NWIS-TRU Programs

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Historical Emplacement Data Review for Remote-Handled and Contact-Handled Transuranic Waste at Los Alamos National Laboratory

Prepared for Los Alamos National Laboratory
Nuclear Waste and Infrastructure Services
TRU Programs

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TABLE OF CONTENTS

TABLES

LIST OF APPENDICES

LIST OF ACRONYMS

Ac	actinium
AK	acceptable knowledge
Am	americium
Ba	barium
Bi	bismuth
CBFO	Carlsbad Field Office
CH	contact-handled
CMB	Chemistry Metallurgy Baker (Division)
Cs	cesium
CMR	Chemistry and Metallurgy Research (Building)
Ci	curies
DOE	Department of Energy
EPA	Environmental Protection Agency
Eu	Europium
Fr	francium
g	gram
hr	hour
ID	identification
IDCs	item description codes
LANL	Los Alamos National Laboratory
MDA	Material Disposal Area
MFP	Mixed Fission Products
mrem	millirem
MST	Material Science and Technology (Division)
MST-5	Materials Research and Processing Science Group
MT	material type
NMT-7	Nuclear Materials Technology Group
NWIS-TP	Nuclear Waste and Infrastructure Services, TRU Programs
ORNL	Oak Ridge National Laboratory
Pa	protactinium
Pb	lead
PF	Plutonium Facility
Pm	promethium

Po	polonium
Pu	plutonium
QA	quality assurance
QAOs	quality assurance objectives
Ra	radium
Rh	Rhodium
RH	remote-handled
Rn	radon
RSICC	Radiation Safety Information Computation Center
RSWD	Radioactive Solid Waste Disposal (Form)
Ru	ruthenium
Sb	antimony
Sm	samarium
Sr	strontium
SRL	Special Recovery Line
TA	technical area
Te	technecium
Th	thorium
Tl	thallium
TRU	transuranic
TWDB	TRU Waste Database
TWSR	TRU Waste Storage Record (Form)
U	uranium
VOCs	volatile organic compounds
WCPIP	RH-TRU Waste Characterization Program Implementation Plan
WIPP	Waste Isolation Pilot Plant
WPF	Waste Stream Profile (form)
Y	yttrium

HISTORICAL EMPLACEMENT DATA REVIEW FOR REMOTE-HANDLED AND CONTACT-HANDLED TRANSURANIC WASTE AT LOS ALAMOS NATIONAL LABORATORY

1.0 INTRODUCTION

Los Alamos National Laboratory (LANL), established in the 1940s to support the Manhattan Project, is located in northern New Mexico, approximately 30 miles from Santa Fe, and encompasses 43 square miles, 47 separate technical areas (TAs), and more than 2,100 individual facilities [1]. The Department of Energy (DOE) contracts with the University of California to operate LANL. The mission of LANL is critical to DOE defense programs, such as non-proliferation and nuclear safeguards; counter-proliferation; stockpile surveillance; nuclear materials technologies; basic chemistry; environmental stewardship; and waste treatment, minimization and management.

LANL generates transuranic (TRU) waste as a result of various projects and activities. Programs generating TRU waste have included plutonium research and processing, analytical chemistry and metallurgy research, waste minimization and management research, and postmortem studies of irradiated fuels for breeder reactors. TRU waste is either contact-handled (CH) or remote-handled (RH) depending upon the surface dose rate of the waste container. Three facilities have generated the majority of the TRU waste stored at LANL, the Plutonium Facility (PF) located at TA-55, the former plutonium facility at TA-21, and the Chemistry and Metallurgy Research (CMR) facility located in TA-3. Scientific focus areas for the PF are plutonium metallurgy, actinide ceramics, and actinide chemistry [2]. The CMR facility focuses on analytical chemistry and metallurgical studies on small samples of plutonium and other special nuclear materials [3]. Other facilities have generated smaller amounts of TRU waste, and many of these activities were in support of the plutonium research at TA-55.

The RH-TRU waste at LANL has been generated primarily from the hot cells of Wing 9 of the CMR facility at TA-3, with minor amounts being generated at TA-21. LANL began storing RH-TRU waste in shafts at TA-54, Material Disposal Area G (MDA-G) in the 1970s. Shaft storage of RH-TRU wastes at Area G continues today. Area G is located in the east-southeast portion of LANL and is bordered on the north and east by the San Ildefonso Indian Reservation and to the south and west by TA-18, -36, -46, and -51. The TRU wastes addressed in this report are stored in lined shafts of different dimensions and in different waste configurations [4].

2.0 PURPOSE

The purpose of this report is to present the results of a review and compilation of the historical, physical, chemical, and radiological data in support of retrieval and safe interim storage efforts for RH- and CH-TRU waste currently stored in shafts at Area G. This report (1) includes the results of the review of historical data, (2) documents the evaluation of the physical, radiological, and chemical constituents of the wastes and the storage shafts, (3) documents the results of decay calculations for each container, (4) identifies gaps in the historical data required for safe retrieval and subsequent interim storage, and (5) provides recommendations for additional data needs. This report also discusses the justifications for selecting the best data to use for the decay calculations and gap analysis.

3.0 SCOPE

This report includes historical data for four RH-TRU shaft configurations (A, B, C, and D) and one CH-TRU shaft configuration (E). The RH-TRU shaft configurations consist of the following:

- 33 lined shafts, each containing numerous 1- and 2-gallon cans of waste, or larger waste items
- 5 lined shafts, each containing a glovebox hot cell liner within a steel box
- 16 lined shafts, each containing one canister, with each canister containing three drums of waste
- 6 unlined shafts, each containing numerous 1-gallon cans of waste

The CH-TRU shaft configuration is a set of five lined shafts, each containing a CH-TRU waste container commonly referred to as a ‘torpedo’. Each torpedo contains either three 55-gallon drums of tritium contaminated TRU waste or equipment contaminated with tritium.

4.0 BACKGROUND

This section summarizes physical information about the four configurations of shafts and the waste they contain.

4.1 LINED SHAFTS (200 THROUGH 232)

The 33 lined shafts, numbered 200 through 232, were constructed in Shaft Field B. Waste was emplaced in these shafts from 1979 through 1987. The shafts were augered into the volcanic tuff approximately 3 feet in diameter and 18 feet deep. A 13-ft. long by 8.5 inch diameter ¼-inch thick carbon steel pipe liner was placed into the shaft. The steel pipe liner had a steel plate welded to the bottom and a steel cap attached to the top. Crushed tuff, cobbles, and sand were backfilled into the void between the pipe liner and the initial boring. A concrete cap was then placed over the top [4]. Figure 1-5 in *Project Management Objectives for Remote-Handled TRU Wastes Stored in Below-Grade Shafts, TA-54, MDA-G* illustrates the shaft and emplaced waste configuration.

This waste, generated from 1979 through 1987 by the LANL Chemistry Metallurgy Baker (CMB) Division, and later by the Material Science and Technology (MST) Division, is general hot cell debris waste consisting of metals, inorganics, and combustible solids. The majority of the waste was placed into 1-gallon packages, which included an inner galvanized-steel can, a middle plastic liner, and an outer carbon-steel container with a welded steel lid [4]. The average weight of these packages is estimated to be approximately 20 to 30 pounds. Historical data indicates that Shafts 202, 203, 211, and 212 each contain much larger items, weighing 2.3 tons, 880 pounds, or 8 tons, respectively. Shaft 211 lists five items, each weighing 880 pounds [5 and 6]. The waste generator descriptions do not always correlate with the weights reported. For example, the waste description may state “Hot cell waste from CMB1 – CMB14”, with no indication of the physical form of the waste that contributes to a weight of 2.3 tons.

This waste may be considered mixed waste due to the historical use of solvents and the presence of lead in the hot cells [4]. The specific physical, chemical, and radiological characteristics of the waste packages in each lined shaft are listed in Appendix A of this report.

4.2 HOT CELL LINER SHAFTS (302 THROUGH 306)

Five lined shafts, 302 through 306, were constructed and RH-TRU waste placed in them in 1991. They contain hot cell liners, which are decommissioned gloveboxes encased in steel boxes as containers. The shafts exceed 10 feet in depth (to accommodate the outer steel boxes), and measure 9 feet 4 inches by 9 feet 4 inches in cross section. The shafts have a ¼-inch thick carbon steel liner on the sides, with a crushed tuff, cobbles, and a sand bottom, and a ¼-inch thick carbon steel plate welded to the shaft liner on the top [4]. The bottoms of the shaft liners are open. Figures 1-4 and 1-6 in *Project Management Objectives for Remote-Handled TRU Wastes Stored in Below-Grade Shafts, TA-54*, *MDA-G* illustrate these configurations.

The RH-TRU waste consists of five stainless steel alpha-contaminated hot cell liners removed from gloveboxes in hot cells 2, 4, 9, 13, and 14 during decommissioning activities in Wing 9 of the CMR facility (TA-3, Building SM-29). The wastes were generated by the MST-5 (Materials Research and Processing Science) Group. Each hot cell liner was wrapped in 4.5-mil-thick plastic, placed in a 6 foot by 6 foot by 10 foot long steel box, and blocked to limit shifting during transportation and storage. The legs of some of the glovebox hot cell liners may have been removed [4]. Specific physical, chemical, and radiological characteristics of the waste in each of these shafts are listed in Appendix B of this report.

4.3 CANISTER SHAFTS (236 THROUGH 243, AND 246 THROUGH 253)

Each of these 16 shafts are 3 feet in diameter and 16 feet deep. The shafts were designed to contain hot cell debris placed in 55-gallon drums, then placed in stainless steel canisters that fit into a Waste Isolation Pilot Plant (WIPP) 72B cask for transport to WIPP. This waste was generated by metallurgical examination operations conducted in the Wing 9 hot cells located in the CMR facility (TA-3, Building SM-29) [7].

The RH-TRU waste in these canisters was generated during the 1970s and 1980s. It was characterized and packaged during the mid 1980s and early 1990s. The waste is predominately rags, plastic, glassware, tools, and equipment with a minor component of solidified radioactive solutions. Reactor fuel materials were prepared for metallurgical examination and testing by cutting, grinding, polishing, etching, and dissolution of samples. The hot cells were cleaned out between January 31, 1986 and June 5, 1991, and the debris waste placed in 55-gallon drums between March 1993 and August 1995 [7]. Specific physical, chemical, and radiological characteristics of waste in each of these shafts are listed in Appendix C of this report.

4.4 UNLINED SHAFTS (33, 72 THROUGH 76)

The 6 unlined shafts are unlined borings approximately 25 feet deep and 2 feet in diameter that were bored into the volcanic tuff. They are located in Shaft Field C in TA-54, Area G. Waste was emplaced in these shafts from January 1971 through 1973 and contain 1-gallon cans with general hot cell trash from Wing 9 of the CMR building. Two 1-gallon cans were typically placed in a plastic liner bag, and then dropped free-fall from the surface into the shaft. Damage to the containers is likely due to the way the waste was emplaced into the shafts. As these shafts are unlined, moisture could also have caused the cans to corrode, and plastic containers and packaging are subject to radiological degradation [4].

The waste was generated at TA-3, Building 29 and consists of glovebox and hot cell trash, stainless steel cylinders, paper, grindings, and PPE. Specific physical, chemical, and radiological characteristics of the waste in each of the unlined shafts are listed in Appendix D of this report [6].

4.5 TRITIUM TORPEDO SHAFTS (262 THROUGH 266)

Five shafts were constructed to contain torpedo-shaped waste containers. Four of the torpedoes contain three 55-gallon drums each, and the fifth torpedo contains a 20-foot-long tritium tank. This waste was generated from a decommissioning project at TA-55 by the Nuclear Materials Technology Group (NMT-7) and was emplaced in the shafts between 1995 and 1997 [4, 5 and 8].

The waste is tritium contaminated CH-TRU [Material Type- (MT) 52] waste from the Special Recovery Line (SRL) tear-out at TA-55, PF-4. The waste consists primarily of scrap metal (valves, fittings, piping, vessels, pumps, and other equipment) and some combustibles. The combustibles and non-combustibles were not segregated [9]. The waste was bagged out of the glovebox, or, in the case of the processing tank system, disassembled and bagged. The bags were sealed by the twist and tape closure method and placed inside 55-gallon drums that were painted on the inside with asphalt as a barrier to tritium permeation. The drums were also identified with a red "T." The bungs were replaced with a carbon composite filter just prior to their being loaded into the stainless steel torpedoes. Possibly, a Linde Type 4A molecular sieve material was placed in the annular void spaces between the drums and torpedo walls to absorb tritium dioxide escaping through the carbon filter. The vessel heads were welded in place. At the top of the torpedo, a penetration hole was drilled for attachment of a valve, pressure gauge, pressure relief valve, and quick connect to allow for future sampling. The torpedo was flushed with helium to leak test the closure weld [8 and 9]. Specific physical, chemical, and radiological characteristics of waste in each torpedo are listed in Appendix E of this report.

5.0 SOURCES OF INFORMATION REVIEWED

The sources of information reviewed included the following:

- An Excel workbook entitled "Remote handled.xls" created by Jene Vance, Vance & Associates [10]
- LANL TRU Waste Management Database (TWDB) [5]
- Original waste records (i.e., Radioactive Solid Waste Disposal [RSWD] forms, TRU Waste Storage Record [TWSR] forms) [6 and 8].

The initial set of data reviewed was the Remote handled.xls workbook. This workbook did not include data for the tritium torpedoes, and the source of the information was undocumented. Mixed fission product (MFP) activities were calculated, but the equations were not included in the spreadsheet. Section 5.1 describes the data included in this workbook.

A request was initiated to query the TWDB to obtain the information required to support the retrieval and interim safe storage effort. The data fields queried are listed in Section 5.2. The review of the queried results revealed some fields had missing data, especially for the older waste items. The TWDB had been updated several times, and new fields added, but the new fields were not always updated from the original forms. In addition, it was determined that while the information had been entered into the TWDB from the original records, the accuracy had not been verified for entries made before the early 1990s. Therefore, the original waste generator records were required for review to ensure the most complete and accurate information was used.

The original disposal forms were requested and were available with few exceptions. The original RSWD forms were thought to have been archived off-site, and only a microfiche copy of the first page was available on-site. However, upon further investigation, there was no record of any of the RSWDs being sent to a storage facility. The original TWSRs were still stored on-site at LANL and included the supporting documentation. Section 5.3 discusses the data reviewed from the original disposal forms.

Data obtained from original disposal forms (RSWDs, TWSRs) were entered into spreadsheets and independently verified to ensure transcription was accurate. Data from the Remote handled.xls workbook and exported information from the TWDB were used directly.

Initial calculations were performed to: (1) convert MT to individual isotopes, (2) convert grams to curies, and/or (3) calculate MFP activities, if applicable. After apportioning the MT mass into individual isotopic masses, the isotopic masses were converted to curies using the isotopic specific activity in curies per gram (Ci/g) values from Table A-1 of 10 CFR Part 71, Appendix A [11]. The total reported activity of MFP was distributed as activities of individual isotopes (Ba-137m, Cs-137, Eu-155, Pm-147, Rh-106, Ru-106, Sb-125, Sr-90, Te-125m, Y-90) for each package, as needed. These calculations were independently verified to document accuracy. The following sections discuss in detail the type of information obtained from each source and list the specific shafts the data represent. References used for calculating MTs and MFPs are also discussed.

5.1 REMOTE HANDLED.XLS WORKBOOK

The original information obtained was included in an Excel workbook developed by Jene Vance [10]. Table 1 lists the data fields reviewed.

Table 1. Remote handled.xls Workbook Data Fields

Shaft Number	Package Number	Grams of Pu-239
Curies of Pu-239	Curies Calculated from Dose Rate	Mixed Fission Products (Curies)
Measured Dose Rate	Calculated Dose Rate at 1 Meter	Curies of MFP at t=0
Curies of MFP at t=2004	Power from MFP (watts)	Power from Pu (watts)
55-Gallon Drum Dose Rate at Surface (Unshielded)	55-Gallon Drum Dose Rate at 3 feet (Unshielded)	55-Gallon Drum Dose Rate at 10 feet (Unshielded)
55 Gallon Drum Dose Rate at 20 feet (Unshielded)	55-Gallon Drum Dose Rate at 1 foot (3 inches Shielding)	55-Gallon Drum Dose Rate at 1 foot (4 inches Shielding)
55-Gallon Drum Dose Rate at 1 foot (4 inches Shielding)	55-Gallon Drum Dose Rate at 1 feet (inches Shielding)	55-Gallon Drum Dose Rate at 1 feet (6 inches Shielding)
Canister Dose Rate at 15 feet	Transfer Cask Contact Dose Rate	72-B Cask Contact Dose Rate

Much of this radiological information is needed for safe retrieval and interim storage, however, as mentioned previously, the source of the data could not be verified, and the equations used to determine the calculated numbers were not included in the source documents. This Remote handled.xls data source did not include an evaluation of the tritium torpedoes, therefore, Appendices A-1, B-1, C-1, and D-1 are the only spreadsheets containing the data from Remote handled.xls for the wastes in the 33 lined shafts containing waste cans, the 5 lined shafts containing cell liners, the 16 lined shafts containing canisters, and the 6 unlined shafts, respectively.

5.2 TRU WASTE DATABASE

Table 2 lists the data fields queried, exported, and reviewed from the TWDB. They were obtained from the TWDB [5] based on the queries for each shaft number and package ID.

Table 2. TRU Waste Database Data Fields

Data Field	Description
LOC DESC	Description of location where stored
PKG_ID	Uniquely identifies each package of TRU waste. It is a 5 digit barcode label assigned by the waste generator and provided by the TRU Waste Certification Official.
BLDG_CD	Building designation. Will include the technical area and building. May pertain to any or all of the buildings where the package came from, where it is being held, or where it is stored. Value will conform to format in Engineering “Structure TA-NUM”. A leading (zero) will be put in front of TA component if TA is single digit.
GRP	Designation of the LANL group that generated the waste
PKG_DATE	Date packaged
REC_DATE	Date recorded

Data Field	Description
RCV_DATE	Date received at Area G
STORAGE_DATE	Date stored
GROSS_WT	Weight of container and waste
NET_WT	Weight of waste
VOLUME (m^3)	Package volume for standard packages (m^3)
EPA_CD	Hazardous waste code
WASTE DESC	Description of the waste code
COMMENTS	General comments to denote special concerns
RAD_CD	Isotope or material type
GRAMS	Amount of radionuclide in grams
PKG_PE-ACT	Total Pu-equivalent curies
TOTAL DOSE	Total surface dose rate, mrem/hr

Appendices A-2, B-2, C-2, D-2, and E-1 are spreadsheets developed from the data obtained from the TWDB for the 33 lined shafts containing waste cans, the 5 lined shafts containing hot cell liners, the 16 lined shafts containing canisters, the 6 unlined shafts containing waste cans, and the 5 lined shafts containing tritium torpedoes, respectively.

5.3 ORIGINAL WASTE DISPOSAL RECORDS

Facilities that generated TRU waste were required to complete either an RSWD form or a TWSR form. The original waste records were obtained for packages in all shafts, with the exception of one package, S812303, in Shaft 206.

5.3.1 Radioactive Solid Waste Disposal (RSWD) Forms

RSWDs [6] were available for the wastes in the 33 lined shafts, the 5 hot cell liner shafts, and the 6 unlined shafts. The use of RSWD forms was initiated in 1971 and discontinued in 1992. The original RSWD and any associated supporting documentation were unavailable However, the first page of the RSWD was on microfiche and copies of the microfiche were obtained and used as original data. No supporting documentation was available for review for this report. Table 3 lists the data fields reviewed and evaluated from the first page of the RSWD.

Table 3. Radioactive Solid Waste Disposal Form Data Fields

Shaft Number	Form Number (RSWD Number)	Date (Form Date)
Date Disposed	Group	Technical Area
Building and Room	Wing (if applicable)	Gross Weight (units)
Net Weight (units)	Waste Description	Additional Comments
Hazardous Waste Code	Nuclide	Amount (curies or grams)
Method of Measurement	Dose at Contact	Dose at 1 meter

Appendices A-3, B-3, and D-3 are spreadsheets documenting the data fields obtained from the original RSWDs for wastes in the 33 lined shafts containing waste cans, the 5 lined shafts containing hot cell liners, and the 6 unlined shafts containing waste cans, respectively.

5.3.2 TRU Waste Storage Record (TWSR) Forms

TWSRs [8] were available for the wastes in the 16 canister shafts and the 5 tritium torpedo shafts. The original TWSR packages were available, including the associated supporting documentation. Table 4 lists the data fields reviewed and evaluated.

Table 4. TRU Waste Storage Record Forms Data Fields

Box Serial Number	Waste Package Serial Number	Date Closed
Date Stacked	Group	Technical Area
Building	Gross weight (units)	Organic Material
EPA Code	Internal shielding (material)	Grams and Thickness
Waste Description	Nuclides	Amount
Uncertainty	Gamma dose rate	Neutron Dose Rate
Total dose rate	Alpha contamination	Beta Contamination

Appendices C-3 and E-2 are spreadsheets listing the data obtained from the TWSRs for wastes in the 16 lined shafts containing canisters and the 5 lined shafts containing tritium torpedoes, respectively.

5.4 MATERIAL TYPES AND CALCULATIONS

To compare the isotopic contents reported in the data sources, the masses of isotopes from the original waste records (e.g., RSWDs and TWSRs) were converted into curies. In addition, the masses of different MTs were reported in the original waste documents. Thus, the masses of the MTs were apportioned into masses of individual isotopes based on the definition (i.e., weight percentage) of the MTs. The isotopic weight percentages in Table 5 [12] were used to define the average isotopic content (in weight percentage) of plutonium and uranium material types and enrichments for each MT. The ratios in these tables were calculated under the assumption that no chemical fractionation occurred and, hence, were intended to be used to identify fractionation when it is present by comparing these upper bounds to actual radioassay data [12]. Weapons grade plutonium is typically MT-52. Plutonium from the hot cell debris waste is typically MT-55. MTs listed in the original waste records were assumed to be as follows:

- U-21 was assumed to be a typographical error and should be MT12
- U-25 was assumed to be a typographical error and should be MT35
- U-36 was MT36
- Pu-53 was MT53
- Pu-55 was MT55
- Pu-56 was MT56
- Pu-57 was MT57.

Table 5. Isotopic Content of Plutonium and Uranium Material Types

Material Type (MT)	Isotopic Content (Weight Percent)										
	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	U-234	U-235	U-236	U-238	Am-241	Cs-137
51	0.006	96.77	3.13	0.076	0.018	0.001	0.1	0	0	0.06	4.00E-07
52	0.01	93.78	6	0.2	0.02	0.002	0.1	0	0	0.2	4.00E-07
53	0.03	91.08	8.45	0.366	0.071	0.007	0.09	0	0	0.3	4.00E-07

Material Type (MT)	Isotopic Content (Weight Percent)										
	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	U-234	U-235	U-236	U-238	Am-241	Cs-137
54	0.046	87.42	11.5	0.81	0.22	0.01	0.09	0	0	0.7	4.00E-07
55	0.06	83.88	14.73	1.03	0.304	0.02	0.09	0	0	0.9	4.00E-07
56	0.061	81.9	16.51	1.18	0.355	0.02	0.09	0	0	1	4.00E-07
57	0.433	74.63	20.7	2.55	1.69	0.1	0.08	0	0	2	4.00E-07
42	0.73	1.06	6.4	1.97	89.83	0.3	0.0009	0	0	3	4.00E-07
83	81.2	16.3	2.3	0.12	0.13	18.2	0.012	0	0	0.3	4.00E-09
12	0	0	0	0	0	0.0015	0.23	0.008	99.77	0	0
35	0	0	0	0	0	0.36	37.6	0.14	61.9	0	0
36	0	0	0	0	0	0.63	62.44	0.18	36.75	0	0
38	0	0	0	0	0	1.03	93.04	0.41	5.53	0	0
39	0	0	0	0	0	1.32	97.52	0.17	0.99	0	0

In general, uranium and its isotopes are expected to be present only in trace amounts, if at all, if the feed material did not purposely contain uranium.

The MFP activity distribution was obtained by averaging each isotope's percentage across all the WIPP RH canisters as provided by isotopic information in the TWSRs. Table 6 lists the calculated isotopic fractions.

Table 6. Isotopic Activity Fractions for 1 Ci of Reported MFPs

Isotope	Fraction	Units
Ba-137m	0.2396	Ci
Cs-137	0.2555	Ci
Eu-155	0.0048	Ci
Pm-147	0.0146	Ci
Rh-106	0.0019	Ci
Ru-106	0.0019	Ci
Sb-125	0.0104	Ci
Sr-90	0.2335	Ci
Te-125m	0.0043	Ci
Y-90	0.2335	Ci

5.5 DECAY AND DOSE CALCULATIONS

5.5.1 Decay Calculations

The final, verified spreadsheet data for wastes in the 33 lined shafts, 5 hot cell liner shafts, 16 canister shafts, 6 unlined shafts, and 5 tritium torpedo shafts were used to perform decay calculations. The initial date used for all calculations was the latest date identified on the original waste forms or the TWDB. The final date used in the decay calculations was 2009.

TransOrigin.xls, Version 1.0, A Pre-Post Processor for the ORIGEN2, Version 2.2 Software [13] was used to perform these calculations. This Microsoft Excel spreadsheet application provides a standard interface to process radionuclide data using the Oak Ridge National Laboratory (ORNL) computer code, ORIGEN2, Version 2.2. This isotope generation and depletion code uses the matrix exponential solution method and was developed and distributed by the Radiation Safety Information Computation Center (RSICC) at ORNL. This software calculated and reported the inventory of radionuclides on a given shaft/package basis decayed to a common base year.

The input data were the verified data from the original waste records or the TWDB if the original waste records were insufficient. The input files contained activities for all plutonium and uranium isotopes listed or partitioned isotopes from the listed MTs. The input files also included the partitioned MFP activities. Output files included all daughter products from decay of the input radionuclides. The software was verified by an independent qualified software developer. Appendix F contains the software quality assurance (QA) documentation [14].

Appendices A-4, B-4, C-4, D-4, and E-3 are spreadsheets listing all of the input and output data for the wastes in the 33 lined shafts, 5 hot cell liner shafts, 16 canister shafts, 6 unlined shafts, and 5 tritium torpedo shafts, respectively.

5.6 JUSTIFICATION FOR SELECTING THE FINAL DATA TO BE USED

After the source documents were received and reviewed, the information was entered into spreadsheets and independently verified to assure that no transcription errors occurred. For each shaft configuration, the data from each source document were compared. A determination was made regarding the completeness of the data, the source of the information, and the quality of the data.

5.6.1 Remote handled.xls Workbook

The data from the Remote handled.xls workbook included the wastes in the 33 lined shafts, 5 hot cell liner shafts, the 16 canister shafts, and 6 unlined shafts [10]. While the information was nearly complete for the four configurations, calculated values could not be verified as there was no accompanying information documenting the equations used to construct the spreadsheet. Also, there were some packages missing from the 6 unlined shafts. In addition, the shaft numbers for the canisters were not the same as those documented in the TWDB or on the TWSRs (See Appendix C-1). Consequently, it was determined that this data were not used for the final calculations.

5.6.2 TRU Waste Database

The information in the TWDB was more complete and correlated, in most cases, with other data sources [5]. This database was a work in progress, and, according to LANL staff, data fields were continuously being added over a period of time. In some cases, the new fields were updated with data from the original records, but in many other cases these new fields were left blank if the original data had been entered previously. Before the early 1990s, the database entries were not verified against the original waste records. After the early 1990s, data entry personnel used the double entry verification system for quality control purposes. The TWDB did not always include individual complete radiological information, e.g., the database did not include activity for the MFPs in many cases. Based on this information and evaluation, it was decided that the data in the TWDB would be used as a secondary information source if the information were also available on the original waste records. The TWDB would be used as the primary source if data was missing or illegible on the original records.

5.6.3 Original Waste Records

The original waste records included RSWDs for the wastes in the 33 lined shafts, 5 hot cell liner shafts, and the 6 unlined shafts, and TWSRs for the wastes in the 16 canister shafts and the 5 tritium torpedo shafts [6 and 8]. As discussed previously, the RSWD included the first page of the RSWD, but no supplemental backup data. The RSWD listed the estimated mass of U-235 or Pu-239, or both, and, in most cases, the measured activity of the MFPs. The dose rates at the surface and at one meter were also noted in most cases. However, for some RSWDs, certain information is illegible or blank. When the original RSWD data was not available, the TWDB data was used. Table 7 provides the data fields of interest and primary and secondary sources of information used.

Table 7. Final Data Selection and Justification for Lined Shafts, Hot Cell Liners, and Six Unlined Shafts

Information Field	Primary Source	Secondary Source	Comments
Shaft number - and - Package ID	TWDB	RSWD	TWDB appears to have the most complete list of shafts and correlations to Package ID number. Some RSWDs have illegible form numbers and shaft numbers. However, because portions of these numbers are legible, it is possible to correlate the RSWD numbers to Package ID numbers from the TWDB. Assumption: the Package ID numbers in the TWDB are correct.
Waste Generation Location (Building, Wing, and Room)	RSWD	TWDB	RSWD data are most complete. When available, RSWDs provide the building, and often also provide the wing and room of generation. TWDB provides some data for the building of waste generation for missing RSWD. Assumption: the same building (TA-3, Building SM-29) when no data are available.
Group	RSWD	TWDB	RSWDs and TWDB are combined to provide the most complete data due to missing or illegible RSWDs. RSWDs provide data when field is blank in TWDB.
Date	RSWD	TWDB	RSWDs provide data for most of the packages. TWDB provides data when missing in the RSWDs. Used latest date listed from both sources for decay calculations. RSWDs include "Date Disposed", which generally matches TWDB. An earlier date is also included and is assumed to be the date of RSWD preparation and waste packaging. Some RSWDs also include another date written in lower margin. It is unclear to what this additional date refers to; so, it was not considered.
Gross weight	RSWD	TWDB	RSWDs provide the most complete data, including units. TWDB provides data if RSWD data are missing or illegible. TWDB does not indicate units: therefore it is assumed the data are given in pounds. This assumption is based on the correlation between data in an RSWD and TWDB when provided by both.
Gross volume	RSWD	TWDB	RSWDs provide the most complete data, including units. TWDB provides data if RSWD data are missing or illegible.
Number and Type of Waste Containers	RSWD	NA	RSWDs provide the most complete data. TWDB does not provide data.
Waste Description	RSWD TWDB	NA	Used all data from RSWDs and TWDB, which included waste descriptions, comments, and waste codes. Waste codes are LANL-specific and are different from hazardous waste numbers. A field for EPA hazardous waste numbers was provided in the TWDB, but was blank for all Package IDs, except one. Therefore, it was not used.

Information Field	Primary Source	Secondary Source	Comments
Radiological Information (nuclide, mass, curie, method of measurement)	RSWD	TWDB	RSWD provides the most complete data, which includes estimated Pu-239 and U-235 mass in grams and measured activity of MFPs in Ci. TWDB provides data if RSWD data are missing or illegible. TWDB does not provide data for MFP. Some RSWDs list MT instead of isotopes. This information was used to calculate isotopic distribution and curies for MT.
Dose Rate (contact and 1-meter)	RSWD	TWDB	RSWDs provide the most complete data, which includes a contact and 1-meter dose rate reading for nearly all waste items. Dose rate information is often included in the 'Comments' field. TWDB provides data if RSWD data are missing or illegible.

The TWSRs had the most complete data of all data sources. TWSRs were available for the 16 canisters and the 5 tritium torpedoes. The TWSR data were entered into the TWDB and verified by a second data entry staff member, which was documented on the TWSR form. Supplemental backup information was attached to the TWSR form, and provided additional descriptions regarding contents of the canisters or the torpedoes. Specific radioisotope activities, including individual MFP isotopes, were listed. Table 8 provides the data fields of interest and the primary and secondary sources of information used.

Table 8. Final Data Selection and Justification for Canisters and Tritium Torpedoes

Information Field	Primary Source	Secondary Source	Comments
Shaft number - and - Waste Package Serial Number	TWSR	TWDB	TWSR and the TWDB appear to have equally complete list of shafts and correlations to Package ID number. TWSR did not include shaft number, but did have package number, which was correlated with the data in the TWDB. TWSR and TWDB information agreed.
Generating location (Building, Wing, and Room)	TWSR	TWDB	TWSR data are most complete and provide the building, and often also provide the wing and room of generation. TWDB provides some data for building.
Group	TWSR	TWDB	TWSR provides the most complete data.
Date	TWSR	TWDB	TWSR provides most complete data. Used latest date listed from both sources, which provides conservative approach for decay calculations.
Gross weight	TWSR	TWDB	TWSR provides the most complete data, including units. Used TWDB if TWSR data are missing or illegible. TWDB does not indicate units. Assumption: the data are given in pounds. This assumption is based on the correlation between data in the TWSR and TWDB when provided by both.
Gross volume	TWSR	TWDB	TWSR provides the most complete data, including units. TWDB provides data if TWSR data are missing or illegible.
Number and Type of Waste Containers	TWSR	NA	TWSR provides the most complete data. TWDB does not provide data.
Waste Description	TWSR	TWDB	Used all data from TWSR and TWDB, which included waste descriptions, comments, and non-radioactive hazardous materials. A field for EPA hazardous waste numbers was provided in the TWDB, but was blank for all Package IDs. Therefore, it was not used.

Information Field	Primary Source	Secondary Source	Comments
Radiological Information (nuclide, mass, curie, method of measurement)	TWSR	TWDB	TWSR provides the most complete data. This includes Pu-239, U-235, and a listing of MFPs in Ci. TWDB does not provide data for MFP.
Dose Rate (contact and 1-meter)	TWSR	TWDB	TWSR provides the most complete data, which includes total dose rate and gamma and neutron dose rates. Contamination information is also included. TWDB provides data if TWSR data are missing or illegible.

6.0 RADIOLOGICAL AND CHEMICAL DATA

As discussed in Section 5.6, the data in the original waste records (RSWDs for the 33 lined shafts, 5 hot cell liners, and 6 unlined shafts, and TWSRs for the 16 canisters and the 5 tritium torpedoes) were the most complete and were used to calculate the MFPs and the MT activities and to perform the decay calculations. In the absence of data or if the original waste record data were illegible, the data from the TWDB were used. In all cases, these two sources of information provided sufficient radiological data to perform the calculations. LANL began using Item Description Codes (IDCs) and Waste Profile Forms (WPF) in 1990. In 1992, IDCs were discontinued. The following sections discuss each shaft storage configuration and the radiological and chemical data results.

6.1 LINED SHAFTS

Radiological and chemical information was reviewed for each waste package in each of the 33 lined shafts. Appendix A contains four sets of spreadsheets: A-1 is the data from the Remote handled.xls workbook, A-2 is the data from the TWDB, A-3 is the data from the RSWDs, and A-4 is the final activity and dose rate used and the results of the decay calculations. Table 9 lists the minimum and maximum Pu-239, Pu-241, and U-235 activity and initial and decayed surface dose rates in all of the 33 lined shafts and tentatively identified hazardous waste codes. The hazardous waste codes were tentatively identified based on reviewed source documents [4].

Table 9. Summary Data for the Waste in the 33 Lined Shafts

Item	Units	Minimum	Maximum
Pu-239	Curies	2.48E-03	1.24E+01
U-235	Curies	2.0E-07	8.14E-04
Pu-241	Curies	1.83E-02	8.10E+01
Dose rate (surface) initial	mrem/hr	10	1,200,000
Dose rate (surface) decayed	mrem/hr	10	1,029,000
	Hazardous Waste Codes		**Constituents**
Chemical codes	D008		Lead
	F001, F002, F003, F004, F005 (possible pending AK investigation)		Organic solvents

The tables in the appendices reflect the data considered to be the most critical for the decay calculations and safe retrieval and interim storage. Many other data points were reviewed but were not included in this report. Appendix G-1 lists the data fields that were included in the original source documents, but not included in the appendices for the 33 lined shafts.

6.2 HOT CELL LINER SHAFTS

Radiological and chemical information was reviewed for each hot cell liner in each shaft. Appendix B contains four sets of spreadsheets: B-1 is the data from the Remote handled. xls workbook, B-2 is the data from the TWDB, B-3 is the data from the RSWDs, and B-4 is the final activity and dose rate used and the results of the decay calculations. Table 10 lists the reported minimum and maximum Pu-239, Pu-241, U-235, and U-234 activity and initial and decayed surface dose rates found for all of the canisters.

Table 10. Summary Data for the Hot Cell Liners

Item	Units	Minimum	Maximum
Pu-239	Curies	1.85E-02	7.91E-02
Pu-241	Curies	3.75E-01	1.61E+00
U-235	Curies	2.85E-06	1.24E-05
U-234	Curies	9.16E-05	3.99E-04
Dose rate (surface) initial	mRem/hr	200	800
Dose rate (surface)decayed	mRem/hr	130	2200
	Hazardous Waste Codes		**Constituents**
Chemical Codes	None		None

The available data for the hot cell liners included the RSWDs and supplemental information. Based on the information from the original generator, the hot cell liners contain no hazardous constituents.

The tables in the appendices reflect the data considered to be the most critical for the decay calculations and safe retrieval and interim storage. Many other data points were reviewed but were not included in this report. Appendix G-2 lists the data fields that were included in the original source documents, but not included in the appendices for the 5 hot cell liner shafts.

6.3 CANISTER SHAFTS

Radiological and chemical information was reviewed for each canister in each shaft. Appendix C contains four sets of spreadsheets: C-1 is the data from the Remote handled.xls workbook, C-2 is the data from the TWDB, C-3 is the data from the TWSRs, and C-4 is the final activity and dose rate used and the results of the decay calculations. The radionuclide information listed in this report is taken from the original TWSRs and does not reflect the radiological characterization performed by the Central Characterization Project (CCP) using the dose to curie (DTC) method and documented in an AK summary report [7]. In 2000, headspace gas samples were obtained on ten of the canisters to determine the flammable gas generation and decay heat and evaluate compliance with the transportation requirements specified in the 72-B Safety Analysis Report for Packaging (SARP) [15]. The canisters were sampled over a minimum of six times over a period of 15 weeks. Results showed that the maximum measured hydrogen concentration of 2.3 percent was far below the 5 percent lower explosive limit [16]. In 2003, the CCP prepared five reports including the AK summary report [7], a RH certification plan [17], a QA equivalency demonstration [18], an equivalency matrix [19], and a radiological characterization report [20] for the 16 canisters. These documents formed the basis for the LANL RH-TRU waste certification demonstration program.

Table 11 lists the reported minimum and maximum Pu-239 and U-235 activity, initial and decayed surface dose rates found for all of the 16 canisters, and hazardous waste codes. The purpose of this report is to review and document the data required for safe retrieval and interim storage, whereas, the AK summary report [7] was prepared to meet the requirements of the RH-TRU Waste Characterization Program Implementation Plan (WCPIP) [21].

Table 11. Summary Data for the 16 Canisters

Item	Units	Minimum	Maximum
Pu-239	Curies	2.31E-02	1.69E+01
U-235	Curies	1.49E-06	2.66E-04
Dose rate (surface) initial	mrem/hr	800	260,000
Dose rate(surface) decayed	mrem/hr	520	170,000
	Hazardous Waste Codes		**Constituents**
Chemical Codes	D005, D006, D007, D008, D009, D011		Barium Cadmium Chromium Lead Mercury Silver
	F001, F002, and F005		Solvents

The tables in the appendices reflect the data considered to be the most critical for the decay calculations and safe retrieval and interim storage. Many other data points were reviewed but were not included in this report. Appendix G-3 lists the data fields that were included in the original source documents, but not included in the appendices for the 16 canister shafts.

6.4 UNLINED SHAFTS

Radiological and chemical information was reviewed for packages in each unlined shaft. Appendix D contains four sets of spreadsheets: D-1 is the data from the Remote handled.xls workbook, D-2 is the data from the TWDB, D-3 is the data from the RSWDs, and D-4 is the final activity and dose rate used and the results of the decay calculations. Table 12 lists the reported minimum and maximum Pu-239 and U-235 activity and initial and decayed surface dose rates found for all of the shafts.

Table 12. Summary Data for the Unlined Shafts

Item	Units	Minimum	Maximum
Pu-239	Curies	5.0E-03	2.0E+01
U-235	Curies	1.0E-01	5.0E+01
Dose rate (surface) initial	mRem/hr	10	500
Dose rate (surface)decayed	mRem/hr	4	200
	Hazardous Waste Codes		**Constituents**
Chemical Codes	Unknown		Unknown

The available data for the unlined shafts included the RSWDs and supplemental information. No information was available for this report regarding hazardous waste codes. Item number S002253 was listed on the RSWD as being in shaft 77, however, this report included it in shaft 76.

The tables in the appendices reflect the data considered to be the most critical for the decay calculations and safe retrieval and interim storage. Many other data points were reviewed but were not included in this report. Appendix G-1 lists the data fields that were included in the original source documents, but not included in the appendices for the 6 unlined shafts.

6.5 TRITIUM TORPEDO SHAFTS

Radiological and chemical information was reviewed for each torpedo in each shaft. Appendix E contains three sets of spreadsheets: E-1 is the data from the TWDB, E-2 is the data from the TWSRs, and E-3 is the final activity and dose rate used and the results of the decay calculations. Note that the tritium torpedoes were not evaluated in the Remote handled.xls workbook; therefore, there are only three spreadsheets for this configuration. Table 13 lists the reported minimum and maximum Pu-239, U-235, and tritium (H-3) activity and initial and decayed surface dose rates for all of the canisters.

Table 13. Summary Data for the Tritium Torpedoes

Item	Units	Minimum	Maximum
Pu-239	Curies	8.32E-02	1.70E+00
Pu-241	Curies	2.93E-01	6.61E+00
H-3	Curies	3.20E-02	2.72E+03
Dose rate (surface) initial	mrem/hr	0.1	3.0
	Hazardous Waste Codes		**Constituents**
Chemical codes	None		None

As expected, the dose rates for the tritium torpedoes do not qualify this waste as RH-TRU waste. TWSRs for the tritium torpedoes do not list any hazardous materials. The documentation reviewed indicated that hydrogen getters were to be placed inside the waste containers to absorb hydrogen generated due to alpha radiolysis for a period of 20 years. There is no indication that hydrogen getters were ever used.

The tables in the appendices reflect the data considered to be the most critical for the decay calculations and safe retrieval and interim storage. Many other data points were reviewed but were not included in this report. Appendix G-4 lists the data fields that were included in the original source documents, but not included in the appendices for the 5 tritium torpedo shafts.

7.0 GAP ANALYSIS

The RH-TRU WCPIP [21] is a programmatic document that specifies how RH-TRU waste characterization will be implemented at sites that generate and/or store RH-TRU wastes and provides quality assurance objectives (QAOs) for certification purposes.

All sites are required to collect, review, and document AK information for their TRU waste characterization program. The result of the AK process is an auditable record and an AK summary report.

The information required for safe retrieval and interim storage operations includes physical, radiological, and chemical data for the shafts and the waste contained in the shafts. However, it does not require that the WIPP RH-TRU waste characterization QAOs be met. The information gathered, reviewed, and documented in this report can be used as supplemental AK source documentation and is not intended to meet the requirements of the WCPIP [21]. However, this report and the reference documents will be placed in the Nuclear Waste and Infrastructure Services, TRU Programs (NWIS-TP) records center. The following sections discuss the data gaps for each of the five waste storage configurations.

7.1 LINED SHAFTS

The lined shaft configuration is one of two configurations that pose the most challenges for safe retrieval and interim storage. This storage configuration and the unlined shafts have the least reliable data reviewed at this time.

The RSWDs for the wastes in the lined shafts are incomplete and sometimes illegible. Only the first page of the RSWD form was available from microfiche. The data used in this report were usually a combination of the TWDB and the RSWD information. There was no RSWD for item number S812303. Questions regarding the dose rates remain, as the dose rate was sometimes written in the waste description box and the units not always clearly identified. Most references described the lined shafts as containing one- or two-gallon cans; however, data from the TWDB and the RSWDs state that there are larger items weighing 880 pounds, 2.3 tons, or 8 tons, which is inconsistent with the waste descriptions. A reactor vessel inside a cask, weighing approximately 8 tons was emplaced in shaft 212. That shaft has a larger diameter in order to fit the reactor vessel in it, and is most likely, not TRU waste. Discussions with CMR personnel also indicated that the large weights listed on the RSWDs do not reflect the actual weight of the items placed in the shafts.

Due to the configuration of the shafts and the waste emplaced in them, it is expected that the integrity of at least some of the cans is breached and there may be potential contamination either from breached cans or from surrounding shafts. Additional concerns are the potential for flammable gases inside the shafts, the integrity of the shafts, and surface contamination of the cans.

7.2 HOT CELL LINER SHAFTS

The RSWDs for the hot cell liners includes supplemental information from the generator. Form numbers, dates, originating group, building, TA, wing, program code, shaft number, dose rate, volume, hazardous constituents, and waste description are legible and largely complete. The radionuclide mass was determined from analysis, and the MFP activity was estimated. There is currently no information regarding the status of the shafts themselves, the surface contamination on the steel boxes, or the integrity of the steel boxes. These boxes are non-standard packages and have had no formal design review. Concentrations, if any, of flammable volatile organic compounds (VOCs) are also unknown, but none are likely to be present since the liner over pack boxes were sealed. However, samples for flammable VOCs will be collected before retrieval operations begin.

7.3 CANISTER SHAFTS

The canister data have been assembled and reviewed by the CCP and documented in an AK summary report [6]. This report has been previously reviewed by the EPA and Carlsbad Field Office (CBFO). There is no information at this time regarding the current status of the shafts themselves, or whether there is surface contamination on the canisters. Concentrations of flammable VOCs in the shafts are also unknown at this time, but considered to be unlikely since the canisters are sealed. However, samples for flammable VOCs will be collected before retrieval operations begin.

7.4 UNLINED SHAFTS

The 6 unlined shafts are the oldest emplaced waste configuration discussed in this report. The RSWDs are microfiche copies and the data was sometimes hard to read or in two cases, unreadable. If the data were unreadable, the TWDB information was used for further calculations.

The integrity of the unlined shafts is questionable. Due to the length of time the waste has been stored in the shafts, the fact that the shafts are unlined, and the emplacement method used, it is likely that at least some of the cans are breached or corroded. It is expected that contamination of the shaft and the contents has occurred from the breached cans.

7.5 TRITIUM TORPEDO SHAFTS

The TWSRs for the tritium torpedoes include supplemental information from the generator, TWSR numbers, dates, originating group, building, TA, wing, program code, dose rate, weight, hazardous constituents, and waste descriptions. The TWSRs are legible and largely complete. Supplemental information includes drawings of the torpedoes, memoranda describing the packaging, and the proposed waste configuration of the drums inside. The radionuclide mass for each isotope was estimated.

There are questions regarding the capacity of the molecular sieve material and radiolytic gas generation issues. The documentation indicated that hydrogen getter material was to be added, however, there is no documentation that it was actually added. These questions will be discussed in Section 8.0. In addition, there is currently no information regarding the status of the shafts themselves, the surface contamination of the torpedoes, or the integrity of the torpedoes as they are non-standard packages. Concentrations of flammable VOCs in the shafts are also unknown at this time, but are unlikely since the torpedoes are sealed. However, samples for flammable VOCs will be collected in the shafts and from within the torpedoes before retrieval operations begin.

8.0 RECOMMENDATIONS

Based on the discussion throughout this report, the following recommendations are suggested:

- Originally, it was thought that retrieval the original RSWDs and supporting documentation for the 33 lined shafts and 6 unlined shafts from off-site storage for further evaluation was possible. It was later learned that there is no record of the RSWDs being sent to storage. Therefore, the forms used for this report are all that is available at this time and no further recommendation is made.
- Conduct interviews with personnel knowledgeable about the physical form of the waste, chemical constituents, packaging, radiological data, and dose rates, for the 33 lined shafts, 6 unlined shafts, and the hot cell liner shafts.
- Calculate estimated gas generation rates based on the waste form and the radionuclides known to be present
- Prepare a field characterization plan for the 33 lined shafts, 5 hot cell liner shafts, and 6 unlined shafts. Include surface dose rate determinations, swipes for surface contamination, flammable gas determinations, and physical status using visual examination of the shafts and containers inside the shafts
- Prepare a field characterization plan for the 16 canisters. Include surface dose rate determinations, swipes for surface contamination, flammable gas determinations, and physical status of the shafts and the canisters inside the shafts

- Assess historical engineering documentation for the tritium torpedo packaging configuration
- Calculate radiolysis calculations to estimate maximum pressure due to tritium radiolysis of any entrained water
- Assess molecular sieve design criteria and calculate the capacity
- Conduct interviews with cognizant personnel to determine if getters were placed in the waste containers
- Prepare a field characterization plan for the tritium torpedo shafts. Include surface contamination, flammable gas determinations, and physical status of the shafts and containers inside the shafts

9.0 REFERENCES

1. "Laboratory Organization," Los Alamos National Laboratory, http://www.lanl.gov/organization/
2. "The Los Alamos Plutonium Facility: A World Class Model," *Dateline: Los Alamos*, November-December, 1996.
3. "Chemistry and Metallurgy Research Building," Los Alamos National Laboratory Public Affairs Office, April 2004.
4. *Draft Feasibility Study for the Retrieval of Remote-Handled Transuranic Waste at Los Alamos National Laboratory*, prepared for Los Alamos National Laboratory by IT Corporation, Boissiere Engineering and Applied Robotics, Inc., and Roy F. Weston, Inc., September 1997.
5. TRU Waste Management Database. Los Alamos National Laboratory.
6. Radioactive Solid Waste Disposal (RSWDs), Form HS 10-2A (12/89) (33 lined shafts and hot cell liners).
7. *CCP Acceptable Knowledge Summary Report for RH TRU Debris Waste Packaged from January 31, 1986 to June 5, 1991*, Revision 0, Draft A, Los Alamos National Laboratory, Los Alamos, NM, 2003.
8. TRU Waste Storage Records, Form 1562 (tritium torpedoes and canisters).
9. R.E. Wieneke (NMT-2, LANL) Memorandum to D.P. Taggert (EM-7, LANL), "Packaging Agreement for Tritium Contaminated Transuranic Waste from TA-55," August 23, 1993.
10. Jene Vance, Vance and Associates, Excel spreadsheet.
11. 10 CFR 71, Packaging and Transportation of Radioactive Material, Appendix A, Table A-1, "A1 and A2 Values for Radionuclides."
12. Central Characterization Project, *Los Alamos National Laboratory Pu-239 Contaminated Mixed Heterogeneous Debris*, CCP-AK-LANL-006, Revision 2, Carlsbad, NM.
13. TransOrigen.xls, Version 1.0, a Pre-Post-Processor for the ORIGEN2, Version 2.2 Software, An Excel Spreadsheet Application, prepared by Weston Solutions, Inc. for Los Alamos National Laboratory.

14. Weston Solutions, Inc., *Calculation Report, TransOrigen.xls, Version 1.0, a Pre-Post-Processor for the ORIGEN2, Version 2.2 Software, An Excel Spreadsheet Application*, Version 1.00, prepared for Los Alamos National Laboratory, September 30, 2005.

15. VECTRA Technologies, Inc. Safety Analysis Report for the RH-TRU 72-B Waste Shipping Package, San Jose, California, 1999.

16. R. Villarreal, L. Field, L. Bustos, W. Sandoval, K. Hollis (LANL), and S. Djordjevic (DJINDECO Consulting), *Headspace Gas Sampling of Remote-Handled Transuranic Waste Containers at Los Alamos National Laboratory Fiscal Year 2000 Year-End Status Report*, Los Alamos National Laboratory, September 2000.

17. *CCP Remote-Handled TRU Waste Certification Plan*, CCP-PO-020, Revision 0, Draft B, September xx, 2003.

18. *CCP Qualification of Acceptable Knowledge for RH TRU Waste through a Quality Assurance Equivalency Demonstration*, CCP-QP-036, Revision 0, Draft A, xx/xx/2003.

19. *CCP Los Alamos National Laboratory Quality Assurance Equivalency Summary Report and QAPD Matrix for Remote-Handled TRU Debris Waste*, CCP-AK-LANL-003, Revision 0, October xx, 2003.

20. *Radiological Characterization of LANL RH TRU Waste Packaged in 16 WIPP Canisters*, CCP-AK-LANL-002, Revision 0, xx/xx/03.

21. DOE, *Remote-Handled TRU Waste Characterization Program Implementation Plan*, DOE/WIPP-02-3214, Revision 0D (Subject to Approval), Carlsbad Field Office, October 30, 2003.