copper, and rubber. A reasonable upper limit is 100 lb (4.5E+04 g) of copper, but this number is highly speculative. The uncertainty is perhaps an order of magnitude in both directions.	Detailed data form; Smith (1980), Smith and Hine (1982), and Smith (1983)	An upper-limit estimate is 4.5E+04 g. Copper is likely present in other general waste streams, in the form of copper wiring or copper tubing. There is no information to support an estimate of the quantity in the other streams.
Cyanide	CFA-684-1H	One entry is for sodium cyanide and is 936 g. The other entry is an unknown quantity of liquid cyanide (cation unknown) sorbed on vermiculite in a 5-gal container. As a conservative estimate, assume that the 5-gal container holds a concentrated cyanide solution (10% by volume). The amount would be on the order of 0.5 gal, or 2 L × 1,000 g/L = 2,000 g. The total of the two entries is 2.9E+03 g.	Detailed data form	An upper-limit estimate is 2.9E+03 g

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Dibutylethylcarbutol	RFO-DOW-15H	It has been reported that enriched uranium recovery included a solvent extraction process that used dibutylethylcarbutol and dodecane. It is expected that these organic compounds would have been disposed of in this waste stream. No information is available on dibutylethylcarbutol quantities at the RFP. No way to provide a realistic estimate of the total quantity is apparent at present. A rough estimate was developed as follows. Assume that the dibutylethylcarbutol was mixed with dodecane or kerosene, and disposed of as part of the "other organic" constituents in this stream (57,493 gal buried). These "other organics" consist of 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, and used oils. The dibutylethylcarbutol and kerosene would have been part of the used oils. Assume that 10% of the volume of "other organics" (5,749 gal) contained dibutylethylcarbutol and that 25% of this volume was dibutylethylcarbutol. Assume that the density is 1 g/mL. Thus, there is 1,437 gal × 3,785 mL/gal × 1 g/mL = 5.4E+06 g.	ChemRisk (1992b) and Kudera (1987)	A best estimate is 5.4E+06 g
	RFO-DOW-18H	As discussed under stream RFO-DOW-15H, the enriched uranium recovery included a solvent extraction process that used dibutylethylcarbutol and dodecane. It is expected that these organic compounds would have been disposed of primarily in waste stream RFO-DOW-15H. Traces of dibutylethylcarbutol may have remained in the enriched uranium of stream	ChemRisk (1992a) and Kudera (1987)	
	RFO-DOW-18H	RFO-DOW-18H, but the quantities would be negligible compared with the portion that went into stream RFO-DOW-15H.		
Diisopropylfluoro-phosphate	OFF-UOW-1H	This contaminant was used at the generator in laboratory experiments on animals. The quantity in the waste is unknown, but it is believed to be a very small fraction (<<1%) of the 12.97 m^3 of highly varied waste in the stream. Thus, the quantity of the contaminant would be <<0.1 m^3, and <<E+05 g.	Detailed data form; Clements (1980)	The quantity is unknown, but is believed to be <<E+05 g
Ether	TAN-607-3H	The detailed data form contains no information useful for estimating the quantity of ether. The volume of the waste stream is 653 m^3. The quantity of ether would be a small fraction of that volume, but the fraction is unknown.	Detailed data form	There is no information to support an upper-limit estimate

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Ethyl alcohol	OFF-WSU-1H	Most of the waste in the 2.15-m^3 stream is paper, glassware, animal carcasses, and aqueous solutions. The contaminant is believed to be <10% of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.22 m^3, or 1.8E+05 g at a specific gravity of 0.8.	Detailed data form; Clements (1980)	A best estimate is 7.1E+07 g; see the evaluation of Versenes
Hydrofluoric acid	NRF-618-1H	This stream consists of dissolved fuel rods (assumed to be dissolved in hydrofluoric acid), which were sorbed on vermiculite and placed in poly bottles. The stream volume (container volume) is 5.5 m^3. If the contents of the bottles were 80% of the waste container volume and the volume of hydrofluoric acid was 50% of the bottle volume, then the hydrofluoric acid volume is roughly 2.2 m^3. At a specific gravity of 1.0, the hydrofluoric acid mass is approximately 2.2E+06 g.	Detailed data form	An upper-limit estimate is 2.2E+06 g
Lead	ALE-ALE-1H	The volume of the stream is 3,544 m^3. One-half is D&D waste; the remainder is laboratory waste, filters, and miscellaneous items. The stream contains a very wide range of scrap materials: building rubble, electrical wiring, machinery, piping, heat exchangers, rags, metal turnings, glassware, filters, radiography sources, etc. The radiography sources are mentioned in connection with a substream from one laboratory building that contributed 5% of the waste. Lead was probably used to shield the sources. However, there is no basis for a reasonable upper-limit estimate on the amount of lead in this large-volume stream.	Detailed data form; Kee (1982)	Of the 13 streams with unknown quantities of lead, upper limits can be estimated for 4 streams totaling 2.0 E+07 g. The lead in two additional streams (CFA-633-1H and OFF-ATI-1H) is believed to be very small by comparison (e.g., <E+05 g), if present at all. For the seven remaining streams, no estimate can be developed. The waste records for those streams mention no items likely to contain lead in amounts approaching that of the massive reactor shield in OFF-SAM-2H. However, the cumulative amount of lead from NRF, in stream NRF-617-2H, could be considerable.
	ANL-765-2H	The detailed data form contains no useful information for estimating the quantity of lead, other than the total stream volume of 12.32 m^3.	Detailed data form	
	ANL-785-1H	The detailed data form contains no useful information for estimating the quantity of lead, other than the total stream volume of 77.79 m^3.	Detailed data form	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Lead (continued)	CFA-633-1H	The volume of the stream is 14 m^3. The stream contains many types of scrap materials, mostly combustibles. The data form suggests that lead is a very minor constituent. Assume that the amount of lead is very small compared with the amount in other unknown streams (e.g., <E+05 g).	Detailed data form	
	CFA-638-1H	This stream consists of two small shielded casks, with a total volume of 0.2265 m^3. Each cask is about one-half the size of a 55-gal drum. The data gatherer assumed that the shielding was lead. The contents are two sealed sources, with 1 mCi total of Co-60. The source capsules are likely quite small. As a reasonable upper limit, assume that the lead lining is 1 in. thick and that the total drum surface area is 2 drums × [(.785 × 4 ft^2 × 2 ends) + (3.14 × 2 ft × 1.5 ft)] = 31 ft^2. The volume is 2.6 ft^3, or 0.074 m^3, approximately one-third of the volume of the casks. The mass of lead is 2.6 ft^3 × 687 lb/ft^3 = 1,786 lb = 8.1E+05 g, a near-upper limit on what the casks could accommodate structurally.	Detailed data form	
	NRF-617-2H	This stream composites all of the lead and asbestos from NRF from 1955 through 1983. The volume of the stream is unknown, and the volumes of the two contaminants are unknown. There is no way to estimate reasonable upper limits for the quantities of lead and asbestos. The quantities could be large.	Detailed data form	
	OFF-ATI-1H	The detailed data form indicates that, although lead is a waste from the generator's processes, lead is not believed to be present in the INEL waste shipments or, if present, it is present in extremely small quantities. The total stream volume is 1,390 m^3. The stream is mostly metal scrap and some test fuels. Assume that the amount of lead is very small compared with the amount in other unknown streams (e.g., <E+05 g).	Detailed data form	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Lead (continued)	OFF-LRL-1H	Six drums had 5.1-cm lead lining, plus there were a few lead bricks. Assume that the 5.1-cm (2-in.)-thick lining covers the total drum surface area of 6 drums × [(.785 × 4 ft^2 × 2 ends) + (3.14 × 2 ft × 3 ft)] = 151 ft^2. The lead volume is 25 ft^3, or 0.71 m^3. Assume 5 bricks per drum @ 10 cm × 20 cm × 5 cm for 6 drums = 0.03 m^3. The total is 0.73 m^3. This volume is conservatively very high because each drum would weigh 0.74 m^3 × 35.31 ft^3/m^3 × 687 lb/ft^3/6 drums = 2,990 lb, well beyond the structural limit of a drum. The total mass of lead = 2,990 lb × 6 × 454 = 8.1E+06 g.	Detailed data form	
	OFF-LRL-2H	The estimate above for stream OFF-LRL-2H includes the lead in this stream, also.	Detailed data form	
	OFF-SAM-2H	The lead is in a stainless steel, aluminum, and lead reactor shield weighing 36,000 lb (volume stated as 47.3 m^3). Shield dimensions are 2.9 × 4.9 × 3.4 m. If the lead is 1/2 in. (0.013 m) thick × 81 m^2 in area, extending around the complete periphery, the total lead volume is 1.05 m^3. (NOTE: The 81 m^2 was arrived at by multiplying combinations of the dimensions of the shield: 2 [(2.9)(4.9) + (4.9)(3.4) + (3.4)(2.9)]. At a density of 687 lb/ft^3, the mass would be approximately 25,000 lb (1.1E+07 g), about two-thirds of the total mass of the shield. This is a reasonable fraction, so these assumptions are used here. Total radioactivity in the shipment is 0.4 Ci, so it is unlikely that other lead shielding was present.	Detailed data form; (Clements 1980)	
	TAN-607-3H	The detailed data form contains no useful information for estimating the quantity of lead, other than the total stream volume of 7,208 m^3 and the fact that a multitude of waste types are included.	Detailed data form	
	TAN-607-4H	The detailed data form contains no information useful for estimating the quantity of lead. The volume of the waste stream is 255 m^3. The quantity of lead would be a small fraction of that volume, but the fraction is unknown.	Detailed data form	
	TAN-607-5H	The detailed data form contains no information useful for estimating the quantity of lead. The volume of the waste stream is 7,208 m^3. The quantity of lead would be a small fraction of that volume, but the fraction is unknown.	Detailed data form	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit* quantity for each stream	Source(s) of information	Reasonable upper limit* on total unknown quantity over all streams shown
Lithium hydride	OFF-ATI-1H	A disassembled solid lithium hydride reactor shield may have been included in the waste shipped to the SDA, or it may have been shipped elsewhere.	Detailed data form; Clements (1980)	There is no firm evidence that the lithium hydride reactor shield was sent to the SDA. Therefore, no upper-limit estimate of the quantity of lithium hydride is made here.
Lithium oxide	RFO-DOW-3H	It has been stated that the second-stage sludge may contain lithium batteries. No other information on this subject is available. Lithium metal was used as the anode in commercially available alkaline batteries before 1970. The lithium in a discharged alkaline battery would be present as lithium oxide. No basis is currently available for estimating the quantity of lithium oxide. A search of RFP purchasing records for the time period might be helpful, but there is no way to reliably estimate how many of the purchased batteries are in the second-stage sludge. The amount is simply unknown, believed to be trace quantities.	Detailed data form	There is no information to support an estimate
Magnesium	OFF-NMR-1H	The reference report indicates that the amount of magnesium was small-to-trace quantities. Magnesium was added as an amendment for soil in which studies of plant uptake of radionuclides were performed. The waste soil was placed in 13 drums. A reasonable upper limit is believed to be less than 1 kg per drum, or about E+04 g for the stream. The physical form was probably a compound commonly used in fertilizers.	Detailed data form; Clements (1980)	A best estimate is 2.8E+05 g of magnesium
	OFF-SAM-2H	One 55-gal drum contains shavings of magnesium alloyed with 3% thorium and 1% zinc. It is assumed that no other waste is in the drum and that the drum is relatively heavy, weighing 600 lb. The upper limit on the quantity of magnesium would then be approximately 2.7E+05 g.	Detailed data form; Clements (1980)	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Magnesium oxide	RFO-DOW-3H	This waste stream was produced by precipitation of the hydrated oxides of plutonium and americium from basic aqueous waste. Ferric sulfate, calcium chloride, magnesium sulfate, and flocculating agents were added to the solution to increase the efficiency of precipitating the very small amounts of radionuclides. The sludge that is produced consists mainly of the hydrated oxides of these compounds and 50 to 70 wt.% water. There is no magnesium metal in this waste stream. Assume that the stream consisted of 750 drums per year for 17 years (from 1954 through 1970). Assume a filled container weighs 500 lb, of which the tare weight is 70 lb. The waste, which weighs 430 lb, contains 50 lb of cement; 50% of the remaining sludge is water. Thus, the sludge without the water weighs 190 lb and contains the oxides of iron, calcium, magnesium, and the flocculating agents. Assume 25% of the dry sludge is MgO, or 47.5 lb/drum. 47.5 lb/drum × 454 g/lb × 750 drums/yr × 17 yr = 2.8E+08 g of magnesium oxide.	Clements (1982)	A best estimate is 2.8E+08 g of magnesium oxide
Manganese	OFF-NMR-1H	The reference report indicates that the amount of manganese was small-to-trace quantities. Manganese was added as an amendment for soil in which studies of plant uptake of radionuclides were performed. The waste soil was placed in 13 drums. A reasonable upper limit is believed to be less than 1 kg per drum, or about E+04 g for the stream. The physical form was probably a compound commonly used in fertilizers.	Detailed data form; Clements (1980)	An upper-limit estimate is E+04 g
Mercury	CFA-610-1H	One shipment contained 2 ft^3 of mercury batteries in a cardboard box. The mercury in a battery is estimated at 30% by volume (1% as mercury and the remainder as mercuric oxide), per material safety data sheets for mercury batteries. If the batteries were packed in the box with a volumetric efficiency of 80%, an upper-limit amount of mercury would be roughly 0.48 ft^3. However, considering the weight of the mercury results in a lower estimate: assume the maximum weight of the filled cardboard box is 100 lb. At a density of 695 lb/ft^3 for HgO, the box could hold only 0.14 ft^3 of HgO, even if the weight of all other battery constituents were ignored. The mass would be 0.14 ft^3 × 695 lb/ft^3 × 454 g/lb = 4.4E+04 g. Another shipment contained 30 ft^3 of mud contaminated with mercury. Hot spots from INEL mercury spills have been as high as 80,000 ppm. Assuming 10% of the mud contained mercury at 80,000 ppm and the	Detailed data form; material safety data sheets	An upper-limit estimate is 1.2E+06 g

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Mercury (continued)	CFA-610-1H	remaining 90% was relatively clean (10 ppm), the average concentration would be about 8,000 ppm. The amount of mercury would be 0.24 ft^3. Assuming liquid mercury, the mass would be 0.24 ft^3 × 846 lb/ft^3 × 454 g/lb = 9.2E+04 g. The total for the two shipments is about 1.4E+05 g.		
	OFF-ATI-1H	The detailed data form indicates that the quantity of mercury is "negligible" if present at all. The cited reference indicates mercury present as small quantities in plastic bottles. The total volume of the waste stream is 1,390 m^3. Assume that the amount of mercury is small compared with the amount in other unknown streams (e.g., <E+05 g).	Detailed data form; Clements (1980)	
	RFO-DOW-3H	Mercury metal was used at the RFP mostly in instruments such as barometers and thermometers, plant machinery, mercury switches, and experimental apparatus. Mercury was collected from plant sources and purified by distillation at the plant. It was recycled back to the originating area in 5-lb containers. There were no large sources of mercury at the RFP. The second-stage sludges (RFP Content Code 002) may contain mercury batteries and small amounts of mercury in pint bottles. Assume that about 100 lb (4.5E+04 g) of mercury annually, or 7.7E+05 g total during 17 years, were disposed of in this waste stream. Assume that the amount of mercury in the mercury alkaline batteries that may have been discarded in this stream is negligible by comparison.	ChemRisk (1992b) and Clements (1982)	
	TAN-607-3H	The detailed data form contains no information useful for estimating the quantity of mercury.	Detailed data form	
	TAN-607-5H	The detailed data form indicates that within a 120-ft^3 container was canned mud containing mercury. Assume that the mud filled the container up to the weight limit of about 10,000 lb. Also, assume that the mud contained mercury at an average concentration of 8,000 ppm (as developed above for stream CFA-610-1H). Assuming liquid mercury at 846 lb/ft^3 and mud at 120 lb/ft^3, the density of mud-mercury mixture would be about 126 lb/ft^3. The weight limit of 10,000 lb would be reached with 79 ft^3 of the mixture. The weight of mercury would be 79 ft^3 × 0.008 × 846 lb/ft^3 × 454 g/lb = 2.4E+05 g.	Detailed data form; interview with INEL Waste Area Group-1 manager	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit* quantity for each stream	Source(s) of information	Reasonable upper limit* on total unknown quantity over all streams shown
Methyl alcohol	OFF-UOW-1H	Most of the waste in the 12.97-m^3 stream is paper, laboratory clothing, glassware, and animal carcasses. Small amounts of various laboratory chemicals are included. The contaminant is believed to be a small fraction (<1%) of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.13 m^3, or 1.0E+05 g, at a specific gravity of 0.8.	Detailed data form; Clements (1980)	An upper-limit estimate is 2.8E+05 g; see the evaluation of Versenes
	OFF-WSU-1H	Most of the waste in the 2.15-m^3 stream is paper, glassware, animal carcasses, and aqueous solutions. The contaminant is believed to be <10% of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.22 m^3, or 1.8E+05 g, at a specific gravity of 0.8.	Detailed data form; Clements (1980)	
Nickel	TAN-633-4H	The nickel was present in the form of an unknown amount of nichrome cladding and structural material. The amount cannot be estimated, but is expected to be small because this stream consists of metallurgical samples and test specimens.	Detailed data form	There is no information to support an upper-limit estimate.
Nitric acid	OFF-GEC-1H	A small fraction of this highly varied 7-m^3 stream is nitric acid. However, the nitric acid was neutralized before placement in containers filled with cement. A reasonable upper limit is believed to be 0.7 m^3 of nitric acid, although all of the acid may have been neutralized. At a specific gravity of 1.5, the upper limit mass would be $0.7 \times 1.5 \times 10^6 = 1.1E+06$ g.	Detailed data form; Clements (1980)	An upper-limit estimate is 2.3E+06 g
	OFF-UNR-1H	The nitric acid may or may not have been shipped to the SDA. The shipment totaled 8.04 m^3 of miscellaneous laboratory waste and radioactive sources. Nitric acid is believed to have been a minor constituent. Any nitric acid would have been in 1-L bottles. A reasonable upper limit is hypothesized as 10% of the shipment volume, or 0.8 m^3. At a specific gravity of 1.5, the upper-limit estimate is $0.8 \times 1.5 \times 10^6 = 1.2E+06$.	Detailed data form; Clements (1980)	
	RFO-DOW-4H	Nitric acid was used in large volumes at the RFP. However, any nitric acid in liquid form in the waste was made basic to precipitate the radionuclides. Nitric acid was also absorbed by rags and filters, and may have been present as a film on metal equipment. Thus, no substantial amount of nitric acid is expected to be present in the RFP waste streams. However, contact of nitric acid with cellulosic materials such as rags could have formed nitrocellulose. See the separate discussion under the entry for nitrocellulose.	Detailed data form	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Nitric acid (continued)	RFO-DOW-6H	Filters in the exhaust system of the gloveboxes could have contained some condensed nitric acid. However, the waste was normally dry when it was packaged. If the waste was damp, some absorbent material was added to the waste. The filters were made out of asbestos, which is a naturally occurring mineral silicate fiber. Therefore, only trace amounts of nitric acid could have been in the filters, and no cellulose was present to form any nitrocellulose. It is estimated that no nitrocellulose is present in this waste stream.	Clements (1982)	
Nitrobenzene	RFO-DOW-15H	It has been reported that this waste stream contains trace quantities of organic laboratory waste such as nitrobenzene. No information is available on nitrobenzene quantities used in RFP operations. No method is currently apparent to provide a realistic estimate of the total quantity of nitrobenzene in this stream. Therefore, the quantity is left as "unknown—trace."	Clements (1982)	No information is available to support a best estimate. The quantity is "unknown—trace."
Nitrocellulose	RFO-DOW-4H	Some of the rags in the "Paper and Rags—Moist" category (RFP Content Code 336) were used to clean up liquid nitric acid from inside gloveboxes. Before 1970, most of these moist rags containing nitric acid were disposed of without removal of the nitric acid. The chemical reaction between the nitric acid and the rag would form nitrocellulose. No information is available on the quantity of rags used to clean up nitric acid. However, because this waste stream also contains plastics, overalls, surgeon's gloves, cardboard, wood, etc., it is estimated that 10% of this waste stream was rags and 10% of the rags contained nitric acid. Assume that all of this waste was in 55-gal drums and that each drum contained 125 lb of waste. Assume that 700 drums of this waste were disposed of annually for 17 years (1954 to 1970). The assumption of 1% of the waste being present as nitric acid/rags would give the following estimate: 0.01 × 125 lb × 454 g/lb × 700 drums/yr × 17 yr = 6.8E+06 g of nitrocellulose if total reaction occurred.	Detailed data form; Clements (1982)	A best estimate is 6.8E+06 g
	RFO-DOW-6H	Filters in the exhaust system of the gloveboxes could have contained some condensed nitric acid. However, the waste was normally dry when it was packaged. If the waste was damp, some absorbent material was added to the waste. The filters were made out of asbestos, which is a naturally occurring	Clements (1982)	

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit* quantity for each stream	Source(s) of information	Reasonable upper limit* on total unknown quantity over all streams shown
Nitrocellulose (continued)	RFO-DOW-6H	mineral silicate fiber. Therefore, only trace amounts of nitric acid could have been in the filters, and no cellulose was present to form any nitrocellulose. It is estimated that no nitrocellulose is present in this waste stream.		
Organic acids (assumed to be ascorbic acid)	RFO-DOW-2H	See the evaluation of Versenes.	Clements (1982)	A best estimate is 7.1E+07 g
Organophosphates	RFO-DOW-15H	This stream reportedly contains trace quantities of organic laboratory waste such as organophosphates. Early plutonium recovery reportedly included a solvent extraction process using tributylphosphate. These organic compounds were probably disposed of in this stream. No data are available on quantities used at the RFP to make a reliable estimate. Assume that the organophosphates were usually used in a solvent extraction process and were combined with a kerosene or fuel oil compound such as dodecane. This combination would have been disposed of as part of the "other organic" constituents in this waste stream (57,493 gal buried). The "other organics" consist of 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, and used oils. Organophosphates and kerosene were part of the "used oils." Assume that 10% of the volume of "other organics" (5,749 gal) contained organophosphates, and 25% of this volume (1,437 gal) were the organophosphates. Use a density of 1 g/mL. Thus, there would be 1,437 gal × 3,785 mL/gal × 1 g/mL = 5.4E+06 g organophosphates. Take all of this to be tributylphosphate.	Clements (1982), ChemRisk (1992b), and Kudera (1987)	A best estimate is 5.4E+06 g, assumed to be all tributylphosphate
PCBs	RFO-DOW-15H	Unknown volumes of oils containing PCBs were processed with other organic waste in this waste stream. The concentration of PCBs in the PCB oils processed may have exceeded 500 ppm in some cases. The PCB oils would have been part of the "other organic" constituents in this waste stream (57,493 gal). These "other organics" consist of 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, and used oils. The PCB oils would have been part of the "used oils." Assume that 10% of the volume of "other organics" (5,749 gal) contained PCB oils and that 25% of this volume (1,437 gal) was actually PCB oils at a concentration of 500 ppm. Assume that the density of the PCBs is 0.9 g/mL. Thus, an estimate is 1,437 gal × 3,785 mL/gal × 0.9 g/mL × 5E-04 g PCB/g oil = 2.4E+03 g.	Clements (1982) and Kudera (1987)	A best estimate is 2.4E+03 g

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Sodium	D&D-IET-1H	Nearly all of the sodium was removed in a special processing operation. However, a few tens of grams of sodium are believed to have remained in the components that went to the SDA. It is assumed here that a maximum of 1E+02 g of sodium was disposed of in the SDA in this stream.	Detailed data form	An upper-limit estimate is 1E+02 g
	OFF-ATI-1H	It is believed that no bulk quantities of sodium were included in the shipments to the SDA. It is probable that small quantities of reacted or unreacted sodium were in the SDA waste. Aside from the statement that the quantities were likely small, there is no way to make an upper-limit estimate. The stream volume was large (1,390 m^3), but it included a large variety of waste.	Detailed data form; Clements (1980)	
Sodium nitrate	OFF-NMR-1H	The reference report indicates that the amount of sodium nitrate was small-to-trace quantities. The sodium nitrate resulted from neutralization of acidic radioactive waste solutions used in separation processes on laboratory samples. Most of the waste in the 3.96-m^3 stream is believed to be glassware, paper, soil, and cement. The sodium nitrate is estimated to be <5% of the stream total, i.e., <0.2 m^3, or <4.5E+05 g at a specific gravity of 2.26.	Detailed data form; Clements (1980)	An upper-limit estimate is 4.5E+05 g
Sodium-potassium	OFF-ATI-1H	It is believed that no bulk quantities of NaK were included in the shipments to the SDA. It is probable that small quantities of reacted or unreacted NaK were in the SDA waste. Aside from the statement that the quantities were likely small, there is no way to make an upper-limit estimate. The stream volume was large (1,390 m^3), but included a large variety of waste.	Detailed data form; Clements (1980)	There is no information to support an upper-limit estimate. The quantity is likely to be "small."
Terphenyl/diphenyl	CFA-690-1H	A note at the bottom of Part C of the data form states "P-terphenyl (Santo wax) with a CAS # of 92-94-4 was disposed of as a liquid with a quantity estimated of 90,754 gallons, ±10%." P-terphenyl (para terphenyl) is also called Santo Wax P. At a specific gravity of approximately 1.2, the quantity of contaminant would be 90,754 gal × 3,785 mL/gal × 1.2 g/mL = 4.1E+08 g.	Detailed data form	An upper-limit estimate is 5.9E+08 g of terphenyl and 1.8E+08 g of diphenyl.

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit* quantity for each stream	Source(s) of information	Reasonable upper limit* on total unknown quantity over all streams shown
Terphenyl/diphenyl (continued)	PER-ORM-1H	The following information was obtained from a note at the bottom of Part C, as well as from Parts A and E of the data form: "Barrels disposed of were sometimes empty and sometimes full of Santo-R wax (especially 1963)." "Santo-Wax R consisted of terphenyl and diphenyl." "Many barrels of contaminated Santo-R wax disposed of at RWMC. Some were empty. Most were approximately 75% full." The total stream volume was 914.6 m^3. The stream was mostly scrap metals and combustibles. No information is available on the relative proportions of terphenyl and diphenyl in Santo-R Wax. It was assumed that one-third of the total stream volume was Santo-R wax, or 304.9 m^3. Santo-R wax was assumed to consist of equal portions of terphenyl and diphenyl. At a specific gravity of approximately 1.2, the quantity of terphenyl and diphenyl would be 1/2 × 304.9 m^3 × 10^6 mL/m^3 × 1.2 g/mL = 1.8E+08 g each.	Detailed data form	
Toluene	OFF-WSU-1H	Most of the waste in the 2.15-m^3 stream is paper, glassware, animal carcasses, and aqueous solutions. The contaminant is believed to be <10% of the stream. Thus, an upper limit on the quantity of the contaminant would be 0.22 m^3, or 2.0E+05 g at a specific gravity of 0.9.	Detailed data form; Clements (1980)	An upper limit estimate is 2.0E+05 g
Versenes [assumed to be ethylenediaminetraacetic acid (EDTA)]	RFO-DOW-2H	Liquid waste was usually generated by the analytical laboratories and contained chemicals that could complex plutonium and keep it in solution during precipitation treatment. The complexing chemicals included alcohols, organic acids, and Versenes [trade name for a series of chelating agents based on ethylenediaminetetraacetic acid (EDTA)]. This liquid waste was processed separately with Portland cement to form a solid cement monolith. No quantities or specific chemical names of the complexing agents have been given; therefore, they are listed by only their generic name. Assume that 125 drums of this waste have been disposed of annually for 17 years (1954 through 1970). This is equal to 2,125 drums. It has been reported that 26.4 gal of liquids containing these chemicals was placed into each drum. No information is available on the concentration of these chemicals in the liquid. Assume that one-third of the volume (8.8 gal) is Versenes.	Clements (1982)	A best estimate is 7.1E+07 g

Table D-1. (continued).

Contaminant	Streams where listed	Evaluation of possible upper-limit[a] quantity for each stream	Source(s) of information	Reasonable upper limit[a] on total unknown quantity over all streams shown
Versenes [assumed to be ethylenediaminetraacetic acid (EDTA)](continued)	RFO-DOW-2H	Alcohols and organic acids are also assumed to be 8.8 gal each per drum. Assume that the density of the liquid is 1 g/mL. The amount of Versenes, alcohols, or organic acids in this stream is 8.8 gal/drum × 2,125 drums × 3,785 mL/gal × 1 g/mL = 7.1E+07 g each. Assumed specific compounds are, respectively, EDTA, ethyl alcohol, and ascorbic acid.		

a. As explained in the text, for waste from non-RFP generators, the estimates of the unknown quantities of contaminants are generally upper-limit estimates; for waste from the RFP, the estimates are generally best estimates. If the RFP was the dominant contributor of the unknown quantities of the contaminant, the estimate is called a best estimate. Otherwise, the estimate is generally called an upper-limit estimate.

Table D-2. Volumes and volume percents of each Rocky Flats Plant buried waste stream (based on 1971 through 1981 data).

Stream number	Stream name	Drums/year[a] (average)	Drum volume[a] (m^3/yr)	Boxes/year[b] (average)	Box volume[b] (m^3/yr)	Total volume (m^3/yr)	Volume percent of total
RFO-DOW-1H	Benelex, plexiglas	6.7	1.4	1.6	5.1	6.5	0.24
RFO-DOW-2H	Cemented sludges	123.7	25.8	—	—	25.8	0.94
RFO-DOW-3H	Uncemented sludges	1,543.9	321.4	—	—	321.4	11.72
RFO-DOW-4H	Combustibles	1,498.1	311.9	128.7	408.2	720.1	26.26
RFO-DOW-5H	Concrete, brick	166.2	34.6	19.5	61.9	96.4	3.52
RFO-DOW-6H	Filters	66.0	13.7	79.6	252.5	266.2	9.71
RFO-DOW-7H	Glass	267.1	55.6	0.1	0.3	55.9	2.04
RFO-DOW-8H	Glovebox gloves	70.9	14.8	—	—	14.8	0.54
RFO-DOW-9H	Metals	330.6	68.8	311.7	988.7	1,057.5	38.57
RFO-DOW-10H	Mixed waste	10.6	2.2	33.4	105.9	108.1	3.94
RFO-DOW-11H	Molds and crucibles	124.7	26.0	—	—	26.0	0.95
RFO-DOW-12H	Particulate	130.5	27.2	4.7	14.9	42.1	1.53
RFO-DOW-13H	Resins	2.9	0.6	—	—	0.6	0.02
RFO-DOW-14H	Salts	2.4	0.5	—	—	0.5	0.02
	Total	4,344.3	904.4	579.3	1,837.4	2,741.8	100.00

a. It is assumed that each drum is a 55-gal drum.

b. It is assumed that each box is 4 × 4 × 7 ft.

Table D-3. Total volume of Rocky Flats Plant buried waste streams RFO-DOW-1H through RFO-DOW-14H from 1954 through 1970.

Year	Volume from Lee (1971) (ft^3)	Volume of organic sludge (ft^3)	Volume of evaporator salt (ft^3)	Corrected volume (ft^3)	Corrected volume (m^3)
1954	23,992	—	—	23,992	679
1955	39,377	—	—	39,377	1,115
1956	41,814	—	—	41,814	1,184
1957	66,777	—	—	66,777	1,891
1958	58,240	—	—	58,240	1,649
1959	73,517	—	—	73,517	2,082
1960	68,683	—	—	68,683	1,945
1961	86,124	—	—	86,124	2,439
1962	97,281	—	—	97,281	2,755
1963	118,541	—	—	118,541	3,357
1964	132,936	—	—	132,936	3,765
1965	121,952	—	—	121,952	3,454
1966	171,555	1,963	—	169,592	4,803
1967	205,701	40,750	8,926	156,025	4,419
1968	345,765	17,580	20,601	307,584	8,711
1969	239,033	3,919	14,425	220,689	6,250
1970	347,765	7,124	20,719	319,922	9,060
Total	2,239,053	71,336	64,672	2,103,045	59,558

Table D-4. Estimated annual volumes (m^3) of Rocky Flats Plant waste streams RFO-DOW-1H through RFO-DOW-14H.

	Waste Stream														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
1954	1.63	6.38	79.58	178.31	23.90	65.93	13.85	3.67	261.89	26.75	6.45	10.39	0.14	0.14	**679**
1955	2.68	10.48	130.68	292.80	39.25	108.27	22.75	6.02	430.06	43.93	10.59	17.06	0.22	0.22	**1,115**
1956	2.84	11.13	138.76	310.92	41.68	114.97	24.15	6.39	456.67	46.65	11.25	18.12	0.24	0.24	**1,184**
1957	4.54	17.78	221.63	496.58	66.56	183.62	38.58	10.21	729.36	74.51	17.96	28.93	0.38	0.38	**1,891**
1958	3.96	15.50	193.26	433.03	58.04	160.12	33.64	8.90	636.02	64.97	15.67	25.23	0.33	0.33	**1,649**
1959	5.00	19.57	244.01	546.73	73.29	202.16	42.47	11.24	803.03	82.03	19.78	31.85	0.42	0.42	**2,082**
1960	4.67	18.28	227.95	510.76	68.46	188.86	39.68	10.50	750.19	76.63	18.48	29.76	0.39	0.39	**1,945**
1961	5.85	22.93	285.85	640.48	85.85	236.83	49.76	13.17	940.72	96.10	23.17	37.32	0.49	0.49	**2,439**
1962	6.61	25.90	322.89	723.46	96.98	267.51	56.20	14.88	1,062.60	108.55	26.17	42.15	0.55	0.55	**2,755**
1963	8.06	31.56	393.44	881.55	118.17	325.96	68.48	18.13	1,294.79	132.27	31.89	51.36	0.67	0.67	**3,357**
1964	9.04	35.39	441.26	988.69	132.53	365.58	76.81	20.33	1,452.16	148.34	35.77	57.60	0.75	0.75	**3,765**
1965	8.29	32.47	404.81	907.02	121.58	335.38	70.46	18.65	1,332.21	136.09	32.81	52.85	0.69	0.69	**3,454**
1966	11.53	45.15	562.91	1,261.27	169.07	466.37	97.98	25.94	1,852.52	189.24	45.63	73.49	0.96	0.96	**4,803**
1967	10.61	41.54	517.91	1,160.43	155.55	429.08	90.15	23.86	1,704.41	174.11	41.98	67.61	0.88	0.88	**4,419**
1968	20.91	81.88	1,020.93	2,287.51	306.63	845.84	177.70	47.04	3,359.83	343.21	82.75	133.28	1.74	1.74	**8,711**
1969	15.00	58.75	732.50	1,641.25	220.00	606.88	127.50	33.75	2,410.63	246.25	59.38	95.63	1.25	1.25	**6,250**
1970	21.74	85.16	1,061.83	2,379.16	318.91	879.73	184.82	48.92	3,494.44	356.96	86.07	138.62	1.81	1.81	**9,060**
Total	**142.94**	**559.85**	**6,980.20**	**15,639.93**	**2,096.44**	**5,783.08**	**1,214.98**	**321.61**	**22,971.52**	**2,346.59**	**565.80**	**911.24**	**11.91**	**11.91**	**59,558**
Vol %	0.24	0.94	11.72	26.26	3.52	9.71	2.04	0.54	38.57	3.94	0.95	1.53	0.02	0.02	**100%**

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Appendix E

Assumed Distributions of Generic Terms and Dual Entries for Radioactivity in the RWMIS Shipping Record Rollups for Use in the CIDRA Versus RWMIS Comparisons

Appendix E

Assumed Distributions of Generic Terms and Dual Entries for Radioactivity in the RWMIS Shipping Record Rollups, for Use in the CIDRA Versus RWMIS Comparisons

The Radioactive Waste Management Information System (RWMIS) shipping records contain generic entries [e.g., mixed activation products (MAP), mixed fission products (MFP)] for a substantial fraction of the radioactivity in the waste. Realistic comparisons of the activities of radionuclides in the Contaminant Inventory Database for Risk Assessment (CIDRA) database with those in RWMIS require that the generic entries first be replaced conceptually by radionuclide distributions. This appendix provides the distributions used for each major waste generator.

For the purpose *only* of the comparisons, the generic entries in RWMIS were replaced conceptually using the simplified method described below. *The conceptual replacement of the generic entries does not replace or affect the detailed distributions used in CIDRA in any way, nor were the generic entries in RWMIS actually replaced.*

The method used to conceptually replace the generic entries in RWMIS was based on a simplified application of the radionuclide distributions in CIDRA. For several major waste generators [Test Area North (TAN), Test Reactor Area (TRA), and Naval Reactors Facility (NRF)], the distributions in CIDRA generally differ from one waste stream to another because nuclear physics calculations were used to develop the distributions. For these generators, simplified (approximate average) distributions were developed and used in these comparisons to replace the RWMIS generic entries for the generator.

For other major waste generators [Idaho Chemical Processing Plant (ICPP) and Argonne National Laboratory-West (ANL-W)], fixed distributions generally had been used by the data gatherers each time a generic entry was identified in the records for a generator (see Sections 2.4.3 and 2.4.5, respectively). For these generators, the same radionuclide distributions were used for the comparisons as were used when the information was entered into CIDRA. Generic entries for waste from the other category of generators were handled similarly in the comparisons.

RWMIS contains no generic entries for Rocky Flats Plant (RFP) waste.

RWMIS also contains many dual-radionuclide entries (e.g., Zr-Nb-95). The assumptions made for these entries in the comparisons are also listed in this appendix.

A. ASSUMED DISTRIBUTIONS OF DUAL-RADIONUCLIDE ENTRIES IN RWMIS

RWMIS entry	Assumed distribution	Remarks
Zr-Nb-95	0.5 Zr-95, 0.5 Nb-95	Assumed to be in equilibrium
Sr-Y-90	0.5 Sr-90, 0.5 Y-90	Assumed to be in equilibrium
Ce-Pr-144	0.5 Ce-144, 0.5 Pr-144	Assumed to be in equilibrium
Ru-Rh-106	0.5 Ru-106, 0.5 Rh-106	Assumed to be in equilibrium
Ba-La-140	0.5 Ba-140, 0.5 La-140	Assumed to be in equilibrium
Sr-89-90	All Sr-90	Conservative assumption[a]
Ce-141-144	All Ce-144	Conservative assumption[a]

B. MISCELLANEOUS ASSUMPTIONS CONCERNING RADIONUCLIDE ENTRIES IN RWMIS

Sn-119	Convert to Sn-119m	Sn-119 is not radioactive

C. ASSUMED DISTRIBUTIONS OF GENERIC RADIONUCLIDE TERMS IN RWMIS

(Totals may not always add to exact unity because of round-off.)

1. Test Area North

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MAP	2.4E+04	Fe-55	0.349
		Co-60	0.334
		Ni-59	0.115
		Mn-54	0.059
		Fe-59	0.048
		Cr-51	0.041
		Co-58	0.033
		Nb-95	0.012
		Ni-63	0.009
		Total	1.000
MFP	2.0E+04	Cs-137	0.246
		Sr-90	0.117
		La-140	0.095
		Ce-141	0.087
		Ba-140	0.081
		Pr-143	0.076

a. Conservative in terms of half-life and radiotoxicity.

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MFP (continued)		Zr-95	0.069
		Y-91	0.065
		Sr-89	0.058
		Ru-103	0.044
		Rh-103m	0.033
		Ce-144	0.025
		H-3	0.004
		Total	1.000
Unidentified beta-gamma	1.5E+02	Cs-137	0.503
		Sr-90	0.497
		Total	1.000
Unidentified alpha	1.0E-01	Same as for TRA	

2. Test Reactor Area

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MAP	7.4E+05	Co-60	0.53
		Ni-63	0.40
		H-3	0.06
		C-14	0.01
		Total	1.00
MFP	9.5E+05	Cs-137	0.69
		Ce-144	0.22
		Sb-125	0.04
		Eu-155	0.032
		Sr-90	0.012
		Tc-99	0.0009
		I-129	5×10^{-8}
		Total	1.00
Unidentified beta-gamma	1.2E+05	Co-60	0.41
		Ni-63	0.31
		Cs-137	0.15
		H-3	0.05
		Ce-144	0.05
		C-14	0.009
		Sb-125	0.008

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
Unidentified beta-gamma (continued)		Eu-155	0.007
		Sr-90	0.003
		Ni-59	0.0004
		Tc-99	0.0002
		I-129	2×10^{-8}
		Total	1.00
Unidentified alpha	2.0E+00	Cm-242	0.26
		Pu-239	0.24
		Pu-238	0.22
		Am-241	0.12
		Cm-244	0.12
		Pu-240	0.04
		Total	1.00

3. Idaho Chemical Processing Plant

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MAP	2.3E+04	Co-58	0.500
		Mn-54	0.500
		Total	1.000
MFP	1.0E+05	Ce-144	0.197
		Pr-144	0.197
		Cs-137	0.100
		Sr-90	0.100
		Y-90	0.100
		Ru-106	0.100
		Rh-106	0.100
		Sb-125	0.044
		Zr-95	0.031
		Nb-95	0.031
		Total	1.000
Unidentified beta-gamma	1.2E+03	Ce-144	0.197
		Pr-144	0.197
		Cs-137	0.100
		Sr-90	0.100
		Y-90	0.100
		Ru-106	0.100

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
Unidentified beta-gamma (continued)		Rh-106	0.100
		Sb-125	0.044
		Zr-95	0.031
		Nb-95	0.031
		Total	1.000
Unidentified alpha	None		

4. Naval Reactors Facility

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MAP	2.9E+04	Co-60	0.50
		Fe-55	0.40
		Ni-63	0.10
		Total	1.00
MFP	5.4E+05	Sr-90	0.50
		Cs-137	0.50
		Total	1.00
Unidentified beta-gamma	3.9E+05	Co-60	0.50
		Fe-55	0.40
		Ni-63	0.10
		Total	1.00
Unidentified alpha	3.9E-03	Same as for TRA	

5. Argonne National Laboratory-West

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MAP	1.8E+03	Co-60	0.55
		Cr-51	0.20
		Mn-54	0.15
		Co-58	0.10
		Total	1.00

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MFP	3.4E+04	Sr-90	0.50
		Cs-137	0.30
		Ce-144	0.20
		Total	1.00
Unidentified beta-gamma	8.0E+03	Sr-90	0.50
		Cs-137	0.30
		Ce-144	0.20
		Total	1.00
Unidentified alpha	6.4E-01	Same as for TRA	

6. Rocky Flats Plant

No generic entries

7. Other

Term	RWMIS activity (Ci)	Assumed distribution	
		Nuclide	Fraction
MAP	8.8E+02	Co-60	0.75
		Fe-59	0.25
		Total	1.00
MFP	3.3E+04	Cs-137	0.50
		Sr-90	0.50
		Total	1.00
Unidentified beta-gamma	3.0E+03	Co-60	0.375
		Cs-137	0.25
		Sr-90	0.25
		Fe-59	0.125
		Total	1.000
Unidentified alpha	1.3E-02	Same as for TRA	

Appendix F

Summary of Results of Environmental Monitoring at the Subsurface Disposal Area

Appendix F

Summary of Results of Environmental Monitoring at the Subsurface Disposal Area

This appendix provides summary tables of environmental monitoring results at the Subsurface Disposal Area (SDA). These summary tables provide a broad indication of what contaminants have been detected in the monitoring for comparison with the data compiled in Contaminant Inventory Database for Risk Assessment (CIDRA) database. Separate tables are given for radiological and nonradiological contaminants. Within each table, separate entries are also provided for the results of routine monitoring and special studies because the statistical criteria often varied in the studies.

The radiological contaminants, which are presented in Table F-1, include those most frequently detected in Radioactive Waste Management Complex (RWMC) environmental samples and others included in routine screening tests. Monitoring data included in this review span 18 years (1976 through 1993); however, only years for which detectable levels were reported appear in Table F-1.

Because Table F-1 is a high-level rollup table for comparison only, the minimum and maximum reported values of concentration were compiled for each medium by combining the results from all of the sampling methods. If only one sample was evaluated, only the single result is listed in the table. Air contaminant concentrations include data from both high- and low-volume air samplers. Soil concentrations include both surface and near-surface values. Concentrations in subsurface sediments (deeper than near-surface) are reported separately. Contaminant concentrations in samples from all monitoring wells were combined to report a range of concentrations. No distinction between sampling locations within the SDA, monitoring instrumentation, sampling locations, or number of positive samples was considered in this rollup table. Only a gross range in concentration values is presented.

The environmental medium terms (e.g., groundwater, subsurface water, and perched water) used in the routine monitoring and special studies reports to describe the subsurface have not always been defined clearly or used consistently. Because the purpose here is to indicate which contaminants have been detected, not the environmental media in which they were detected, no attempt is made to define what is meant by the various terms. The contaminant concentrations are presented with their associated environmental medium term used in the cited report.

Below-measurable concentrations are denoted as below detection limit (BDL). Detection limits for major radiological contaminants monitored at the SDA are included in the annual monitoring reports. Significant concentration results generally reflect a 95% confidence level, and the uncertainty for analytical results is $\pm 2\ \sigma$ for radionuclides. Data reported for biotic vegetation and air sampling are provided by analyses conducted by the Radiological and Environmental Sciences Laboratory (RESL).

Table F-2 summarizes results of routine monitoring and special studies for nonradiological contaminants. Monitoring for nonradiological contaminants is smaller in scope than monitoring for radiological contaminants. Organic compounds and metals have been monitored regularly at the SDA

since 1987. Special studies were conducted in the years listed in Table F-2. Maximum and minimum contaminant concentrations are presented for each medium sampled.

Generally, data reported for nonradiological contaminants reflect an uncertainty of $\pm 1\ \sigma$. Below-measurable levels are indicated as practical quantitation level (PQL). PQL values for nonradiological contaminants measured in the SDA are given in the annual monitoring reports.

The detection of contaminants in environmental media at the RWMC does not always imply that the contaminants came from the inventoried SDA waste. Contaminants detected in environmental samples collected at the RWMC could have also resulted from (a) emissions from other Idaho National Engineering Laboratory (INEL) facilities, (b) atmospheric fallout from weapons testing, (c) natural occurrence, (d) cross-contamination or erroneous laboratory analysis, or (e) waste located in other parts of the RWMC. Eliminating the other potential sources of contamination requires rigorous design and execution of the sampling and analysis and careful interpretation of the results. Such evaluations are beyond the scope of these simplified comparisons.

The special studies cited in this appendix, RESL data, and subsurface water sampling and analysis by the U.S. Geological Survey (USGS) are believed to be of acceptable reliability for use in the comparisons. However, in spite of rigorous monitoring activities, contaminants in aquifer samples collected by the USGS at the RWMC could have been the result of waterborne effluents upgradient from other INEL facilities. A case-by-case analysis is required to postulate the source of each detected contaminant.

The data from INEL contractor routine monitoring at the RWMC before approximately 1983 are considered to be of lower reliability. Quality assurance of the monitoring activities was minimal. In many cases, no control samples were collected or the control samples were from inappropriate locations. In 1983, detailed reviews of the objectives, procedures, and data were completed for the INEL contractor monitoring activities at the RWMC, which led to major improvements in sampling design, laboratory analysis, data evaluation, and quality assurance. The monitoring activity reviews continue to be held regularly. For the INEL contractor routine monitoring, only contaminant concentrations in air, subsurface and surface water, and subsurface and surface soil data obtained in 1984 or later are considered sufficiently reliable for these comparisons. For the present comparisons, the biotic data from all years are considered reliable.

The summary environmental monitoring data are not compared here against background concentrations of the contaminants. Some of the listed detections may represent concentrations of contaminants at background levels.

Table F-1. Summary of results from routine monitoring and special studies for radiological contaminants.

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
Ac-228	Aquifer	(EMU) 1979	(2.2±1.7)E-07 μCi/mL
Ag-110m	Air	(EMU) 1980	(0.26±0.10 to 0.39±0.12)E-13 μCi/mL
	Surface water	(EMU) 1977	6.0E-10 μCi/mL
	Soil	(EMU) 1979–1980	BDL to (1.12±0.32)E-07 μCi/g
Am-241	Aquifer	(EMU) 1976, 1981, 1982, 1984, (SS) 1987	(1.5±0.6)E-11 to (2.0±1.0)E-10 μCi/mL BDL to (5.3±1.3)E-10 μCi/mL
	Perched water	(SS) 1976–1977	BDL
	Surface water	(EMU) 1977, 1983–1985, 1990, 1991, 1992, 1993 (SS) 1984	(1.2±0.2)E-10 to 2.5E-08 μCi/mL (88.6±7.2)E-08 μCi/mL
	Surficial sediment	(SS) 1989	(13±2 to 154,000±3,000)E-15 Ci/g
	Subsurface sediment	(SS) 1975–1977, 1985–1988, 1989	BDL to (1.55±0.4)E-03 μCi/g
	Soil	(EMU) 1977–1981, 1984, 1986, 1988, 1991, 1992 (SS) 1986, 1989, 1992	BDL to (981.0±82.0)E-07 μCi/g (8.0±2.0)E-9 to (1.54±0.03)E-04 μCi/g
	Biota—vegetation	(EMU) 1984, 1986, 1987, 1990, 1991, 1992, 1993	BDL to (3.9±0.6)E-08 μCi/g
	Biotic—soil	(EMU) 1984–1986, 1990	4.0E-08 to (32.0±3.0)E-06 μCi/g
	Biotic—tissue	(EMU) 1987, 1989	BDL to (4.7±0.3)E-07 μCi/g
	Air	(EMU) 1978–1981, 1984–1993	(1.6±0.4)E-17 to 9.8E-14 μCi/mL
Ba-140	Air	(EMU) 1980	(5.0±2.0 to 8.0±4.0)E-15 μCi/mL
Ce-141	Aquifer	(EMU) 1983	(0.180±0.075)E-06 μCi/mL
	Perched water	(SS) 1976–1977	BDL
	Surface water	(EMU) 1977, 1981	5.6E-08 to (3.08±2.56)E-09 μCi/mL
	Soil	(EMU) 1979–1981	(0.65±0.27 to 4.81±1.94)E-07 μCi/g
	Air	(EMU) 1978–1981, 1983–1984	(0.49±0.2)E-15 to 7.90E-14 μCi/mL

Table F-1. (continued).

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
Ce-144	Perched water	(SS) 1976–1977	BDL
	Subsurface sediment	(SS) 1975–1978	BDL to (3.92±0.57)E-07 μCi/g
	Surface water	(EMU) 1976–1979	(35.4±7.4)E-09 to 1.3E-06 μCi/mL
	Soil	(EMU) 1978–1981	(1.16±0.47 to 117.0±36.0)E-07 μCi/g
	Air	(EMU) 1978–1981, 1983–1984	(0.7±0.4)E-15 to 3.93E-12 μCi/mL
Co-58	Soil	(EMU) 1978–1981	(0.41±0.4 to 1.40±0.45)E-07 μCi/g
	Air	(EMU) 1978–1981, 1983, 1985	(0.67±0.15)E-15 to 1.04E-13 μCi/mL
Co-60	Aquifer	(EMU) 1980 (SS) 1987	(0.11±0.10)E-07 μCi/mL BDL
	Perched water	(SS) 1976–1977	BDL
	Subsurface sediment	(SS) 1976–1988, 1989	BDL to 2.8E-04 pCi/g
	Surface water	(EMU) 1977	1.80E-09 μCi/mL
	Surficial sediment	(SS) 1989	(24±8 to 360±17)E-15 Ci/g
	Soil	(EMU) 1977–1981 (SS) 1978, 1986	(1.25±0.61 to 266.0±8.0)E-07 μCi/g BDL to (9.23±0.31)E-07 μCi/g
	Biota—vegetation	(EMU) 1983	(0.7±0.2 to 1.0±0.3)E-06 μCi/g
	Biotic—soil	(EMU) 1984	(0.77±0.14)E-06 μCi/g
	Biotic—tissue	(EMU) 1987, 1991, 1992	(1.84±0.18 pCi/g to 6.7±0.7)E-07 μCi/g
	Air	(EMU) 1978–1981, 1983, 1986	(0.89±0.32)E-15 to 1.75E-12 μCi/mL
Cr-51	Surface water	(EMU) 1977	5.30E-09 μCi/mL
	Soil	(EMU) 1978–1981	(4.63±2.76 to 19.3±5.9)E-07 μCi/g
	Air	(EMU) 1978–1981, 1983	(4.94)E-15 to 1.80E-12 μCi/mL

Table F-1. (continued).

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
Cs-134	Surface water	(EMU) 1977, 1979, 1981	(0.89±0.69 to 8.6±1.04)E-09 μCi/mL
	Soil	(EMU) 1978-1981	(0.68±0.33 to 16.1±0.57)E-07 μCi/g
	Biota—vegetation	(EMU) 1987	(1.07±0.14 to 1.5±0.2)E-07 μCi/g
	Air	(EMU) 1978-1981, 1985	(1.11±0.46)E-15 to 1.03E-13 μCi/mL
Cs-137	Aquifer	(EMU) 1976-1977, 1980, 1986 (SS) 1987	(1.6±0.7)E-08 to (0.09±0.03)E-06 μCi/mL BDL
	Perched water	(SS) 1976-1977	BDL
	Subsurface sediment	(SS) 1975-1988, 1989	BDL to (1,090±30)E-05 μCi/g
	Surface water	(EMU) 1976-1977, 1979-1981, 1983-1986, 1988, 1990, 1993	(1.4±0.4)E-09 to (202.4±0.36)E-08 μCi/mL
	Surficial sediment	(SS) 1989	(27±8 to 1,800±70)E-15 Ci/g
	Soil	(EMU) 1977-1981, 1984, 1988, 1992 (SS) 1978, 1989	(1.13±0.43)E-07 to (40±2.0)E-06 μCi/g (1.8±7.0)E-08 to (153±0.05)E-06 μCi/g
	Biota—vegetation	(EMU) 1983-1984, 1987	(0.69±0.19)E-07 to (2.8±0.2)E-04 μCi/g
	Biotic—soil	(EMU) 1984, 1986, 1990	(8.0E-08 to 0.94±0.24)E-06 μCi/g
	Biotic—tissue	(EMU) 1987, 1991, 1992	(4.1±0.8)E-07 to (7.32±0.23)E-06 μCi/g
	Air	(EMU) 1978-1981, 1984-1985, 1987, 1991	(0.5±0.2)E-15 to (9.08±0.47)E-13 μCi/mL
Eu-152	Surface water	(EMU) 1976, 1978-1979	0.78E-09 to (1.8±0.4)E-08 μCi/mL
	Soil	(EMU) 1978-1981 (SS) 1978	(1.56±1.55)E-07 to 1.06E-06 μCi/g BDL to (2.06±0.36)E-07 μCi/g
	Air	(EMU) 1978-1981	(9.25±2.39)E-15 to (9.57±1.37)E-13 μCi/mL
	Biotic—tissue	(EMU) 1987	(14.3±1.8 to 52.4±1.8)E-07 μCi/g

Table F-1. (continued).

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
Eu-154	Subsurface sediment	(SS) 1985	(29±9)E-09 μCi/g
	Surface water	(EMU) 1976, 1979	(8.6±1.76)E-09 to (1.7±0.3)E-08 μCi/mL
	Surficial sediment	(SS) 1989	29±9E-15 Ci/g
	Soil	(EMU) 1979–1981 (SS) 1978, 1989	(1.82±0.64 to 3.20±1.21)E-07 μCi/g BDL to (2.74±0.28)E-07 μCi/g
	Biotic—tissue	(EMU) 1987	(7.4±1.3 to 39±3)E-07 μCi/g
	Air	(EMU) 1978–1981	(3.10±1.50)E-15 to (2.09±0.82)E-13 μCi/mL
Eu-155	Air	(EMU) 1981	(5.31±2.1)E-15 to (1.13±0.36)E-13 μCi/mL
	Soil	(EMU) 1981	(3.23±1.46)E-07 μCi/g
Fe-59	Aquifer	(EMU) 1976	(2.1±0.7)E-08 μCi/mL
	Soil	(EMU) 1979–1981	BDL to (2.47±0.71)E-07 μCi/g
	Air	(EMU) 1978–1981	BDL to 4.29E-13 μCi/mL
H-3	Aquifer	(EMU) 1977–1993 (SS) 1984–1986, 1987	(6.0±4.0)E-07 to (2.7±0.4)E-06 μCi/mL <BDL to (1.9±0.4)E-06 μCi/mL
	Perched water	(SS) 1976–1977 (EMU) 1992, 1993	(5.4±0.1 to 18.0±1.0)E-06 μCi/mL BDL to (0.4±0.2)E-06 μCi/mL
Hf-181	Soil	(EMU) 1978–1981	(0.30±0.27 to 4.40)E-07 μCi/g
	Air	(EMU) 1978–1981	1.21E-15 to (1.58±0.77)E-13 μCi/mL
Hg-203	Soil	(EMU) 1980–1981	(0.90±0.39 to 2.14±0.63)E-07 μCi/g
	Air	(EMU) 1978–1981	(0.54±0.43)E-15 to (0.65±0.42)E-13 μCi/mL

Table F-1. (continued).

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
I-131	Air	(EMU) 1980	BDL to (0.9±0.6)E-15 μCi/mL
Mn-54	Aquifer	(EMU) 1977	(1.8±0.7 to 1.9±0.7)E-08 μCi/mL
	Soil	(EMU) 1979–1981	(0.60±0.44 to 1.74±0.59)E-07 μCi/g
	Air	(EMU) 1978–1981, 1983	BDL to (1.19±1.03)E-13 μCi/mL
Nb-95	Surface water	(EMU) 1977	5.70E-07 μCi/mL
	Soil	(EMU) 1978–1981	(0.82±0.27 to 4.0)E-07 μCi/g
	Air	(EMU) 1978–1981	(1.22±0.18 to 3.48±1.5)E-13 μCi/mL
Pb-212	Aquifer	(EMU) 1978	(5.3±2.6)E-08 μCi/mL
Pu-238	Aquifer	(EMU) 1981, 1983 (SS) 1987	(1.0±0.8 to 8.1±0.8)E-10 μCi/mL Not detected
	Perched water	(SS) 1976–1977, 1989	BDL to (3.22±0.17)E-08 μCi/mL
	Surface water	(EMU) 1983	(0.015±0.004)E-08 μCi/mL
	Surficial sediment	(SS) 1989	(5.2±1.7 to 6,400±200)E-15 Ci/g
	Subsurface sediment	(SS) 1975–1988, 1989	BDL to (3.8±0.4)E-07 μCi/g
	Soil	(EMU) 1979–1981, 1988, 1991 (SS) 1989 (SS) 1992	(0.009±0.008 to 0.72±5.0)E-06 μCi/g (3.8±0.4)E-07 μCi/g (7.2±1.5)E-08 to (4.0±0.3)E-06 μCi/g
	Soil water	(SS) 1989	(5.3±1.3)E-10 μCi/mL
	Biota—vegetation	(EMU) 1984, 1986–1987, 1990	BDL to (0.08±0.01)E-06 μCi/g
	Biotic—tissue	(EMU) 1987, 1989	BDL to (2.2±0.2)E-07 μCi/g
	Air	(EMU) 1980, 1986–1988	(4±1)E-18 to (5.0±0.08)E-15 μCi/mL

Table F-1. (continued).

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
Pu-239/240	Aquifer	(SS) 1985–1986, 1987	BDL
	Perched water	(EMU) 1976 (SS) 1989	(0.25±0.09)E-10 μCi/mL (5.8±0.2)E-08 μCi/mL
	Subsurface sediment	(SS) 1975–1978, 1985–1988, 1989	BDL to (11±0.5)E-03 μCi/g
	Surface water	(EMU) 1983–1985	(0.016±0.006 to 0.15±0.06)E-08 μCi/mL
	Surficial sediment	(SS) 1989	(5.5±1.6 to 33,400±600)E-15 Ci/g
	Soil	(EMU) 1976–1977, 1979–1981, 1986, 1988, 1991, 1992, 1993 (SS) 1989 (SS) 1992	BDL to (0.23±0.05)E-07 μCi/g (3.34±0.06)E-05 μCi/g (6.0±1.5)E-08 to (1.16±0.07)E-05 μCi/g
	Soil water	(SS) 1989	(8±7)E-11 μCi/g
	Biota—vegetation	(EMU) 1986, 1987, 1990	(1.0±0.2)E-08 to (1.05±0.08)E-06 μCi/g
	Biotic—soil	(EMU) 1984, 1986–1990	(4.0E-08 to 16.5±0.8)E-06 μCi/g
	Biotic—tissue	(EMU) 1987, 1989	(2.7±0.8 to 30±2)E-08 μCi/g
	Air	(EMU) 1980, 1984–1988, 1990–1993	(2.0±0.6)E-18 to (1.8±0.1)E-15 μCi/mL
Ru-103	Surface water	(EMU) 1977, 1981	(2.78±0.79)E-09 to 1.40E-07 μCi/mL
	Soil	(EMU) 1978–1981	(0.70±0.38 to 3.50)E-07 μCi/g
	Air	(EMU) 1978–1980, 1983	(1.07±0.93)E-15 to 1.12E-13 μCi/mL
Ru-106	Surface water	(EMU) 1976–1977, 1979	(30±11 to 32.2±6.2)E-09 μCi/g/mL
	Soil	(EMU) 1979–1981	(4.18±2.40)E-07 to 2.26E-06 μCi/g
	Biota—vegetation	(EMU) 1978	2.44E-06 μCi/g
	Air	(EMU) 1978–1981	(14.0±3.4)E-15 to (5.88±1.83)E-13 μCi/mL
Sb-124	Soil	(EMU) 1979–1981	(0.53±0.24 to 1.13±0.43)E-07 μCi/g
	Air	(EMU) 1979–1981	(1.02±0.27)E-15 to (0.58±0.15)E-13 μCi/mL

Table F-1. (continued).

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
Sb-125	Surface water	(EMU) 1978–1981	(1.40±0.67 to 7.35±1.31)E-07 μCi/mL
	Soil	(EMU) 1978–1981	(1.40±0.67 to 7.35±1.31)E-07 μCi/g
	Biotic—tissue	(EMU) 1987	BDL to 7.8±1.2E-07 μCi/g
	Biota—vegetation	(EMU) 1987	(1.6±0.3 to 1.8±0.4)E-07 μCi/g
	Air	(EMU) 1978–1981, 1984	BDL to (310±100)E-15 μCi/mL
Sc-46	Soil	(EMU) 1979–1981	(0.84±0.61 to 1.78±0.65)E-07 μCi/g
	Air	(EMU) 1978–1981	(0.59±0.42)E-15 to (0.52±0.20)E-13 μCi/mL
Sr-90	Aquifer	(EMU) 1978–1979, 1985–1987 (SS) 1987	(5.0±4.0)E-09 to (2.3±0.3)E-08 μCi/mL BDL to (0.7±0.14)E-08 μCi/mL
	Perched water	(EMU) 1976, 1980, 1988	BDL to (0.09±0.04)E-07 μCi/mL
	Subsurface sediment	(SS) 1975–1988, 1989	BDL to (1.28±0.04)E-06 μCi/g
	Surface water	(EMU) 1987	(<1.6±0.3)E-09 to (1.70±0.10)E-06 μCi/mL
	Surficial sediment	(SS) 1989	(58±19 to 1,280±40)E-15 Ci/g
	Soil	(EMU) 1988, 1991, 1992 (SS) 1989	(0.22±0.7 to 2.2±0.2)E-06 μCi/g (1.28±0.04)E-06 μCi/g
	Biotic—soil	(EMU) 1984	(0.11±0.01 to 0.6±01)E-06 μCi/g
	Biota—vegetation	(EMU) 1983–1984, 1986–1987, 1990, 1992, 1993	(9±2)E-08 to 8.7E-02 μCi/g
	Biotic—tissue	(EMU) 1987, 1989	(2.5±0.3 to 6.5±0.5)E-07 μCi/g
	Air	(EMU) 1986, 1987, 1988, 1993	(8±2)E-17 to (5.5±0.9)E-16 μCi/mL
Ta-182	Soil	(EMU) 1979–1981	(2.23±1.14 to 3.84±1.46)E-07 μCi/g
	Air	(EMU) 1979–1981	(4.30±1.78)E-15 to (3.50±1.00)E-13 μCi/mL

Table F-1. (continued).

Contaminant	Environmental medium	Years in which contaminant was sampled for and detected[a]	Concentration range
U-234	Soil	(EMU) 1986 (SS) 1992	4.0±1.0E-07 μCi/g (7.9±1.0)E-7 to (1.39±0.11)E-06 μCi/g
	Biota—vegetation	(EMU) 1985, 1987	(2.3±0.3 to 3.9±0.5)E-08 μCi/g
	Biotic—tissue	(EMU) 1987	(2.8±0.4)E-08 to (3.6±0.4)E-07 μCi/g
U-235	Soil	(SS) 1983	(0.34±0.003 to 0.06±0.01)E-06 μCi/g
	Biota—vegetation	(EMU) 1987	(1.6±0.5 to 2.3±0.6)E-09 μCi/g
	Biotic—tissue	(EMU) 1987, 1989	BDL to 1.4±0.2E-08 μCi/g
U-237	Air	(EMU) 1980	(1.6±1.0 to 8.0±2.0)E-15 μCi/mL
U-238	Soil	(SS) 1983-1984, 1992	(8.0±1.0)E-07 to (1.43±0.1)E-06 μCi/g
	Biota—vegetation	(EMU) 1987	(2.9±0.4 to 4.0±0.6)E-08 μCi/g
	Biotic—tissue	(EMU) 1987, 1989	(2.5±0.4)E-08 to (1.2±0.2)E-07 μCi/g
Y-91	Soil	(EMU) 1979-1980	BDL to (934±538.0)E-07 μCi/g
	Air	(EMU) 1979-1980	(1.46±1.14)E-15 to (322±84.0)E-13 μCi/mL
Zn-65	Soil	(EMU) 1979-1981	BDL to (1.93±0.83)E-07 μCi/g
	Air	(EMU) 1978-1981	BDL to (1.11±0.90)E-13 μCi/mL
Zr-95	Surface water	(EMU) 1977	3.4E-07 μCi/mL
	Soil	(EMU) 1979-1981	(1.55±0.93 to 5.00)E-07 μCi/g
	Air	(EMU) 1978-1981	(1.54±0.66 to 168.0±8.0)E-15 μCi/mL

a. Years spanned by environmental monitoring results (EMU) presented here are 1976 through 1993. Results from special studies (SS) span years as shown.

BDL — Below detection limit.
EMU — Data compiled from routine monitoring results published by the Environmental Monitoring Unit.
SS — Special studies. Data compiled from studies other than those that are part of the routine monitoring program.

Table F-2. Summary of results from routine monitoring and special studies for nonradiological contaminants.

Contaminant	Medium	Years in which contaminant was detected[a]	Concentration
ORGANICS			
1,1,1-trichloroethane	Aquifer, perched	(EMU) 1987–1993 (SS) 1987–1988, 1993	<0.2 to 0.9 μg/L <0.2 to 15.0 μg/L
	Soil/soil gas	(SS) 1987	<0.01 μg/L
	Borehole vapor	(SS) 1987, 1988	BDL to 120 mg/m^3
	Air	(SS) 1991, 1994	1.4 μg/m^3
1,1,2-trichlorotrifluoroethane	Perched water	(EMU) 1987–1990 (SS) 1987–1988	37 to 250 μg/L <0.2 to 250 μg/L
	Air	(SS) 1989	24 to 120 mg/m^3
	Soil borehole vapor	(SS) 1987	PQL to 120 μg/L
	Soil/soil gas	(SS) 1987	NR to 310 μg/L
1,1-dichloroethane	Aquifer	(EMU) 1987–1993 (SS) 1987–1988, 1990–1991	<0.2 to 5.6 μg/L <0.2 to 13 μg/L 5.6 to 22 μg/L
	Perched water	(EMU) 1987–1990 (SS) 1987, 1993	5.6 to 22 μg/L 0.3 to 13 μg/L
1,1-dichloroethylene	Aquifer	(EMU) 1987–1993 (SS) 1987–1988, 1990–1991	<0.2 to 1.0 μg/L <0.2 to 3.0 μg/L
	Perched water	(EMU) 1987–1990 (SS) 1987	0.8 to 2.6 μg/L <0.8 μg/L
2-butanone	Air	(SS) 1994	0.4 μg/m^3
Acetone	Sedimentary interbed	(SS) 1987	11 μg/kg
	Air	(SS) 1994	3.0 μg/m^3
Carbon tetrachloride	Aquifer	(EMU) 1987–1993 (SS) 1987–1991	<0.2 to 2.8 μg/L <0.2 to 6.6 μg/L
	Perched water	(EMU) 1987–1990 (SS) 1987, 1988, 1993	230 to 1,400 μg/L <0.2 to 2,100 μg/L
	Air	(SS) 1987, 1989	17 to 5,800 mg/m^3
	Borehole vapor	(EMU) 1987 (SS) 1987–1988	0.1 to 36 mg/m^3 BDL to 5,800 μg/L
	Soil/soil gas	(SS) 1987, 1992	0.22 to 1,400 ppb

Table F-2. (continued).

Contaminant	Medium	Years in which contaminant was detected[a]	Concentration
Chloroform	Aquifer	(EMU) 1987–1993 (SS) 1987–1991	<0.2 to 1.0 μg/L <0.2 to 3 μg/L
	Perched water	(EMU) 1987–1990 (SS) 1987–1988, 1990–1991, 1993	300 to 940 μg/L <0.2 to 1,500 μg/L
	Air	(SS) 1989, 1994	1.7 to 320,000 $\mu g/m^3$
	Soil/borehole vapor	(SS) 1987, 1988, 1992	BDL to 330 μg/L
	Sedimentary interbed	(SS) 1987	120 μg/kg
Dichlorodifluoromethane	Aquifer	(EMU) 1987–1993 (SS) 1987–1991	<0.2 to <2.6 μg/L <0.2 to 3.0 μg/L
	Air	(SS) 1994	0.3 $\mu g/m^3$
	Perched water	(EMU) 1987–1990 (SS) 1987–1988, 1990–1991	BDL to 0.3 μg/L <0.2 to 3 μg/L
Methylene chloride	Sedimentary interbed	(SS) 1987	42 μg/kg
	Perched water	(SS) 1993	BDL to <100 μg/L
	Air	(SS) 1991, 1994	0.05 $\mu g/m^3$
Phenol	Aquifer	(SS) 1991	0.046 mg/L
Tetrachloroethylene	Aquifer	(EMU) 1987–1993 (SS) 1987, 1989–1991	<0.2 to 4.5 μg/L <0.2 to 3.0 μg/L
	Air	(SS) 1994	4.2 $\mu g/m^3$
	Perched water	(EMU) 1987–1990 (SS) 1987, 1988, 1990–1991, 1993	4.5 to 1,200 μg/L <0.2 to 230 μg/L
	Soil/borehole vapor	(SS) 1987, 1992	BDL to 62 μg/L
	Soil/soil vapor	(SS) 1987	3 to 40 μg/L
Toluene	Aquifer	(EMU) 1987–1993 (SS) 1987, 1988, 1990, 1991	<0.2 to <1.0 μg/L <0.2 to 3.0 μg/L
	Air	(SS) 1994	0.3 $\mu g/m^3$
	Perched water	(EMU) 1987–1990 (SS) 1987–1988, 1990–1991, 1993	<0.2 to 0.3 μg/L <0.2 to 100 μg/L
	Soil/borehole vapor	(SS) 1987, 1992	0.3 to 191 μg/L

Table F-2. (continued).

Contaminant	Medium	Years in which contaminant was detected[a]	Concentration
Trichloroethylene	Aquifer	(EMU) 1987–1993 (SS) 1987–1988	<0.2 to 1.4 μg/L <0.2 to 860 μg/L
	Perched water	(EMU) 1987–1990 (SS) 1987–1988, 1990–1991, 1993	BDL to 860 μg/L <0.2 to 1,600 μg/L
	Air	(SS) 1987, 1989	11 to 380 mg/m^3
	Soil/borehole vapor	(SS) 1987, 1992	BDL to 690 μg/L
	Sedimentary interbed	(SS) 1987	81 μg/kg
METALS			
Antimony	Perched water	(SS) 1988, 1993	2.2 to 70.0 μg/L
Arsenic	Aquifer	(SS) 1987	1 to 14.3 μg/L
	Perched water	(SS) 1988, 1993	<2.0 to 4.2 μg/L
Barium	Sedimentary interbed	(SS) 1987	392 mg/kg
	Perched water	(SS) 1988, 1993	18 to 1,260 μg/L
Beryllium	Perched water	(SS) 1988, 1993	<0.5 to 6.4 μg/L
	Subsurface soil	(SS) 1991	1.9 to 2.7 mg/kg
	Sedimentary interbed	(SS) 1987	1.4 mg/kg
Boron	Surface soil	(SS) 1982	190 mg/kg
Cadmium	Perched water	(SS) 1988, 1993	<1 to 16.1 μg/L
	Surface soil	(SS) 1982	0.50 mg/kg
Chromium	Surface water	(EMU) 1986	2.2±0.1 mg/L
	Aquifer	(SS) 1985–1986, 1987	0.05 to 56±10 μg/L
	Perched water	(SS) 1993	<6.0 to 50 μg/L
	Sedimentary interbed	(SS) 1987	40.0 mg/kg
	Soil	(SS) 1982	3.5 mg/kg
Cobalt	Perched water	(SS) 1988, 1993	<12.0 to 72.4 μg/L

Table F-2. (continued).

Contaminant	Medium	Years in which contaminant was detected[a]	Concentration
Copper	Perched water	(SS) 1988, 1993	<7.0 to 10.8 μg/L
	Soil	(SS) 1982	6.9 mg/kg
	Sedimentary interbed	(SS) 1987	30.3 mg/kg
Lead	Perched water	(SS) 1988, 1993	<5 to 21.5 μg/L
	Surface soil	(SS) 1982	8.8 mg/kg
Mercury	Subsurface soil	(SS) 1991	1.40 to 5,320 mg/kg[b]
	Perched water	(SS) 1988, 1993	<0.1 to 3.4 μg/L
	Soil vapor	(SS) 1990	ND
	Sedimentary interbed	(SS) 1987	0.6 mg/kg
Nickel	Sedimentary interbed	(SS) 1987	34.4 mg/kg
	Perched water	(SS) 1988, 1993	9 to 996 μg/L
Selenium	Sedimentary interbed	(SS) 1987	1.0 mg/kg
	Subsurface water	(SS) 1987, 1988	ND to 3 μg/L
	Perched water	(SS) 1993	1.1 to 97.9 μg/L
Silver	Sedimentary interbed	(SS) 1987	2.4 mg/kg
	Perched water	(SS) 1988, 1993	<1 to 1.6 μg/L
Thallium	Sedimentary interbed	(SS) 1987	2.4 mg/kg
	Perched water	(SS) 1988, 1993	0.9 μg/L
Tin	Sedimentary interbed	(SS) 1987	244 mg/kg
	Perched water	(SS) 1988	1,000 μg/L
Vanadium	Sedimentary interbed	(SS) 1987	53.3 mg/kg
	Perched water	(SS) 1988, 1993	<15.0 to 16.4 μg/L
Zinc	Surface soil	(SS) 1982	37.0 mg/kg
	Perched water	(SS) 1988, 1993	4.3 to 945 μg/L
	Sedimentary interbed	(SS) 1987	2.4 mg/kg

Table F-2. (continued).

Contaminant	Medium	Years in which contaminant was detected[a]	Concentration
OTHER[c]			
Chloride	Aquifer	(EMU) 1979, 1982–1993	9±1 to 105±11 ppm
	Perched water	(EMU) 1982–1993 (SS) 1993	62±6 to 93±9 ppm 4,980 to 635,000 µg/L
	Surface soil	(SS) 1982	150 mg/kg
Cyanide	Perched water	(SS) 1988	5 µg/L
	Sedimentary interbed	(SS) 1987	1.25 mg/kg
Nitrate	Aquifer	(EMU) 1982, 1983, 1987	0.5 to 12 mg/L
	Perched water	(SS) 1993	130 to 2,040 µg/L
	Surface water	(EMU) 1980–1982	0.08 to 4.7 mg/L
	Surface soil	(EMU) 1980–1983 (SS) 1982	1-49 ppm 0.28 mg/kg
Sodium ion	Surface water	(EMU) 1983–1986	6 to 100±10 mg/L
	Aquifer	(EMU) 1979, 1982–1993	6±1 to 52±5 ppm
	Perched water	(EMU) 1985–1987, 1992	BDL to 100±10 ppm
Sulfate	Perched water	(SS) 1988	1 µg/L
	Perched water	(SS) 1993	6,290 to 40,800 µg/L
	Perched water	(SS) 1985	19.95 µg/L
Sulfide	Sedimentary interbed	(SS) 1987	200 mg/kg

a. Concentrations included in this table were actually detected in those years indicated. Occasionally, contaminants were monitored during a year, but the analyses were not available for inclusion in the annual EMU report.

b. Detections involved drilling directly into a disposal unit.

c. Contaminant monitoring occurred from 1976 through 1993.

BDL — Below detection limit.
EMU — Data compiled from routine monitoring results published by the Environmental Monitoring Unit.
ND — Not detected.
NR — Minimum measured concentration was not reported in the reference source practical quantitation limit.
PQL — Practical quantitation limit.
SS — Special studies. Data compiled from studies other than those that are part of the routine monitoring program at the SDA.

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Appendix G

Contaminant Profile Data Sheets

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Appendix G

Contaminant Profile Data Sheets

This appendix presents profile data sheets for the contaminants that were among those present in the largest quantities. Profile data sheets appear separately for nonradiological contaminants and radiological contaminants.

The profile data sheets provide a quick reference summary for each of the principal contaminants. Each sheet very briefly lists typical physical and chemical forms and properties of the contaminant, common uses, general presence in the environment, toxicology, and the results of environmental monitoring at the Subsurface Disposal Area (SDA). For radiological contaminants, the radiological properties and radiotoxicity are included.

The caution concerning environmental monitoring results, stated in Section 6.3.6 and in Appendix F, is repeated here. Detection of contaminants in environmental media at the SDA does not always imply that the contaminants came from the SDA waste. Contaminants detected in monitoring could also have resulted, for example, from emissions at other facilities.

Profile Data Sheets for Some Nonradiological Contaminants of Interest

ASBESTOS

Synonyms: Various types: chrysotile, crocidolite, actinolite, amosite, anthophyllite, and tremolite.

Chemical Abstract Services (CAS) No.: 1332-21-4 (each type of asbestos also has its own CAS number)

Physical Form

Asbestos is comprised of fibers or filaments from naturally occurring mineral silicates. The fibrous structure of asbestos distinguishes it from other minerals.

Chemical Form

Asbestos is divided into two groups, of which there are six types. The distinction between the two groups is that in one, the minerals have a sheet or layered structure, and in the other, they have a chain-like crystal structure. Chrysotile is the most commonly used of the six types of asbestos.

Chemical and Physical Properties

Asbestos may be white, blue, brown, gray, green, or yellow in color. It is noncombustible and conducts heat and electricity poorly. These properties, along with strength, flexibility, brittleness, and color, vary depending on which type of asbestos is being used.

Common Uses

Asbestos has been used in fireproof fabrics, brake linings, gaskets, roofing compositions, electrical and thermal insulations, and paint filler and as a reinforcing agent in rubber, plastics, and cement. Chrysotile accounts for 95% of the asbestos found in buildings.

Asbestos was extensively used for many years in construction until the 1970s, when governmental regulations began restricting its use.

General Presence in the Environment

Asbestos is a naturally occurring mineral throughout the world, and it is extracted from the earth in the form of rock and then processed. It is ubiquitous in the human environment; virtually everyone has been slightly exposed to asbestos to some extent through its use in construction.

Toxicology Highlights

Asbestos is a known human carcinogen. However, to be a significant health concern, the airborne fibers must be inhaled. Acute exposure to asbestos dust can be irritating to the skin or eyes and can cause irritation internally when ingested or inhaled. Chronic effects of long-term exposure

are a high incidence of lung, laryngeal, and gastrointestinal cancers. The risks of low-level, nonoccupational exposure have not been established.

Environmental Monitoring Results at the SDA

Asbestos has not been monitored in environmental media at the SDA.

BERYLLIUM

CAS No.: 7440-41-7

Physical Form

Beryllium is a grayish-white metal.

Chemical Form

Beryllium is processed from several different ores, such as beryllium silicate and bertrandite, by exposure to the acid salts of the metal. There are many compounds of beryllium, but it is also often used in the elemental form.

Chemical and Physical Properties

Beryllium is a hard, odorless, brittle metal that is soluble in most acids and alkalies. It is the only stable, light-weight metal that has a high melting point, and it has an especially high strength-to-weight ratio.

Common Uses

The primary use for beryllium is as a hardening agent in alloys, mainly copper and aluminum, and as an oxide in ceramics. It has been used increasingly in the atomic energy industry as a source of neutrons when bombarded with alpha particles and as a neutron moderator in nuclear reactors. Beryllium is also used in radio tube parts and aerospace structures.

General Presence in the Environment

Beryllium is present naturally in the earth's crust at 2 to 10 ppm and is found in ores such as beryl, beryllium silicate, and bertrandite throughout the world. Widespread use has not been made of beryllium, so it is not encountered frequently in the human environment.

Toxicology Highlights

Beryllium is a probable human carcinogen. The most serious health hazards relate to inhalation of dust, which occurs in industries where beryllium is processed or milled. Acute exposure may result in respiratory disorders, dermatitis, corneal burns, and nonhealing ulcerations. Chronic exposure may cause pulmonary disease or cancer, which may take many years to appear.

Environmental Monitoring Results at the SDA

Beryllium has been detected occasionally in environmental media at the SDA.

CADMIUM

CAS No.: 7440-43-9

Physical Form

Cadmium is a blue-white metal in the elemental state.

Chemical Form

Cadmium is a metal or a grayish-white powder. It is most commonly found in compounds of oxides, hydrates, and chlorides.

Chemical and Physical Properties

Cadmium tarnishes in moist air, has poor corrosive resistance, becomes brittle when heated, is soluble in acids, lowers the melting point of some alloys, and can react vigorously with oxidizing materials.

Common Uses

Cadmium is used in brazing alloys and solders, fire protection systems, batteries, power transmission wires, television phosphors, electroplating and machinery enamel, fungicides, and photography and for the control of atomic fission in nuclear reactors.

General Presence in the Environment

Cadmium does not occur naturally uncombined, and only one cadmium mineral (cadmium sulfate) exists. It is usually found in combination with lead, copper, or zinc ore. Its fumes can be found in the atmosphere in areas where it is processed industrially, in welding shops, and where scrap metals containing cadmium have been remelted. It can also be found in dump sites where products that contain cadmium have been disposed of.

Toxicology Highlights

Cadmium is a probable human carcinogen. The risk of cancer depends on the duration and level of exposure. Cadmium targets the kidneys, blood, prostate, and respiratory tract. Exposure to cadmium has cumulative effects, and its fumes are highly toxic when inhaled. Chronic exposure to cadmium may cause permanent damage to the lungs or nervous system.

Environmental Monitoring Results at the SDA

Cadmium has been detected rarely in environmental media at the SDA.

CARBON TETRACHLORIDE

Synonyms: Carbon chloride, perchloromethane, tetrachloromethane, and R-10 refrigerant.

CAS No.: 56-23-5

Physical Form

Carbon tetrachloride is a clear, colorless, heavy liquid.

Chemical Form

Carbon tetrachloride is an organic solvent classified as a halogen compound or chlorinated hydrocarbon.

Chemical and Physical Properties

Carbon tetrachloride has a characteristic sweetish odor and is stable under normal temperatures and pressures. Decomposition at high temperatures creates very toxic fumes of phosgene and corrosive and toxic fumes of chlorides and oxides.

Common Uses

Carbon tetrachloride has been used as a refrigerant, agricultural fumigant, active insecticide, and solvent and in the production of semiconductors. It has been very effective in suppressing the flammability of more flammable fumigants and was commonly found in fire extinguishers. At one time, it was also used as a common household spot remover and dry cleaning agent. Since carbon tetrachloride has been recognized as a carcinogen, its use has been sharply curtailed.

General Presence in the Environment

Carbon tetrachloride is manufactured by the reaction of chlorine with methane. Because this is a manufactured chemical having widespread use, it has been introduced into the environment through industry and its use as a consumer product.

Toxicology Highlights

Carbon tetrachloride is considered to be a probable human carcinogen. It is a skin and eye irritant. The liver is sensitive to exposure to carbon tetrachloride. Chronic exposure to high concentrations can result in depression of the central nervous system. Acute exposure can cause functional and destructive injury of the liver and kidneys or possibly cancer.

Environmental Monitoring Results at the SDA

Carbon tetrachloride is detected frequently in environmental media at the SDA.

LEAD

CAS No.: 7439-92-1

Physical Form

Lead is a silvery-gray solid metal in the elemental state.

Chemical Form

Lead is found mainly in mineral form and rarely in the elemental state. There are more than 70 lead compounds, both organic and inorganic. Lead also occurs in uranium and thorium minerals, arising from radioactive decay.

Chemical and Physical Properties

Lead is a heavy, dense, malleable, gray solid that resists corrosion and is relatively impenetrable to radiation. Lead is compatible with a variety of substances and has one of the widest ranges of application of any metal, except possibly iron. It dissolves in nitric and sulfuric acid.

Common Uses

The most common uses of lead are in the manufacture of storage batteries and in the production of gasoline additives (which is being phased out because of adverse health effects). Lead is used in paints, bullets, and solder and fusible alloys and in construction. It is also used as protective shielding against sources of radiation.

General Presence in the Environment

Lead exists widely throughout the world in a number of ores. It is found widely in the human environment by virtue of its use in paints and as a gasoline additive. The major portion of lead in air is in inorganic form.

Lead dust and fumes can be found in indoor firing ranges and smelting industries. Trace amounts of lead can be found in some drinking water and in food through its absorption by plants.

Toxicology Highlights

Lead fumes and lead compounds cause poisoning after prolonged exposure. Skin absorption is of significance only from organic lead compounds. Lead is a probable human carcinogen.

Early signs of lead poisoning are fatigue and sleep disturbances. Chronic exposure can cause anemia, cancer of the kidneys, nervous system damage, and reproductive defects.

Environmental Monitoring Results at the SDA

Lead has been detected rarely in environmental media at the SDA.

MERCURY AND ITS COMPOUNDS

CAS No.: 7439-97-6

Physical Form

Mercury is a silvery liquid with a metallic luster or mirror-like appearance.

Chemical Form

There are at least 68 inorganic and 42 organic derivatives of mercury. Mercuric sulfide is the chief source of elemental mercury. Other common forms are mercury sulfate, mercury nitrate, mercury chloride, phenyl mercury acetate, and mercury oxides.

Chemical and Physical Properties

Mercury is a metal that remains liquid throughout a broad range of temperatures. In its pure form, it is stable under normal conditions, odorless, insoluble in water, and extremely heavy. It is incompatible with many chemicals, such as strong oxidizing agents, and when in contact with them, can become explosive and emit highly toxic vapors.

Common Uses

Mercury is used in amalgams and electrical apparatus; in the production of chlorine and caustic soda, thermometers, batteries, and vapor pressure lamps; and as a coolant and gamma ray absorber in nuclear power plants. It is most recently being used as a catalyst in polyurethane foams.

General Presence in the Environment

Mercury ore is found in rocks of all classes, the most common being cinnabar. Naturally occurring vapor concentrations in the air vary widely around ore deposits and areas of volcanic activity. Mercury can be found in drinking water and in food sources in trace amounts. It is frequently encountered in the human environment from the disposal of scrap batteries and mercury-containing products and at mildew-resistant, mercury-containing paint and mercury treatment facilities where it is processed.

Toxicology Highlights

Mercury poisoning may damage the kidneys, brain, nerves, gastrointestinal system, and respiratory tract.

Environmental Monitoring Results at the SDA

Mercury has been detected rarely in environmental monitoring at the SDA; it has also been detected in direct sampling of the Acid Pit.

METHYLENE CHLORIDE

Synonyms: Methylene dichloride, dichloromethane, and methane dichloride.

CAS No.: 75-09-2

Physical Form

Methylene chloride is a colorless liquid.

Chemical Form

Methylene chloride is an organic solvent classified as a halogenated aliphatic compound.

Chemical and Physical Properties

Methylene chloride is a colorless, volatile liquid with a penetrating ether-like odor. It is soluble in alcohol and ether, slightly more soluble in water than other chlorinated solvents, nonflammable and nonexplosive in air, and can be broken down by heat to form an acid.

Common Uses

Methylene chloride is used as a blowing agent in foams and in plastic processing. As a solvent, it has many applications, including coating photographic films, aerosol formulations, extraction processes, and paint stripping. Because methylene chloride has a narcotic effect at high concentrations, it was once used as an anesthetic.

General Presence in the Environment

Methylene chloride is not known to occur naturally in the human environment; however, through its widespread use as a blowing agent for foams and as a solvent in industry and consumer products, it can be found as a contaminant in the atmosphere and soil and in areas where products containing methylene chloride have been disposed of.

Toxicology Highlights

Methylene chloride is a probable carcinogen. Symptoms of exposure may be dizziness, nausea, and irritation of the skin and eyes. Exposure may also damage the central nervous system.

Environmental Monitoring Results at the SDA

Methylene chloride has been detected rarely in environmental media at the SDA.

METHYL ISOBUTYL KETONE

Synonyms: 4-methyl-2-pentanone, isopropyl acetone, hexone, and MIBK.

CAS No.: 108-10-1

Physical Form

Methyl isobutyl ketone is a clear liquid.

Chemical Form

Methyl isobutyl ketone is an organic solvent classified as an aliphatic ketone.

Chemical and Physical Properties

Methyl isobutyl ketone is a colorless, stable liquid with a pleasant odor. It is slightly soluble in water, has a low boiling point, may react violently with oxidizers, and is flammable as a liquid or vapor. Its vapors are heavier than air and may travel a considerable distance.

Common Uses

Methyl isobutyl ketone is used as a solvent in gums and resins, paints, varnishes, and lacquers; in the manufacture of methylamyl alcohol; in extraction processes, including extraction of uranium from fission products; in organic synthesis; and as a denaturant for alcohol.

General Presence in the Environment

Methyl isobutyl ketone is not found naturally in the human environment; however, through its widespread use as a solvent in industry and consumer products, it has been introduced into the environment. It has been found as a contaminant in water and air in small quantities.

Toxicology Highlights

In both acute and chronic exposure, inhalation of methyl isobutyl ketone is the principal health hazard. It can affect the central nervous system and respiratory system.

Environmental Monitoring Results at the SDA

Methyl isobutyl ketone has not been detected in environmental media at the SDA.

1,1,1-TRICHLOROETHANE

Synonyms: Methyl chloroform, trichloromethylmethane, and alpha-trichloroethane.

CAS No.: 71-55-6

Physical Form

1,1,1-trichloroethane is a clear, colorless liquid.

Chemical Form

1,1,1-trichloroethane is an organic solvent classified as an aliphatic halogen compound.

Chemical and Physical Properties

1,1,1-trichloroethane has a mild, sweet odor and is chemically reactive to metals such as zinc and aluminum. It slowly decomposes over time, yielding hydrogen chloride, and is noncombustible as a liquid; however, its vapors are flammable.

Common Uses

1,1,1-trichloroethane is used almost exclusively as a solvent in cleaning, degreasing of metals, and textile processing. It has some use as a constituent in food packaging and a propellant in aerosols and is used in the manufacture of cosmetics.

General Presence in the Environment

1,1,1-trichloroethane is not known to occur naturally in the human environment; however, through widespread use as a solvent and in consumer products, it is generally present in the atmosphere at about 1 ppb.

Toxicology Highlights

1,1,1-trichloroethane is probably the least toxic of the chlorinated solvents. The principal response from acute or chronic exposure is depression of the central nervous system by inhalation of its vapors. It can also cause eye and skin irritation.

Environmental Monitoring Results at the SDA

1,1,1-trichloroethane is detected frequently in environmental media at the SDA.

TRICHLOROETHYLENE

Synonyms: Trichloroethene, acetylene trichloride, ethylene trichloride, and TCE.

CAS No.: 79-01-6

Physical Form

Trichloroethylene is a colorless liquid.

Chemical Form

Trichloroethylene is an organic solvent classified as an aliphatic halogen compound.

Chemical and Physical Properties

Trichlorethylene is a colorless liquid that has a sweet odor and is virtually insoluble in water. It is stable under normal temperatures and pressures, has a low boiling point, and is nonflammable.

Common Uses

Trichloroethylene is a common solvent used in industry for the degreasing of metals; the manufacture of organic chemicals and pharmaceuticals; dry-cleaning; in paints and varnishes, adhesives, and textile processing; and as a fumigant. Its continued use in foods, drugs, and cosmetics is prohibited.

General Presence in the Environment

Although trichloroethylene is not known to occur naturally, it is widely distributed in the human environment and has been detected in air, food, and water. It has been introduced to the environment by dry-cleaners, the food processing industry, and in landfills where it has been disposed of. It has been implicated as a possible factor in the depletion of the ozone layer.

Toxicology Highlights

The most significant source of exposure to trichloroethylene is from inhalation of its vapors and absorption through the gastrointestinal tract and skin. Inhalation can cause giddiness, headaches, and sleepiness. The target organs include the liver and central nervous system. Studies are underway as to its potential carcinogenicity.

Environmental Monitoring Results at the SDA

Trichloroethylene has been detected frequently in environmental media at the SDA.

1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE

Synonyms: Freon 113, refrigerant 113, Freon TF solvent, and trichlorotrifluoroethane.

CAS No.: 76-13-1

Physical Form

1,1,2-trichloro-1,2,2,-trifluoroethane is a colorless liquid.

Chemical Form

1,1,2-trichloro-1,2,2-trifluoroethane is an organic compound classified as a chlorinated aliphatic halogen or nonhydrogenated fluorocarbon. It is one of many fluorine-containing compounds.

Chemical and Physical Properties

1,1,2-trichloro-1,2,2-trifluoroethane is a colorless, volatile liquid. It is slightly flammable and extremely persistent, but it is stable under normal temperatures and pressures. The chlorine atoms present in 1,1,2-trichloro-1,2,2,-trifluoroethane directly contribute to its hazardous properties and persistence in the atmosphere.

Common Uses

1,1,2-trichloro-1,2,2-trifluoroethane is available commercially, with the most common use being as a solvent for cleaning electronic equipment and degreasing machinery. It has also been used in fire extinguishers, solvent drying, dry-cleaning solvents, and as a blowing agent and refrigerant.

General Presence in the Environment

Although 1,1,2-trichloro-1,2,2-trifluoroethane does not occur naturally, it can be found in the environment, especially in the stratosphere, where it produces significant amounts of chlorine atoms and leads to the destruction of atmospheric ozone. 1,1,2-trichloro-1,2,2-trifluoroethane is released in the industrial setting through evaporation at room temperature, adherence to cleaned parts when removed, and accidental loss in the refrigeration manufacture industry.

Toxicology Highlights

The most likely exposure to 1,1,2-trichloro-1,2,2,-trifluoroethane is by inhalation of the vapors. In small quantities, it is fairly nontoxic; however, in both acute and chronic exposure, it may target the cardiovascular system. Contact with the skin or eyes can cause redness and irritation.

Environmental Monitoring Results at the SDA

1,1,2-trichloro-1,2,2-trifluoroethane has been detected frequently in environmental media at the SDA.

MISCELLANEOUS ACIDS

CAS No.: Not applicable

Physical Form

Acids can be a gas or liquid and can range from transparent to dark in color.

Chemical Form

All acids contain hydrogen and can be classified as organic or inorganic. Some of the major acids are sulfuric acid (H_2SO_4), nitric acid (HNO_3), and hydrogen fluoride (HF).

Chemical and Physical Properties

Acid solutions have one or more of the following properties: sour taste, ability to make litmus dye turn red and to cause other indicator dyes to change to characteristic colors, and ability to react with and dissolve certain metals and react with bases or alkalies. Hydrogen fluoride, nitric acid, and sulfuric acid are all strong irritants, corrosive, and considered to be fuming acids.

Common Uses

Sulfuric acid, nitric acid, and hydrogen fluoride are commonly used acids. All three are used as laboratory reagents, in steel or stainless-steel processing, and in the manufacture of fertilizers. Sulfuric acid is also used in batteries, electroplating baths, iron, rayon, and film. Nitric acid is used in pharmaceutical processing, metallurgy, ore flotation, urethane, rubber chemicals, and the reprocessing of spent nuclear fuel. Hydrogen fluoride is used in aluminum production, fluorocarbons, glass etching, and gasoline and uranium processing.

General Presence in the Environment

Sulfuric acid, nitric acid, and hydrogen fluoride are present in the human environment because of their widespread use. Detection occurs mainly in industrial and manufacturing areas where large quantities of acids are used for specific processes (e.g., nitrogen oxide and dioxide are byproducts of nitric acid, and sulfuric dioxide and trioxide are byproducts of sulfuric acid). These acids can be emitted through exhaust stacks, leaking pipes, or spills.

Toxicology Highlights

Inhalation of fumes emitted from the acids themselves or from the processes they are used in is the principle hazard for toxic exposures. Most acids are strong irritants and can cause digestive disorders, lung or kidney damage, and respiratory problems. In addition, hydrogen fluoride, sulfuric acid, and nitric acid can cause burns when inhaled or ingested or when in contact with the skin.

Environmental Monitoring Results at the SDA

Acids have not been monitored at the SDA.

Profile Data Sheets for Some Radiological Contaminants of Interest

AMERICIUM-241

CAS No.: 14596-10-2

Physical Form

Americium is a silver-white crystalline solid.

Chemical Form

Americium (Am)-241 can be found in compounds with oxygen, halogens, or lithium.

Chemical and Physical Properties

Americium is stable under normal pressures and temperatures and is soluble in dilute acids. It is not a fire hazard in solid form; however, it is a dangerous fire hazard as a dust, powder, or fume.

Radiological Properties

Plutonium-241 yields Am-241 upon beta decay. Americium is mainly an alpha-emitter, with some gamma or x-ray radiation. It has a half-life of about 433 years.

Common Uses

Americium-241 is used in gamma radiography and radiochemical research, as a diagnostic aid in bone mineral analysis, and in electronic devices such as smoke detectors.

General Presence in the Environment

Americium is not found naturally in the environment, but it exists as fallout from nuclear weapons testing.

Radiotoxicology Highlights

Americium-241 emits alpha radiation during radioactive decay. Intact skin is an effective barrier for alpha radiation; therefore, the effects of americium are observed after it has been ingested or inhaled. After inhalation, Am-241 resides principally in the lungs.

Environmental Monitoring Results at the SDA

Americium-241 is detected frequently in environmental media at the SDA.

CARBON-14

CAS No.: None

Physical Form

Carbon is most commonly seen as a black elemental solid, but it is also found as diamonds, an oxidized gas (CO and CO_2), or trapped in a metallic matrix or on the surface of nonmetallic substances.

Chemical Form

Carbon is found in all organic compounds.

Chemical and Physical Properties

Carbon, especially when finely divided, readily oxidizes to CO and CO_2.

Radiological Properties

Carbon (C)-14 is a low-energy beta emitter from natural sources and from nuclear activities. No gamma rays result from C-14 decay. It has a half-life of 5,730 years.

Common Uses

The natural presence of C-14 in the environment is used by scientists to age-date archeological artifacts containing carbon. It is also used as a radiation source in thickness gauges and as a tracer in organic chemistry procedures.

General Presence in the Environment

Carbon-14 occurs naturally in the environment because of the action of cosmic radiation in the upper atmosphere. In addition, the atmospheric testing of nuclear weapons and the nuclear fuel cycle have added to the worldwide inventory of C-14. Very small amounts of C-14 are found in all living things.

Radiotoxicology Highlights

Because of its low beta energy and the absence of gamma radiation, C-14 is principally an internal hazard. It is readily absorbed into biological systems and tissue. Carbon-14 may preferentially concentrate in one or more parts of the body depending on the nature of the chemical compound into which it has been incorporated, but in general it deposits throughout all parts of the body.

Environmental Monitoring Results at the SDA

Because C-14 is ubiquitous in the environment, no effort has been made to monitor C-14 at the SDA.

CESIUM-137

CAS No.: 10045-97-3

Physical Form

Cesium can be a silvery liquid or a soft solid formed of silver-white hexagonal crystals.

Chemical Form

In nature, cesium is found only in minerals, never in the elemental state. There are many compounds of cesium, the most common being the oxides.

Chemical and Physical Properties

Cesium is an alkali metal that reacts violently with many substances, including water. It has an extremely low melting point, is very sensitive to light, ignites easily, and must be stored in mineral oil or kerosene.

Radiological Properties

Cesium (Cs)-137 is an artificial radionuclide generated through nuclear fission of uranium. It is a beta- and gamma-emitter, with a half-life of about 30 years.

Common Uses

Cesium can serve as a catalyst in the manufacture of synthetic resins and is used in photoelectric cells and as the heat transfer fluid in power generators. Cesium-137 has been approved for sterilization of certain foodstuffs.

General Presence in the Environment

Cesium is found at approximately 2 ppb in seawater and in detectable amounts in plants, animals, humans, mineral waters, soils, and the atmosphere. Cesium-137 is found in the environment as a result of fallout from nuclear weapons testing.

Radiotoxicology Highlights

Prolonged or repeated exposure to Cs-137 by inhalation, ingestion, or skin contact may result in cancers of the thyroid, skin, and bone. Cesium can act as an analog of potassium, which increases its ability to be distributed throughout the body, thereby giving essentially a whole-body dose.

Environmental Monitoring Results at the SDA

Cesium-137 is detected frequently in environmental media at the SDA.

COBALT-60

CAS No.: 10198-40-0

Physical Form

Cobalt is a silver-gray metal and can be formed into pellets or wire needles.

Chemical Form

Cobalt (Co)-60 is available as cobaltous chloride, solid cobaltic oxides, and other compounds.

Chemical and Physical Properties

Cobalt is a steel-gray, shiny, hard, somewhat malleable metal. It is insoluble in water, stable under normal temperatures and pressures, noncombustible except as a powder, and corrodes readily in air.

Radiological Properties

Cobalt-60 is an activation product of the naturally occurring Co-59, when Co-59, as a constituent of alloys, undergoes nuclear irradiation in nuclear reactors. It has a half-life of about 5 years, emitting intense beta and gamma radiation.

Common Uses

Cobalt-60 is one of the most common radioisotopes used in industry and research. It has replaced iridium in cancer and medical research and in the inspection of materials to reveal internal structure or flaws. It has been approved for gamma irradiation of certain foodstuffs.

General Presence in the Environment

Cobalt is found throughout nature, but it is relatively rare. Cobalt-60 is manufactured and is found in the environment as a result of fallout from weapons testing.

Radiotoxicology Highlights

Cobalt-60 emits both beta and gamma radiation; high levels of exposure can be lethal. Cobalt accumulates in numerous organs of the body.

Environmental Monitoring Results at the SDA

Cobalt-60 is detected frequently in environmental media at the SDA.

PLUTONIUM-239 AND PLUTONIUM-240

CAS No.: 7440-07-5

Physical Form

Plutonium is a silver-white crystalline solid.

Chemical Form

Plutonium can be made into many compounds, including oxides, fluorides, hydrides, and nitrates.

Chemical and Physical Properties

Plutonium metal is highly reactive, insoluble in water, and oxidizes rapidly.

Radiological Properties

Plutonium is a manufactured radioactive heavy element, and some of its radionuclides are fissile. Both plutonium (Pu)-239 and Pu-240 are produced by neutron capture in uranium (U)-238, and Pu-239 is also a product from neptunium (Np)-239. Alpha spectrometry cannot distinguish between Pu-239 and Pu-240; therefore, these radionuclides are usually discussed together.

Plutonium is one of the most radiotoxic of the elements. Plutonium-239 and Pu-240 emit alpha particles with approximately the same amount of decay energy being released; however, their half-lives are different. Plutonium-239 has a half-life of about 24,000 years; Pu-240 has a half-life of about 6,600 years.

Common Uses

Plutonium has been used in nuclear weapons, in some reactor fuels, and in remote power-generation applications (e.g., space applications).

General Presence in the Environment

Because plutonium is a manufactured element, it is not found naturally in the environment. It has been released into the atmosphere through nuclear explosions. The minute quantities found in the soil bind tightly, so there is little plant uptake.

Radiotoxicology Highlights

Plutonium-239 and Pu-240 emit alpha radiation during radioactive decay. Intact skin is an effective barrier for alpha radiation; therefore, the effects of plutonium are observed after it has been ingested or inhaled. After inhalation, plutonium may remain in the lungs, but it can move to the

bones and liver. It generally stays in the body for a very long time and continues to expose the surrounding tissues to radiation. Inhalation can cause lung tumors. If the dose is sufficient, radiation sickness, lung cancer, anemia, or bone cancer may occur.

Environmental Monitoring Results at the SDA

Plutonium-239/Pu-240 is detected frequently in environmental media at the SDA.

PLUTONIUM-241

CAS No.: 7440-07-5

Physical Form

Plutonium is a silver-white crystalline solid.

Chemical Form

See profile sheet on plutonium (Pu)-239 and Pu-240.

Chemical and Physical Properties

See profile sheet on Pu-239 and Pu-240.

Radiological Properties

Plutonium is one of the most radiotoxic of the elements. Plutonium-241 decays by emitting beta particles and has a half-life of about 14 years. Its decay produces Am-241.

Common Uses

See the profile sheet on Pu-239 and Pu-240.

General Presence in the Environment

See the profile sheet on Pu-239 and Pu-240.

Radiotoxicology Highlights

The beta radiation from Pu-241 can affect the skin and eyes and injure the body in general, especially if the Pu-241 is inhaled. Although Pu-241 is very toxic, it requires a larger exposure than Pu-239 or Pu-240 to produce damage. Acute or chronic exposure to beta radiation is dependent upon the dose and length of the exposure. If exposure is sufficient, radiation sickness and possible permanent bone, lung, or liver damage may occur.

Environmental Monitoring Results at the SDA

Plutonium-241 has not been monitored at the SDA because it is of a lower radiotoxicity than Pu-238 and Pu-239/240 and is more difficult to measure.

STRONTIUM-90

CAS No.: 7440-24-6 [strontium, CAS number not available for strontium (Sr)-90]

Physical Form

Strontium is a silver-white to pale yellow metal.

Chemical Form

Strontium-90 is available in mixtures of yttrium (Y)-90 and strontium (Sr)-89 chlorides; it can also be made into compounds of carbonates and sulfates.

Chemical and Physical Properties

Strontium-90 is produced in the fission of U-235 and is chemically similar to calcium. It rapidly becomes yellow on exposure to air and ignites easily when exposed to oxygen, forming hydrogen gas. It may react dangerously with oxidizers, acids, or water and when heated, may release toxic gases.

Radiological Properties

Strontium-90 decays into Y-90, which decays to zirconium (Zr)-90. It has a half-life of about 29 years and emits beta radiation with no accompanying gamma radiation.

Common Uses

Strontium-90 is used as a radiation source in industrial thickness gauges, to eliminate static charges, to provide ionizing radiation in luminous paint, and as a nuclear heat source.

General Presence in the Environment

In nature, strontium metal is found in ores throughout the world. It is ubiquitous in the atmosphere in relatively high concentrations and is, therefore, present in all living things. Strontium-90 is present from nuclear weapons tests, producing population exposure mainly through consumption of milk and dairy products, and in the air, water, and soil.

Radiotoxicology Highlights

The effects of acute or chronic exposure to beta radiation from Sr-90 depends upon the dose and length of exposure. Because it is so close to calcium in chemistry and metabolism, it is mainly deposited in areas where new bone cells are being formed. This can cause deformities or paralysis. If exposure is sufficient, radiation sickness or disorders of the lungs, heart, liver, or kidneys may occur.

Environmental Monitoring Results at the SDA

Strontium-90 is detected frequently in environmental media at the SDA.

TRITIUM

CAS No.: 10028-17-8

Physical Form

Tritium [hydrogen (H)-3] is a colorless gas.

Chemical Form

Tritium is one of the three naturally occurring isotopes of hydrogen. It may combine with oxygen to form tritiated water. It may also bond to metals as a hydride.

Chemical and Physical Properties

Tritium is an extra heavy hydrogen and is a product of fission. It is slightly soluble in water and stable under normal temperatures and pressures. It reacts strongly to oxidizers and is an explosive and fire hazard.

Radiological Properties

Tritium has a half-life of about 12 years and is a beta-emitter of very low energy.

Common Uses

Tritium is used in fusion-based thermonuclear weapons (hydrogen bombs), in watch dials and runway lights, in fusion energy research, and as a radioactive tracer in chemical, biochemical, and biological research.

General Presence in the Environment

Tritium is formed naturally from cosmic-ray interactions with the atmosphere. However, the greatest accumulation is from weapons testing. From all sources, it is disseminated in the environment as water and enters the hydrological cycle.

Radiotoxicology Highlights

Tritium enters the body by inhalation of the vapor and by absorption through the skin. Because it mixes with the body water, it does not selectively concentrate in any organ but is distributed uniformly. It leaves the body rapidly with a biological half-life of approximately 10 days. (The biological half-life is the time for a contaminant quantity in the body to be reduced by a factor of two because of biological elimination of the contaminant.) Acute and chronic exposure can cause irritation of the skin, eyes, and respiratory system and can possibly cause permanent damage. If exposure is sufficient, radiation sickness and possibly cancer or damage to the organs that tritium comes in contact with may occur.

Environmental Monitoring Results at the SDA

Tritium is detected frequently in environmental media at the SDA (see caution in the introduction to this appendix).

URANIUM-238

CAS No.: 7440-61-1

Physical Form

Uranium is a grayish-white solid.

Chemical Form

Uranium-238 is a naturally occurring radioactive isotope of uranium (U). Uranium-238 constitutes more than 99% of natural uranium, whereas U-235 constitutes less than 1%. Uranium is used in many compounds (e.g., as a nitrate, chloride, phosphate, fluoride, or sulfate).

Chemical and Physical Properties

Uranium is a dense solid that is strongly electropositive, reactive, ductile, and malleable.

Radiological Properties

Uranium-238 is fissionable and may be activated to produce Pu-239 in a reactor. Uranium-238 has a half-life of about 4.5 billion years. It decays mainly by alpha emission followed by some beta and gamma emission.

Common Uses

The most important use of U-238 is in nuclear energy applications, such as its use as nuclear fuel in breeder reactors. (U-235 is used to enrich natural uranium in nuclear fuel and was the energy source in the original atom bomb.) Compounds of uranium have been used to extend the life of incandescent lamps and have been used in photography and in making special steels. Uranium carbide is a good catalyst for the production of synthetic ammonia.

General Presence in the Environment

Uranium-238 is present naturally in the environment. Uranium is distributed abundantly in the soil and rocks and is also found in fertilizers, which explains its presence in food and human tissues at very low concentrations.

Toxicological Highlights

Uranium produces adverse health effects from both radioactive decay and from the element itself (e.g., chemical toxicity). Adverse health effects from both of these aspects are discussed in the following paragraphs.

Radiotoxicity

Uranium-238 emits alpha radiation during radioactive decay. Intact skin is an effective barrier for alpha radiation; therefore, the main routes of entry into the body are inhalation and ingestion. The target organs are the respiratory system, blood, liver, lymphatic system, kidneys, skin, and bone marrow. Cancer of the lung, bone, and lymphatic tissues has been reported for soluble compounds, whereas cancer of the lymphatic and blood-forming tissues has been reported for insoluble compounds.

Chemical Toxicity

Typically, the water soluble forms of uranium are more toxic than the insoluble forms. Following ingestion, the uranyl ion is rapidly absorbed from the gastrointestinal tract. Approximately 60% of the uranium ingested is excreted in 24 hours and 25% may be fixed to the bone. The uranyl ion can cause acute renal damage and failure, which may be fatal. However, if exposure is not severe, the tissue may be able to regenerate itself.

Environmental Monitoring Results at the SDA

Uranium-238 is detected rarely in environmental media at the SDA.

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