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ACRONYMS AND ABBREVIATIONS

AMAD	activity median aerodynamic diameter
AVLIS	Atomic Vapor Laser Isotope Separation
CEDE	committed effective dose equivalent
CFR	Code of Federal Regulations
dpm	disintegrations per minute
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
F	fast (solubility rate)
HEPA	high-efficiency particulate air (filter)
HEU	highly enriched uranium
HPGe	hyperpure germanium
ICP-MS	inductively coupled plasma-mass spectroscopy
ICRP	International Commission on Radiological Protection
IRF	intake retention fraction
KPA	kinetic phosphorescence analysis
LINAC	linear accelerator
LLNL	Lawrence Livermore National Laboratory
LSC	liquid scintillation counting
M	moderate (solubility rate)
MDA	minimum detectable amount
MDC	minimum detectable concentration
M&E	Mechanical and Electrical (Engineering Divisions)
MFP	mixed fission products
NESHAP	National Emission Standard for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health
R&D	Research and Development
S	slow (solubility rate)
TEDE	total effective dose equivalent
TRU	transuranic
U.S.C.	United States Code
WB	whole-body

5.1 INTRODUCTION

Site Profiles, which include Technical basis documents (TBDs), are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised when additional relevant information is obtained about the affected site(s). These documents may be used to assist the NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384l (5) and (12)). EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)." 42 U.S.C. § 7384l(12). Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For DOE employees with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision (42 U.S.C. § 7384n(b)) says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the [probability of causation] guidelines established under subsection (c) ..." 42 U.S.C. § 7384n(b). Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program." 42 U.S.C. § 7384l(12). While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer (i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty") does not contain such an exclusion. Therefore, the statute requires NIOSH to include all radiation exposures in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

This Site Profile documents historical practices at the Lawrence Livermore National Laboratory (LLNL) and provides information for the evaluation of internal and external dosimetry data for unmonitored and monitored workers; it can serve as a supplement to, or substitute for, individual monitoring data.

This document provides a uniform and consistent approach to assessing occupational internal dose at the Lawrence Livermore National Laboratory (LLNL) for dose reconstructions for NIOSH in relation to the EEOICPA. It provides guidance to dose reconstructors on input parameters that are specific to

LLNL employees, as well as the approach for employees with either missing or no monitoring information.

LLNL workers handled a variety of radionuclides as part of their routine work. The key elements in the source term were plutonium and tritium, although others were used at various times and in various forms. For the purposes of dose reconstruction it can be assumed that internal source terms were introduced at LLNL's inception on September 2, 1952.

Prior to the early 1960s, the only methodology that LLNL used to monitor employees for intakes of radionuclides at LLNL was urine bioassay, with the primary focus on excreted tritium. It is not clear when bioassay monitoring first began, but it continues to this day for plutonium, americium, uranium, mixed fission products, a variety of tracer radionuclides, iodine, and tritium (Mansfield 2000). Air monitoring in workplaces and in the breathing zones of employees has been a common surveillance method. However, LLNL apparently did not use the data acquired through that program, which are not readily associated with individual exposures, to prepare the dose of record for employees.

In vivo methodologies began on an investigational basis in 1964, focused on high-energy (i.e., greater-than-200-keV) gamma emitters. In the 1970s, there were attempts to detect low-energy photon emitters (i.e., 60-keV gammas from the decay of ^{241}Am and even plutonium L-shell X-rays). LLNL can provide a broad spectrum of *in vivo* counting services with varying degrees of detectability (Mansfield 2000).

From at least the late 1980s (and possibly before), action levels were based on the amount of radionuclide excreted or detected in the whole body (Mansfield 1989). Later, assessments of intakes and even doses were based on *in vivo* and *in vitro* monitoring results, using computer programs developed by LLNL (Mansfield 2000). Both *in vivo* and *in vitro* analysis data records and associated interpretations exist from the 1960s and appear to be retrievable.

A review of in-house procedures used to assess the concentration of radioactivity in urine indicates that quality control steps were an integral part of the process (LLNL 1979). For example, LLNL ran duplicates consistently, and comparisons of results to "known quantities" were a critical step. Therefore, *in vitro* results from in-house processing are generally reliable. However, interpretation of those results can be difficult, primarily because they might not have considered the contribution of environmental radioactivity (i.e., uranium, thorium). Because sample collection could have occurred at work (e.g., "in-field" tritium analyses, Monday morning urines), cross-contamination could be an issue.[1]

Nevertheless, dose reconstructors can prepare reasonably reliable, yet conservative (i.e., designed to maximize the resulting dose) estimates of dose for claimants by simply knowing the dates of employment, the claimant's work locations, and *in vivo* and *in vitro* bioassay results. Other variables, such as particle sizes and clearance classes can be readily reconstructed from historical records. This document includes guidance on selecting source terms, interpreting *in vivo* and *in vitro* measurement results, and instructions for assessing dose for monitored and unmonitored claimants. The information in this document will be updated as new data, information, and reports become available.

[1] Twenty-four-hour collections typically took place at the employee's home on weekends. However, spot samples were often collected in site restrooms (Mansfield 1989).

5.2 SOURCE TERM

The primary LLNL missions have been weapons research and development, controlled nuclear weapons research, peaceful uses of nuclear explosives, biomedical research, and laser fusion research. In addition, work in non-nuclear technologies and materials testing has been ongoing since at least 1976 (LLNL 1977).

If information on the source term to which the claimant has been exposed is available, dose reconstructors should use that source term. However, if no source term information is available, the values and parameters in Table 5-1 provide conservative input to the assessment process.

Unless site-specific information is available, the particle size is assumed to be 5-µm activity median aerodynamic diameter (AMAD), as recommended in ICRP (1994, paragraph 5).

If a monitoring result refers to "weapons grade plutonium," dose reconstructors can use the isotopic mix listed in Table 5-2 for material aging times (Mansfield 2000).

If a monitoring result refers to "uranium," dose reconstructors can use the isotopic mix listed in Table 5-3 for enrichment levels (Mansfield 2000).

5.3 MEASUREMENT METHODS

In vivo measurement methods began at the site as far back as 1964, when LLNL used sodium iodide detectors connected to simple multichannel analyzers to evaluate ^{40}K and fission products in humans. In 1964, a scanning bed, referred to as the "RIDL," was in use at LLNL. This device was a shadow shield counter equipped with a 3-in. by 2-in. sodium iodide detector for detection and quantification of relatively high (i.e., greater than 200 keV) gamma photons. It had some capability for locating the source of radionuclide deposition in subjects. This device was calibrated with a water tank phantom spiked with ^{137}Cs and ^{40}K (Anderson 1964).

Whole-body counting using a shadow shield counter began in the early 1960s. In April 1965, thin crystal studies began (LLNL 1965). In 1965 and 1966, LLNL identified ^{65}Zn in people working in Building 153, which dominated the study types at that time (Anderson 1964).

LLNL began using dual thin crystals in May 1966 to identify and quantify low-energy photon emitters in the chests of workers (Shapiro 1973). In November 1966, Koch hardware that used a 5-in. by

Table 5-1. Source term by building.[a]

(Current) building no.	Building activity	Radionuclide[b]	Activity fraction
131	M&E Divisions	Th-232	2.29E-10
		U-234	8.47E-02
		U-235	1.18E-02
		U-238	9.04E-01
132	Analytical & Nuclear Chemistry Laboratories; Forensic Sciences Center	Th-228	1.2E-10
		Th-230	3.5E-10
		Th-232	7.9E-05
		U-234	3.1E-04
		U-235	7.2E-03
		U-238	9.9E-01
		Pu-238	4.4E-03
		Pu-239	6.7E-06
		Pu-240	1.7E-06
		Pu-241	1.6E-05
		Pu-242	2.0E-10
		Am-241	3.1E-07
151	Isotope Sciences, Environmental Services Laboratory	Ni-63	1.1E-01
		I-129	4.6E-10
		U-233	1.3E-07
		U-234	2.0E-03
		U-235	3.0E-04
		U-236	7.3E-06
		U-238	1.9E-02
		Np-237	8.9E-04
		Pu-236	5.3E-06
151	Isotope Sciences, Environmental Services Laboratory	Pu-238	2.0E-02
		Pu-239	1.7E-01
		Pu-240	3.8E-02
		Pu-241	6.1E-01
		Pu-242	9.5E-05
		Pu-244	5.1E-05
		Am-241	1.0E-02
		Am-243	7.6E-04
		Cm-242	5.1E-06
		Cm-244	1.5E-05
		Cm-246	1.2E-05
		Cm-248	8.0E-06
		Cf-249	1.5E-04
175	U-AVLIS	U-234	3.11E-01
		U-235	9.50E-03
		U-238	6.79E-01
177	U-AVLIS	U-234	3.05E-01
		U-235	1.04E-02
		U-238	6.85E-01
179		U-234	4.38E-01
		U-235	1.24E-01
		U-238	4.38E-01
212	Physics and Space (rotating target neutron source)	H-3	1
222		H-3	6.96E-01
		C-14	5.44E-10
		Ni-63	3.04E-01
		Th-232	6.86E-08
		U-234	2.84E-08
		U-235	1.25E-09
		U-238	7.13E-06
		Pu-239	6.53E-08
223		Pu-238	1.09E-02
		Pu-239	8.78E-01
		Am-241	1.25E-04
		Am-243	1.11E-01
226		H-3	1.00E+00
		U-238	9.67E-06

Table 5-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide[b]	Activity fraction
227		U-234	5.05E-01
		U-235	2.26E-02
		U-238	4.73E-01
231	Safeguards and engineering	Th-232	1.3E-02
		U-234	8.5E-02
		U-235	1.2E-02
		U-238	8.9E-01
235	Characterization studies and ion beam experiments	Th-232	4.0E-08
		U-234	2.7E-01
		U-235	1.6E-02
		U-238	6.7E-01
		Pu-238	3.0E-04
		Pu-239	1.1E-02
		Pu-240	2.5E-03
		Pu-241	2.9E-02
235	Characterization studies and ion beam experiments	Pu-242	1.7E-07
		Am-241	1.4E-03
241	R&D	C-14	2.1E-07
		P-32	8.7E-08
		Th-232	1.9E-12
		U-234	1.0E+00
		U-235	1.8E-06
		U-238	4.0E-05
251	Heavy element facility	U-233	6.58E-09
		Pu-238	2.17E-04
		Pu-239	5.54E-09
		Pu-243	1.45E-06
		Am-241	3.29E-01
		Cm-243	1.69E-01
		Cm-244	5.02E-01
		Cm-248	4.18E-05
		Cf-252	1.37E-05
253	Laboratories and counting rooms	H-3	1.1E-04
		C-14	1.0E-07
		P-32	1.0E-06
		Sr-90	5.5E-06
		Sr-90/Y-90	2.8E-08
		Y-90	3.7E-08
		Cs-137	1.4E-07
		Bi-214	3.3E-01
		Pb-214	3.3E-01
		Po-218	3.3E-01
		Ra-226	1.5E-02
		Th-230	2.0E-08
		U-234	3.7E-04
		U-235	1.6E-05
		U-238	3.5E-04
		Np-237	4.3E-08
		Pu-238	2.6E-06
		Pu-239	6.6E-05
		Pu-240	1.5E-05
		Pu-241	6.5E-04
		Pu-242	9.9E-10
		Am-241	3.1E-06

Table 5-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide[b]	Activity fraction
254	Bioassays and analytical services	H-3	4.4E-02
		C-14	1.4E-02
		P-32	4.0E-03
		P-33	4.0E-01
		S-35	4.1E-02
		Sr-90	9.9E-02
		Y-90	9.9E-02
		I-125	6.3E-02
		Po-209	2.6E-05
		Th-230	6.0E-03
		U-232	2.3E-04
		U-233	1.0E-05
		U-234	4.1E-04
		U-235	1.0E-05
		U-236	3.2E-03
		U-238	8.9E-07
		Pu-238	0.0E+00
		Pu-239	9.0E-05
		Pu-240	0.0E+00
		Pu-241	0.0E+00
		Pu-242	5.5E-04
		Np-237	4.4E-02
254	Bioassays and analytical services	Np-239	1.7E-01
		Am-241	3.2E-05
		Am-243	9.2E-04
		Cm-242	2.5E-04
		Cm-244	3.3E-04
		Cf-249	2.5E-04
		Cf-252	5.4E-03
255	Calibration laboratory	H-3	1.00E+00
281	Tracer and dissolution studies	H-3	3.7E-02
		Be-10	1.5E-02
		C-14	2.8E-01
		Cl-36	1.5E-02
		Ca-41	1.5E-01
		Ni-63	3.1E-01
		Sr-90	1.5E-02
		Th-232	1.1E-06
		U-233	1.9E-04
		U-234	1.9E-04
		U-235	8.1E-06
		U-238	1.8E-04
		U-233/U-238	1.9E-06
		Pu-239	6.3E-04
		Pu-242	2.0E-03
		Pu-244	2.4E-06
		Np-237	1.7E-01
		Am-241	5.4E-04
		Am-241/Np-237	1.4E-04
282	Residual contamination	H-3	1.0E+00
292	Residual contamination rotating target neutron source	H-3	1
298	Laser fusion program	H-3	9.9E-01
		U-234	4.1E-04
		U-235	1.9E-05
		U-238	6.0E-03
321	Milling and shaping	DU Thorium[c]	
321A	Milling and shaping	U-234	1.8E-01
		U-235	2.4E-02
		U-238	7.9E-01

Table 5-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide[b]	Activity fraction
321C	Milling, machining, and shaping	U-234	6.5E-01
		U-235	8.1E-03
		U-238	3.4E-01
322	M&E	U-234	8.1E-01
		U-235	1.2E-02
		U-238	1.8E-01
327	M&E	U-234	7.7E-02
		U-235	8.8E-02
		U-238	8.4E-01
331	Research and laboratories	H-3 (HTO)	4.69E-01
		H-3 (HT)	5.19E-01
		H-3	1.24E-02
332	Gloveboxes, HEPA filters	Pu-239 TRU	
341	Lasers Directorate	U-234	5.70E-02
		U-235	7.69E-03
		U-238	9.35E-01
361	R&D	H-3	5.6E-06
		C-14	3.3E-03
		P-32	8.3E-01
		P-33	1.1E-01
		S-35	5.4E-02
362	R&D	H-3	7.22E-01
		C-14	2.78E-01
363	R&D	H-3	9.99E-01
		C-14	1.11E-07
		P-32	1.42E-03
364	R&D	H-3	1.11E-03
		C-14	2.76E-03
		P-32	9.96E-01
365	R&D	H-3	4.04E-03
		C-14	9.96E-01
366	R&D	H-3	5.00E-01
		P-32	4.38E-01
		P-33	6.25E-02
377	R&D	H-3	7.66E-04
		C-14	3.83E-03
		P-32	9.95E-01
		Ni-63	1.15E-04
378		Co-57	1.44E-03
		Co-60	5.59E-02
		Sr-85	6.52E-02
		Cd-109	3.58E-02
		Cs-134	6.98E-01
		Cs-137	6.98E-02
		U-233	2.14E-04
		U-234	8.66E-07
		U-235	4.84E-08
		U-238	2.00E-06
		Pu-236	2.13E-03
		Pu-239	6.99E-05
		Pu-240	5.59E-05
		Pu-242	1.05E-02
378		Pu-244	3.58E-04
		Np-237	1.44E-06
		Am-241	6.00E-02
		Am-243	4.01E-04
381		H-3	1
391		H-3	1

Table 5-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide[b]	Activity fraction
412W		Ni-59	3.50E-07
		Ni-63	1.00E+00
446		C-14	1
513	Waste processing	H-3	9.85E-01
		U-233	1.52E-05
		U-234	1.08E-03
		U-235	1.52E-04
		U-238	1.04E-02
514	Waste processing	H-3	8.61E-01
514	Waste processing	C-14	2.40E-02
		P-32	6.53E-02
		Th-228	1.47E-05
		Th-229	6.04E-05
		Th-230	5.81E-05
		Th-232	7.87E-05
		U-232	6.08E-05
		U-233	7.01E-03
		U-234	3.60E-03
		U-235	2.18E-04
		U-236	8.92E-07
		U-237	1.82E-09
		U-238	8.29E-03
514	Waste processing	Pu-236	3.67E-08
		Pu-238	4.72E-04
		Pu-239	6.74E-03
		Pu-240	1.68E-03
		Pu-241	1.49E-04
		Pu-242	1.60E-04
		Pu-244	1.09E-06
		Np-237	6.77E-05
		Np-239	2.41E-06
		Am-241	4.23E-03
		Am-243	8.33E-05
		Cm-244	6.76E-05
		Cf-249	9.30E-06
514 Tank Farm		H-3	5.45E-01
		P-32	1.01E-01
		Sr-90	2.05E-01
		Cs-137	1.08E-01
612	Waste storage and repackaging	H-3	9.79E-01
612	Waste storage and repackaging	U-232	1.58E-05
		U-233	2.08E-05
		U-234	4.93E-04
		U-235	1.85E-04
		U-237	3.39E-08
		U-238	2.01E-03
612 Yard		H-3	1.00E+00
625	Waste operations	H-3	2.14E-01
		U-234	2.76E-01
		U-235	4.89E-01
		U-238	2.32E-03
		Pu-238	7.68E-05
		Pu-239	3.40E-03
		Pu-240	3.83E-06
		Pu-241	1.30E-02
		Pu-242	4.46E-08
		Am-241	2.87E-04
2561		U-234	5.00E-01
		U-238	5.00E-01
		U-234	8.01E-02
		U-235	1.12E-02
		U-238	8.66E-01
Site 300-801		H-3	1

Table 5-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide[b]	Activity fraction
Site 300 Pit 7		H-3	1
Site 300-810A		U-234	8.38E-02
		U-235	1.16E-02
		U-238	9.05E-01
Site 300-810B		U-234	8.47E-02
		U-235	1.13E-02
		U-238	9.04E-01
Site 300-850		H-3	9.6E-01
		U-234	3.2E-03
		U-235	4.4E-04
		U-238	3.4E-02
Site 300-851		H-3	9.57E-01
		U-234	9.57E-04
		U-235	1.34E-04
		U-238	1.02E-02
Site 300 Well 8 Spring		H-3	1

a. This table was derived from data reported for calendar years 1992 through 2001 as part of the National Emission Standards for Hazardous Air Pollutants (NESHAPs; 40 CFR Part 61, Subpart H) reporting process (LLNL 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003). As part of its required reporting under NESHAPs, LLNL must monitor emissions by radionuclide and total activity at all building release points. This table only lists buildings for which NESHAPS data was reported; this is not a complete list of all buildings. For a listing of major buildings and activities see Lawrence Livermore National Laboratory- Site Description (ORAU 2005.) While the emissions identified over the years might not be fully representative of the source term in each building, they do provide a reasonable basis, in the absence of claimant-specific monitoring results, for determining the types of radioactive materials to which employees might have been exposed. To develop the table, the isotopic listing of each building in the relevant NESHAPs reports was captured in a building-specific spreadsheet. The annual emissions were totaled for each isotope and then for all isotopes in the listing. Activity fractions were obtained by dividing the activity total by the "all isotopes" total (Berger 2005). The Activity fraction for each radionuclide in the table is that fraction of the total source term present (i.e., the sum of the fractions for each building is equal to "1" or 100% of the mixture). However, those radionuclides with Activity fractions equal to "zero", those with half-lives too short to contribute significant dose (i.e., isotopes of nitrogen and oxygen), and those that contribute submersion dose only were not included in this listing.

b. The list of isotopes was limited to those providing the principal activity or dose. A listing of all isotopes by building is included in Attachment A.

c. LLNL (1987a).

Table 5-2. Isotopic information for aging of weapons-grade plutonium.

Mixture Designation	Fresh	5-year	10-year	15-year	20-year	25-year	30-year
Years of Aging	**0**	**5**	10	15	20	25	30
Specific Activity in Mixture (Ci/g)							
^{238}Pu	6.85E-03	6.59E-03	6.33E-03	6.08E-03	5.85E-03	5.62E-03	5.40E-03
^{239}Pu	5.81E-02	5.81E-02	5.80E-02	5.80E-02	5.80E-02	5.80E-02	5.80E-02
^{240}Pu	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.36E-02	1.36E-02
^{241}Pu	5.98E-01	4.70E-01	3.69E-01	2.91E-01	2.28E-01	1.79E-01	1.41E-01
^{242}Pu	1.57E-06	1.57E-06	1.57E-06	1.57E-06	1.57E-06	1.57E-06	1.57E-06
^{241}Am	0.00E+00	4.24E-03	7.54E-03	1.01E-02	1.21E-02	1.36E-02	1.48E-02
$^{239+240}$Pu	7.18E-02	7.18E-02	7.17E-02	7.17E-02	7.17E-02	7.16E-02	7.16E-02
Pu-alpha	7.87E-02	7.84E-02	7.80E-02	7.78E-02	7.76E-02	7.72E-02	7.70E-02
Activity ratios							
$^{239+240}$Pu:^{241}Am	N/A	1.69E+01	9.51E+00	7.10E+00	5.93E+00	5.26E+00	4.84E+00
$^{239+240}$Pu:^{238}Pu	1.05E+01	1.09E+01	1.13E+01	1.18E+01	1.23E+01	1.27E+01	1.33E+01
Pu alpha:$^{239+240}$Pu	1.10E+00	1.09E+00	1.09E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00
Pu alpha:^{238}Pu	1.15E+01	1.19E+01	1.23E+01	1.28E+01	1.33E+01	1.37E+01	1.43E+01
^{241}Pu: Pu alpha	7.60E+00	6.00E+00	4.73E+00	3.74E+00	2.94E+00	2.32E+00	1.83E+00

1/16th-in. sodium iodide crystal was deployed. Design for the use of hyperpure germanium (HPGe) detectors began in August 1991, with deployment presumed shortly thereafter.

Table 5-3. Isotopic information for various uranium enrichment levels.

Mixture	Radionuclide	Mass fraction	Activity fraction	Specific activity of mix (Ci/g)
DU	U-238	9.975E-1	9.02E-1	3.72E-7
DU	U-235	2.50E-3	1.45E-2	3.72E-7
DU	U-234	5.00E-6	8.4-E-2	3.72E-7
U-Nat.	U-238	9.93E-1	4.77E-1	7.00E-7
U-Nat.	U-235	7.20E-3	2.23E-2	7.00E-7
U-Nat.	U-234	5.60E-5	5.00E-1	7.00E-7
AVLIS 5% Enriched	U-238	9.50E-1	4.11E-1	7.78E-7
AVLIS 5% Enriched	U-235	5.00E-2	1.39E-1	7.78E-7
AVLIS 5% Enriched	U-234	5.60E-5	4.50E-1	7.78E-7
95% HEU	U-238	3.96E-2	1.98E-4	6.27E-5
95% HEU	U-235	9.50E-1	3.06E-2	6.27E-5
95% HEU	U-234	1.04E-2	9.69E-1	6.27E-5

It is not clear whether whole-body or specific organ counting was performed with this technology for routine monitoring over the duration of LLNL history. It appears that few workers were sent for *in vivo* bioassay unless there was a workplace trigger (i.e., elevated airborne radionuclide concentrations or a spill/release); however, baseline and termination counts occurred as early as 1966 (LLNL 1966).

From at least 1966, *in vitro* measurement methods were in use, with routine monitoring occurring annually and semiannually during those early days. Building 331 had a monthly monitoring program in place. During weapons test support periods, routine sampling frequencies for involved employees appear to have been increased to quarterly, with weekly sampling for Building 331 (for tritium) and monthly sampling for Building 251 (LLNL 1966). Around the mid-1980s, the monitoring frequency appears to have been dictated by workplace supervisors (Mansfield 1989, p. 9).

Employees involved in weapons testing at the Nevada Test Site, the Pacific proving grounds, and in Colorado were presumably monitored for internal radiation exposures. However, the monitoring method, frequency, and detection capabilities have not been determined.

Bioassays were supplemented with workplace and/or personal breathing zone airborne monitoring (Mansfield 1989, p. 10). In addition, nasal smears were collected after incidents as a means of assessing intake potential. However, data from nasal smears apparently were not used as input to dose assessments. Nonetheless, the dose reconstructor might come across some of these data in claimant dosimetry records (Mansfield 1989, Appendix A).

Table 5-4, compiled from a variety of LLNL documents (cited in the table footnote), lists *in vivo* and *in vitro* sampling frequencies for various employment periods. In the case of *in vitro* methods, sample sizes may have been “spot” (single void), 24-hour collections, or simulated 24-hour collections, with creatinine corrections performed if the results were indicative of “significant” intakes (Mansfield 2000).

5.3.1 Measurement Types and Detection Levels

A variety of program documents reference detection levels for the various *in vivo* and *in vitro* bioassay methods. These methods are listed in Table 5-5, and the documents are cited in the table footnote.

Table 5-4. *In vivo* and *in vitro* sampling frequencies.

Routine monitoring method	Measurement type	Radionuclide	Period	Building	Frequency
In vitro	Urine	Pu	2000 - present	Site-wide	Semiannual
In vivo	Lung count	Am, Pu	1970 - present	Site-wide	Annual
In vivo	Lung	Weapons-grade Pu	1989[a]	Site-Wide	Annual
In vitro	Urine	Weapons-grade Pu	1989[a]	Site-Wide	Semiannual
In vitro	Urine	U	1980[a]	231	Quarterly
In vitro	Urine	U	1983[a]	251	Quarterly
In vitro	Urine	U	2000 - present	Site-wide	Quarterly, monthly
In vivo	Lung count	U	1985[a]	Site 300	Annual
In vitro	Urine	U	1985[a]	Site 300	Semiannual (collected on Mondays)
In vivo	Lung count	U, Th	2000 - present	Site-wide	Annual, semiannual
In vivo	Lung count	U, Th	1987	Bldg. 321	Annual
In vitro	Urine	Gross alpha, beta (LSC)	2000 - present	Site-wide	As applicable
In vivo	WB scans	MFP	1964 - present		
In vivo	WB scans		2000 - present	Site-wide	Annual
In vitro	Urine	TRU	2000 - present	Site-wide	Annual, semiannual
In vitro	Urine	P-32, C-14 (LSC)	2000 - present	Site-wide	As applicable
In vivo	Thyroid count	I-131	2000 - present	Site-wide	Coordinated with work schedule
In vivo	Thyroid	I-131	1989[a]	Site-Wide	Monthly
In vitro	Urine	Not Specified	1966[a]	101	Quarterly, annual
In vitro	Urine	Not Specified	1966[a]	102	Annual
In vitro	Urine	Not Specified	1966[a]	110	Annual
In vitro	Urine	Not Specified	1966[a]	112	Annual
In vitro	Urine	Not Specified	1966[a]	114C	Annual
In vitro	Urine	Not Specified	1966[a]	117	Quarterly, annual
In vitro	Urine	Not Specified	1966[a]	121	Semiannual
In vitro	Urine	Not Specified	1966[a]	125	Semiannual
In vitro	Urine	Not Specified	1966[a]	127	Semiannual
In vitro	Urine	Not Specified	1966[a]	170	Annual
In vitro	Urine	Not Specified	1966[a]	171	Annual
In vitro	Urine	Not Specified	1966[a]	172	Weekly, monthly
In vitro	Urine	Not Specified	1966[a]	173B	Annual
In vitro	Urine	Not Specified	1966[a]	190	Semiannual, monthly
In vitro	Urine	Not Specified	1966[a]	193	Annual
In vitro	Urine	P-32	1989[a]	Site-Wide	Monthly
In vitro	Urine	HTO	2000 - present	Site-wide	Quarterly, monthly, biweekly, or weekly
In vitro	Urine	HTO	1989[a]	Site-Wide	Weekly, monthly
In vitro	Urine	N-13	1980[a]	151	Weekly, monthly
In vitro	Urine	O-15	1980[a]	151	Weekly, monthly
In vitro	Urine	Ar-37	1980[a]	151	Weekly, monthly
In vitro	Urine	Kr-85	1980[a]	151	Weekly, monthly
In vivo	Wound	Pu-239	1961 - present		PRN

a. Periods shown as a single year were taken from annual reports which did not indicate a beginning date for the stated bioassay period.
Sources: Mansfield 2000, LLNL 1966 Appendix A; Ozaki 1980; Wilson 1982; Leahy 1983; UC (1961, 1964); Gibson 1985; LLNL 1987b.

In some cases, there is evidence that monitoring by a particular methodology was implemented at LLNL, but site-specific detection levels for that methodology were not available. In these cases, detection levels for comparable Los Alamos National Laboratory (LANL) methods were used to complete Table 5-5 because there is evidence of interlaboratory communications on analytical methods over the years, and because both LLNL and LANL were operated by the same contractor at those times, thus further increasing the likelihood for shared procedures (Berger 2005).

In a few instances, neither LLNL nor LANL detection levels were available, thus requiring a surrogate source of information. The ICRP, in Publication 54, specified nominal detection levels for a variety of measurement methods that were comparable to those used at LLNL (ICRP 1988). This industry-

Table 5-5. Bioassay detection levels.

Routine monitoring method	Measurement type	Analysis method	Radionuclide	Period	MDA
In vitro	Urine	Aluminum nitrate/NTA *	Pu-total alpha	1957-1965	0.03 pCi/24-h sample
In vitro	Urine	Zinc Sulfate counting *	Pu-total alpha	1966	0.03 pCi/24-h sample
In vitro	Urine	PHA *	Pu-239, 238	1967-1987	0.03 pCi/24-h sample
In vitro	Urine	24-hr sample, alpha spec	"Pure" Pu	2000 - present	0.01 dpm
In vitro	Urine	24-hr sample, alpha spec	Weapons-grade Pu	2000 - present	0.01 dpm
In vivo	Lung	Phoswich**	Pu-239, Am-241	1970 - present	20, 0.5 nanocuries
In vivo	Lung	Dual Phoswich	Pu-239	1980 - present	>16.3 nCi (2.1 cm CWT)
In vivo	Lung	HPGe arrays	"Pure" Pu-239	2000 - present	200 nCi
In vivo	Lung	HPGe arrays	"Pure" Pu-238	2000 - present	150 nCi
In vivo	Lung	HPGe arrays (Am-241)	Weapons-grade Pu	2000 - present	0.15 nCi
In vitro	Urine	Chemical extraction with proportional counting *	Am-241	1958-1982	0.2 pCi/24-hr
In vitro	Urine	Co-precipitation and alpha spec *	Am-241	1983-1989	0.015 pCi/24-hr sample
In vivo	Lung	HPGe arrays	Am-241	2000 - present	0.15 nCi
In vitro	Urine	24-hr sample, alpha spec	Am-241	2000 - present	0.01 dpm
In vitro	Urine	Fluorophotometric *	DU, Natural U	1949-1976	4 microgram/liter
In vitro	Urine	Fluorophotometric *	DU, Natural U	1976-1978	1 microgram/liter
In vitro	Urine	Delayed Neutron activation analysis *	U-238/U-235	1978-1982	1 microgram per liter
In vitro	Urine	Anion exchange *	DU, Natural U	1982-1987	1 microgram/50 cm3
In vitro	Urine	Spot sample KPA	DU	1987 - 1999	0.04 µg/L
In vitro	Urine	Spot sample KPA	Natural U	1987 - 1999	0.04 µg/L
In vitro	Urine	Spot sample KPA	AVLIS U	1987 - 1999	0.04 µg/L
In vitro	Urine	Alpha spectrometry**	95% U	1987 - 1999	0.3 picocurie/liter
In vitro	Urine	Spot Sample ICP-MS	U	2000 - present	0.002 micrograms
In vivo	Lung	HPGe arrays	DU, natural U	2000 - present	1 nCi
In vivo	Lung	HPGe arrays	AVLIS U, Th, U-235	2000 - present	1 nCi
In vivo	Lung	HPGe arrays	40% U, 95% U	2000 - present	0.1 nCi
In vitro	Urine	TRU-spec column with alpha spectroscopy	Th-232, Th-228	1989-present	0.2 dpm/sample (with Th-232 being equivalent to Th-228)
In vivo	WB Scan	--	Th-232	1970-present	1 nCi (based on Tl-208 with no correction for branching ratio)
In vivo	WB scan	--	Natural Th (Tl-208)	2000 - present	1 nCi
In vitro	Urine	24-hr sample, alpha spec	Cm-244	2000 - present	0.01 dpm
In vivo	Lung	HPGe arrays	Cm-244	2000 - present	100 nCi
In vitro	Urine	24-hr sample, alpha spec	Np-237	2000 - present	0.01 dpm
In vivo	Lung	HPGe arrays	Np-237	2000 - present	0.35 nCi
In vivo	Lung	HPGe arrays	Pa-233	2000 - present	1 nCi
In vitro	Urine	Extraction and gross alpha*	Po-210	1954-1999	0.1 picocurie/liter
In vitro	Urine	24-hr sample, alpha spec	Po-210	2000 - present	0.01 dpm
In vitro	Urine	GM counting *	HTO	1952-1958	1 microcurie/liter
In vitro	Urine	Internal GM counting *	HTO	1958-1968	1 microcurie/liter
In vitro	Urine	Liquid scintillation *	HTO	1969-2000	0.02 microcurie/liter-
In vitro	Urine	Liquid scintillation	HTO	2000 - present	0.01 µCi/L
In vitro	Urine	Gross beta *	Sr-90	1960-1999	See Sr-90 by in-vivo bremsstrahlung for 1970 to 1999; rest 1 picocurie/liter
In vitro	Urine	Gross beta and chemical extraction**	Sr-90	2000 - present	11 picocuries/liter
In vitro	Urine	Gross beta **	C-14	1966-1999	108 picocuries per liter
In vitro	Urine	Liquid scintillation	C-14	2000 - present	0.002 µCi/L
In vitro	Urine	Gross Beta **	I-125, I-131, S-35	1960-1999	100 picocuries per liter
In vitro	Urine	Liquid scintillation	I-125, I-131, S-35	2000 - present	0.002 µCi/L
In vivo	Thyroid count	--	I-131	2000 - present	0.01 nCi
In vivo	WB scan	--	I-131 (TB)	1970 - present	1 nCi
In vivo	Thyroid count	--	I-125	2000 - present	0.02 nCi
In vitro	Urine	Not specified *	P-32	<1975-1983	40 picocuries/L

Table 5-5 (Continued). Bioassay detection levels.

Routine monitoring method	Measurement type	Analysis method	Radionuclide	Period	MDA
In vitro	Urine	Liquid scintillation	P-32, P-33	2000 - present	0.002 µCi/L
In vivo	WB scan	Shadow shield counter	150- to 300-keV gamma emitters	1964 - present	500 gammas per second between 150 and 300 keV
In vivo	WB scan	Shadow shield counter	K-40	1964 – present	150 g K in 20 min (~120 nCi K-40)
In vivo	WB scan	--	Cs-137	1970 - present	1 nCi
In vivo	WB scan	--	Co-60	1970 - present	1 nCi
In vivo	WB scan	--	Ce-144	1970 - present	8 nCi
In vivo	WB scan	--	Ce-141	1970 - present	2 nCi
In vivo	WB scan	--	Ru-103	1970 - present	3 nCi
In vivo	WB scan	--	Ru-106	1970 - present	5 nCi
In vivo	WB scan	--	Zr-95	1970 - present	1 nCi
In vivo	WB scan	--	Mn-54	1970 - present	1 nCi
In vivo	WB scan	--	Zn-65	1970 - present	1 nCi
In vivo	WB scan	--	Na-22	1970 - present	1 nCi

Sources: Mansfield 2000; UC 1964; LRL 1970; Griffith 1980; Berger 2005; Argall 2004..
* Based on LANL information
** Based on ICRP 54 information

standard and peer-reviewed source of information was used to complete Table 5-5 pending future discovery of either LLNL- or LANL-specific replacement information.

The expected intake pattern in most cases is acute intake. At LLNL, airborne and surface contamination was typically controlled to prevent intakes so most intakes would have been the result of unexpected releases. Small intermittent releases could have occurred that were not immediately detectable, so an individual could have had multiple acute intakes.

5.3.2 Reporting Formats and Codes

A variety of codes occur on urine bioassay records generated at or for the LLNL. Table 5-6 is a summary of the codes known at the present time, along with their interpretation.

Table 5-6. Bioassay record codes.

Column no.	Type of entry	Acceptable entries
1 - 6	Employee number	6-digit integer
8 - 27	Employee name	Last name, comma, other names and/or initials
28 - 32	Nuclide analyzed	MFP, ALPHA, PU239, PU238, U238, AM241, CM244, or other nuclides (maximum of 5 characters)
34 - 39	Date	Month, day, year (2 digits each)
41 - 48	Results	Floating point number between 9999999. and 0.000 (F8.3 format)
50 - 51	Error	One standard deviation as a percentage of the result
53	Sample type	U = urine, B = blood, f = feces, n = nose swipe
55	Sample type	R = routine; S = special
57 - 60	Address	Building or trailer number, e.g., B253 or 2532
61 - 63	L code	3-digit L code
65	Frequency	W = weekly; M = monthly; Q = quarterly; S-semiannually; A = annually
67 - 70	Location of exposure	Building number, e.g., B253
72 - 76	Analysis number	Integer value of analysis number assigned to given sample by Bioassay Laboratory
79 - 80	Method	Analytical method used to process the samples: 1 = gross alpha technique (since 1957); 2 = gross beta technique (since 1974); 3 = plutonium separation technique (since 1963); 4 = fluorometric uranium technique (since 1974); 5 – 99 = reserved for future revised techniques

The practice of offsite collection of samples, which takes place approximately 24 to 48 hours after leaving the site, not only minimizes the possibility of sample cross-contamination, but also ensures sample collection after the transfer of the rapid clearance component. Some LLNL employees might have been asked to submit samples *after* 1 or 2 days off from work; there could be notation of that instruction on the analytical record.

LLNL typically collected urine samples in the workplace, usually on a Wednesday. Therefore, contamination of samples from the worker's hands or clothing cannot be ruled out as a contributor to any given result. If a second analysis was performed and if that result was "negative," sample cross-contamination could have been likely during the first.

For in vitro uranium bioassays, a mean background excretion rate for area residents of 0.019 +/- 0.047 (one standard deviation) micrograms per day (males and females) may be used (Mansfield 2000).

If a data set shows an unusually high urinalysis result for a given radionuclide, and if follow-up samples were not consistent with the high result, dose reconstructors can consider the high result an outlier and disregard it. However, if the result is not obviously an outlier, it is claimant-favorable to assume the result is real.

Uncertainties associated with bioassay measurements were not stated in the records.

5.3.3 Assessment of Intake for Unmonitored Claimants

The *in vivo* bioassay sampling program at LLNL was extensive, and there was clear direction to supervisors on individual employee participation in the program. However, there is evidence that participation was not always enforced. Therefore, a means of assessing intake for unmonitored claimants is necessary. There is little correlation between external dosimetry and the bioassay program. From the mid-1950's external dosimetry was administered as a site-wide requirement whereas bioassay was determined by facility supervisors.

For monitored claimants, the omission of regularly scheduled bioassays from the data set will, if interpreted as described in *Internal Dose Reconstruction Implementation Guide* (NIOSH, 2002), result in claimant-favorable assessments of intake.

5.4 SIGNIFICANT INCIDENTS WITH INTERNAL DOSE POTENTIAL

During operations at LLNL, a number of incidents increased the potential for intakes of radioactive materials. If a claimant recalls involvement in one or more of those incidents, dose reconstructors can use the information in Table 5-7 as input to an incident-specific assessment. This list is not all encompassing, many other incidents probably occurred; these are the incidents identified from review of the data capture records. Individual claimant records may provide documentation of involvement in other incidents.

Table 5-7. Input parameters for significant incidents.

Incident date	Incident description	Facility	Other information
March 26, 1963	Criticality	Bldg. 110	Potential for internal and external exposure (iodine, krypton, xenon); monitored participants listed by name in 1963 reference (see below)
November 6, 1975	Radium contamination	Bldg. 343, Rm. 1005	Crystal was removed from radium dial, resulting in spread of contamination
November 23, 1971	Plutonium-contaminated squib valve	Bldg. 343	Direct and indirect bioassays performed on 14 individuals

Sources: Unknown 1963a,b; Leahy 1975; AEC 1971.

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Wilson, R. L., *Establishing Criteria for Routine Uranium Bioassay in Building 231*, memorandum to Distribution, Lawrence Livermore National Laboratory, Livermore, California, November 2.

GLOSSARY

activity median aerodynamic diameter (AMAD)
The diameter of a unit density sphere with the same terminal settling velocity in air as that of the aerosol particle whose activity is the median for the entire aerosol.

acute
Pertaining to intakes received "acutely," i.e., within a short period.

bioassay
Measurement of amount or concentration of radioactive material either in the body or in biological material excreted or removed from the body. Another word for *radiobioassay*.

bioassay procedure
A procedure used to determine the kind, quantity, location, and retention of radionuclides in the body by direct (*in vivo*) measurements or by *in vitro* analysis of material excreted or removed from the body.

body burden
The quantity of radioactive material contained in the individual's body at a particular point in time.

chronic
Pertaining to low-level intakes received on a prolonged basis.

dose
A general term for absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent.

dose equivalent (H)
The product of absorbed dose (D) in rad (or gray) in tissue, a quality factor (Q), and other modifying factors (N). Dose equivalent is expressed in units of rem (or sievert) (1 rem = 0.01 sievert).

exposure
The general condition of being subjected to ionizing radiation, such as by exposure to ionizing radiation from external sources or to ionizing radiation sources inside the body. In this document, exposure does not refer to the radiological physics concept of charge liberated per unit mass of air.

intake
The amount of radionuclide taken into the body by inhalation, absorption through intact skin, injection, ingestion, or through wounds. Depending on the radionuclide involved, intakes can be reported in units of mass, activity, or potential alpha energy.

internal dose or exposure
The dose equivalent received from radioactive material taken into the body (i.e., internal sources).

internal dose assessment
An assessment of the intake and associated internal radiation dose to workers based on measurements taken in the work environment or from individual bioassay measurements.

***in vitro* measurement**
Measurements to determine the presence of or to estimate the amount of radioactive material in the excreta or in other biological materials removed from the body.

***in vivo* measurement**
The measurement of radioactive material in the human body utilizing instrumentation that detects radiation emitted from the radioactive material in the body.

lung solubility type (F, M, or S)
A classification scheme for inhaled material according to its rate of clearance from the pulmonary region of the lung.

minimum detectable amount (MDA)
The smallest amount (activity or mass) of an analyte in a sample that will be detected with a probability of nondetection (Type II error) while accepting a probability of erroneously deciding that a positive (non-zero) quantity of analyte is present in an appropriate blank sample (Type I error).

minimum detectable concentration (MDC)
The minimum detectable amount, MDA, expressed in units of concentration.

monitoring (personnel)
The measurement of radioactivity in the whole body, in a region of the body, in material eliminated from the body or in the air for reasons related to the estimation of intake of radioactive material. The term *monitoring* includes interpretation of the measurements.

occupational dose
An individual's ionizing radiation dose (external and internal) resulting from that individual's work assignment. Occupational dose does not include doses received as a medical patient or doses resulting from background radiation or participation as a subject in medical research programs.

radiation
Ionizing radiation: alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Radiation, as used in this document, does not include nonionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light.

rem
A special unit for dose equivalent. One rem is equal to 0.01 sievert.

routine monitoring
Monitoring carried out at regular intervals during normal operations.

sievert
The special name for the International System unit of dose equivalent. One sievert equals 1 joule per kilogram, which equals 100 rem.

special monitoring

Monitoring carried out in actual or suspected abnormal conditions (i.e., measurements performed to estimate the amount of radionuclide deposited in a person when an intake is known or is suspected to have occurred).

spot sample

A single void of urine.

ATTACHMENT A
SOURCE TERM BY BUILDING
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Table A-1. Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
131	M&E Divisions	Th-232	2.29E-10
		U-234	8.47E-02
		U-235	1.18E-02
		U-238	9.04E-01
132	Analytical & Nuclear Chemistry Laboratories; Forensic Sciences Center	H-3	7.3E-09
		Co-60	1.5E-07
		Th-228	1.2E-10
		Th-230	3.5E-10
		Th-232	7.9E-05
		U-234	3.1E-04
		U-235	7.2E-03
		U-238	9.9E-01
		Pu-238	4.4E-03
		Pu-239	6.7E-06
		Pu-240	1.7E-06
		Pu-241	1.6E-05
		Pu-242	2.0E-10
		Am-241	3.1E-07
		Ni-63	1.1E-01
		Zn-65	5.1E-07
		Sr-90	3.8E-05
		Y-90	3.7E-06
		Tc-99	1.3E-10
		Tc-99m	5.3E-08
		Ru-106	4.6E-09
		Sn-113	1.4E-07
		Sb-125	1.6E-06
		I-129	4.6E-10
		Ba-133	5.1E-08
		Cs-134	5.1E-08
		Cs-136	7.1E-07
		Cs-137	9.5E-05
		Ce-144	8.0E-07
		Pm-147	7.6E-05
		Eu-152	6.5E-08
		Eu-154	6.5E-08
		Eu-155	1.6E-12
		Bi-207	4.2E-05
		Po-209	1.9E-12
		Ra-226	2.5E-08
		Pa-231	2.7E-07
		Th-228	1.4E-09
		Th-229	2.2E-12
		Th-230	1.5E-09
		Th-232	6.4E-08
		U-232	2.7E-11
		U-233	1.3E-07
		U-234	2.0E-03
		U-235	3.0E-04
		U-236	7.3E-06
		U-238	1.9E-02
		Np-237	8.9E-04
		Pu-236	5.3E-06

ATTACHMENT A
SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
151	Isotope Sciences, Environmental Services Laboratory	Pu-238	2.0E-02
		Pu-239	1.7E-01
		Pu-240	3.8E-02
		Pu-241	6.1E-01
		Pu-242	9.5E-05
		Pu-244	5.1E-05
		Am-241	1.0E-02
		Am-243	7.6E-04
		Cm-242	5.1E-06
		Cm-244	1.5E-05
		Cm-246	1.2E-05
		Cm-248	8.0E-06
		Cf-249	1.5E-04
175	U-AVLIS	U-234	3.11E-01
		U-235	9.50E-03
		U-238	6.79E-01
177	U-AVLIS	U-234	3.05E-01
		U-235	1.04E-02
		U-238	6.85E-01
179		U-234	4.38E-01
		U-235	1.24E-01
		U-238	4.38E-01
212	Physics and Space (rotating target neutron source)	H-3	1
222		H-3	6.96E-01
		C-14	5.44E-10
		Ni-63	3.04E-01
		Th-232	6.86E-08
		U-234	2.84E-08
		U-235	1.25E-09
		U-238	7.13E-06
		Pu-239	6.53E-08
223		Pu-238	1.09E-02
		Pu-239	8.78E-01
		Am-241	1.25E-04
		Am-243	1.11E-01
226		H-3	1.00E+00
		U-238	9.67E-06
227		U-234	5.05E-01
		U-235	2.26E-02
		U-238	4.73E-01
231	Safeguards and engineering	Th-232	1.3E-02
		U-234	8.5E-02
		U-235	1.2E-02
		U-238	8.9E-01
235	Characterization studies and ion beam experiments	Th-232	4.0E-08
		U-234	2.7E-01
		U-235	1.6E-02
		U-238	6.7E-01
		Pu-238	3.0E-04
		Pu-239	1.1E-02
		Pu-240	2.5E-03
		Pu-241	2.9E-02

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SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
235	Characterization studies and ion beam experiments	Pu-242	1.7E-07
		Am-241	1.4E-03
241	R&D	C-14	2.1E-07
		P-32	8.7E-08
		Th-232	1.9E-12
		U-234	1.0E+00
		U-235	1.8E-06
		U-238	4.0E-05
251	Heavy element facility	U-233	6.58E-09
		Pu-238	2.17E-04
		Pu-239	5.54E-09
		Pu-243	1.45E-06
		Am-241	3.29E-01
		Cm-243	1.69E-01
		Cm-244	5.02E-01
		Cm-248	4.18E-05
		Cf-252	1.37E-05
253	Laboratories and counting rooms	H-3	1.1E-04
		C-14	1.0E-07
		P-32	1.0E-06
		Sr-90	5.5E-06
		Sr-90/Y-90	2.8E-08
		Y-90	3.7E-08
		Cs-137	1.4E-07
		Bi-214	3.3E-01
		Pb-214	3.3E-01
		Po-218	3.3E-01
		Ra-226	1.5E-02
		Th-230	2.0E-08
		U-234	3.7E-04
		U-235	1.6E-05
		U-238	3.5E-04
		Np-237	4.3E-08
		Pu-238	2.6E-06
		Pu-239	6.6E-05
		Pu-240	1.5E-05
		Pu-241	6.5E-04
		Pu-242	9.9E-10
		Am-241	3.1E-06
254	Bioassays and analytical services	H-3	4.4E-02
		C-14	1.4E-02
		P-32	4.0E-03
		P-33	4.0E-01
		S-35	4.1E-02
		Sr-90	9.9E-02
		Y-90	9.9E-02
		I-125	6.3E-02
		Po-209	2.6E-05
		Th-230	6.0E-03
		U-232	2.3E-04
		U-233	1.0E-05
		U-234	4.1E-04
		U-235	1.0E-05
		U-236	3.2E-03
		U-238	8.9E-07
		Pu-238	0.0E+00
		Pu-239	9.0E-05

ATTACHMENT A
SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
254	Bioassays and analytical services	Pu-240	0.0E+00
		Pu-241	0.0E+00
		Pu-242	5.5E-04
		Np-237	4.4E-02
		Np-239	1.7E-01
		Am-241	3.2E-05
		Am-243	9.2E-04
		Cm-242	2.5E-04
		Cm-244	3.3E-04
		Cf-249	2.5E-04
		Cf-252	5.4E-03
255	Calibration laboratory	H-3	1.00E+00
		C-14	3.50E-10
		P-32	2.80E-08
		S-35	1.20E-09
		Sr-90	4.89E-13
		Y-90	4.89E-13
		I-125	5.91E-08
		I-131	1.80E-07
		Th-230	9.53E-11
		Th-232	2.50E-15
		U-233	2.50E-10
		U-234	1.10E-11
		U-235	2.90E-13
		U-236	8.69E-09
		U-238	4.19E-14
		Pu-239	2.77E-12
		Pu-242	1.40E-11
		Np-237	1.70E-09
		Np-239	1.70E-09
		Am-241	9.54E-13
		Am-243	2.54E-11
		Cm-242	9.09E-12
		Cm-244	9.49E-13
		Cf-252	8.39E-11
281	Tracer and dissolution studies	H-3	3.7E-02
		Be-10	1.5E-02
		C-14	2.8E-01
		Na-22	1.2E-04
		Cl-36	1.5E-02
		Ca-41	1.5E-01
		Mn-54	4.9E-06
		Ni-59	1.0E-04
		Ni-63	3.1E-01
		Co-60	5.0E-06
		Sr-90	1.5E-02
		Tc-99	1.5E-04
		Sb-125	4.9E-08
		Eu-152/Tm-171	1.7E-08
		Eu-154/Eu-155	2.1E-05
		Th-232	1.1E-06
		U-233	1.9E-04
		U-234	1.9E-04
		U-235	8.1E-06
		U-238	1.8E-04
		U-233/U-238	1.9E-06
		Pu-239	6.3E-04

ATTACHMENT A
SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
		Pu-242	2.0E-03
		Pu-244	2.4E-06
		Np-237	1.7E-01
		Am-241	5.4E-04
		Am-241/Np-237	1.4E-04
282	Residual contamination	H-3	1.0E+00
		Rb-86/87	7.5E-09
292	Residual contamination rotating target neutron source	H-3	1
298	Laser fusion program	H-3	9.9E-01
		U-234	4.1E-04
		U-235	1.9E-05
		U-238	6.0E-03
321	Milling and shaping	DU Thorium[b]	
321A	Milling and shaping	U-234	1.8E-01
		U-235	2.4E-02
		U-238	7.9E-01
321C	Milling, machining, and shaping	U-234	6.5E-01
		U-235	8.1E-03
		U-238	3.4E-01
322	M&E	U-234	8.1E-01
		U-235	1.2E-02
		U-238	1.8E-01
327	M&E	U-234	7.7E-02
		U-235	8.8E-02
		U-238	8.4E-01
331	Research and laboratories	H-3 (HTO)	4.69E-01
		H-3 (HT)	5.19E-01
		H-3	1.24E-02
332	Gloveboxes, HEPA filters	Pu-239 TRU	
341	Lasers Directorate	U-234	5.70E-02
		U-235	7.69E-03
		U-238	9.35E-01
361	R&D	H-3	5.6E-06
		C-14	3.3E-03
		P-32	8.3E-01
		P-33	1.1E-01
		S-35	5.4E-02
362	R&D	H-3	7.22E-01
		C-14	2.78E-01
363	R&D	H-3	9.99E-01
		C-14	1.11E-07
		P-32	1.42E-03
364	R&D	H-3	1.11E-03
		C-14	2.76E-03
		P-32	9.96E-01
365	R&D	H-3	4.04E-03
		C-14	9.96E-01
366	R&D	H-3	5.00E-01
		P-32	4.38E-01
		P-33	6.25E-02
377	R&D	H-3	7.66E-04
		C-14	3.83E-03
		P-32	9.95E-01
		Ni-63	1.15E-04
378		Co-57	1.44E-03

ATTACHMENT A
SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
378		Co-60	5.59E-02
		Sr-85	6.52E-02
		Cd-109	3.58E-02
		Cs-134	6.98E-01
		Cs-137	6.98E-02
		U-233	2.14E-04
		U-234	8.66E-07
		U-235	4.84E-08
		U-238	2.00E-06
		Pu-236	2.13E-03
		Pu-239	6.99E-05
		Pu-240	5.59E-05
		Pu-242	1.05E-02
		Pu-244	3.58E-04
		Np-237	1.44E-06
		Am-241	6.00E-02
		Am-243	4.01E-04
381		H-3	1
391		H-3	1
412W		Ni-59	3.50E-07
		Ni-63	1.00E+00
446		C-14	1
513	Waste processing	H-3	9.85E-01
		C-14	2.49E-04
		P-32	3.17E-06
		K-40	5.79E-04
		Mn-54	8.34E-06
		Co-57	7.28E-07
		Co-60	1.03E-04
		Sr-90	7.27E-04
		Nb-95	8.34E-06
		Zr-95	1.30E-05
		Ru-106	6.07E-09
		I-125	7.49E-07
		I-131	2.70E-08
		Ba-133	6.09E-07
		Cs-134	4.13E-06
		Cs-137	2.61E-05
		Cs-138	1.52E-10
		Ce-141	6.07E-09
		Ce-144	9.56E-06
		Eu-152	1.67E-04
		Eu-154	2.12E-07
		Eu-155	3.79E-08
		Tl-208	6.22E-08
		Bi-212	8.50E-08
		Bi-214	5.92E-09
		Pb-210	7.89E-06
		Pb-212	1.43E-07
		Pb-214	2.12E-08
		Ra-223	4.55E-07
		Ra-226	8.65E-08
		Ra-228	4.55E-16
		Ac-228	1.52E-09
		Pa-231	8.50E-07
		Th-226	9.71E-07
		Th-227	1.67E-06

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SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
514		Th-228	4.04E-05
		Th-232	3.51E-06
		Th-234	3.03E-06
		U-233	1.52E-05
		U-234	1.08E-03
		U-235	1.52E-04
		U-238	1.04E-02
		Pu-238	1.74E-09
		Pu-239	2.28E-04
		Pu-240	2.03E-08
		Pu-241	1.27E-06
		Pu-242	6.87E-07
		Am-241	7.62E-04
		Cm-244	3.03E-05
		Cf-249	2.28E-07
		H-3	8.61E-01
		Be-7	7.53E-06
		C-14	2.40E-02
		Na-22	9.05E-05
		P-32	6.53E-02
		S-35	8.42E-03
		K-40	6.11E-05
		Sc-46	5.46E-06
		Cr-51	5.59E-06
		Fe-55	5.42E-06
		Mn-54	1.66E-05
		Co-56	1.82E-07
		Co-57	7.56E-05
		Co-58	5.46E-06
		Co-60	1.09E-04
		Ni-63	1.45E-07
		Zn-65	1.92E-08
		Y-88	5.33E-05
		Sr-89	4.96E-11
		Sr-90	9.13E-04
		Nb-94	1.19E-06
		Nb-95	8.46E-06
		Zr-95	1.20E-07
		Tc-99	6.05E-05
		Ru-103	2.18E-09
		Ru-106	1.33E-06
		Cd-109	2.89E-08
		Sb-125	2.08E-05
		I-125	1.39E-04
		I-131	3.63E-06
		Ba-133	1.02E-04
		Cs-134	6.37E-05
		Cs-137	1.16E-03
		Ce-139	7.14E-13
		Ce-141	1.82E-09
		Ce-144	4.87E-03
		Gd-148	6.04E-05
		Pm-147	3.07E-06
		Sm-151	2.45E-07
		Eu-152	2.29E-04
		Eu-154	2.32E-04
		Eu-155	2.54E-05

ATTACHMENT A
SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
514	Waste processing	Hf-172	7.33E-06
		Lu-173	1.92E-06
		Lu-174	5.42E-06
		W-185	5.62E-09
		Po-209	9.30E-06
		Po-210	9.30E-06
		Bi-207	4.71E-06
		Bi-210	7.14E-07
		Pb-210	5.62E-05
		Ra-226	9.73E-06
		Th-228	1.47E-05
		Th-229	6.04E-05
		Th-230	5.81E-05
		Th-232	7.87E-05
		U-232	6.08E-05
		U-233	7.01E-03
		U-234	3.60E-03
		U-235	2.18E-04
		U-236	8.92E-07
		U-237	1.82E-09
		U-238	8.29E-03
		Pu-236	3.67E-08
		Pu-238	4.72E-04
		Pu-239	6.74E-03
		Pu-240	1.68E-03
		Pu-241	1.49E-04
		Pu-242	1.60E-04
		Pu-244	1.09E-06
		Np-237	6.77E-05
		Np-239	2.41E-06
		Am-241	4.23E-03
		Am-243	8.33E-05
		Cm-244	6.76E-05
		Cf-249	9.30E-06
514 Tank Farm		H-3	5.45E-01
		Be-7	3.33E-07
		C-14	2.59E-03
		Na-22	5.74E-05
		P-32	1.01E-01
		P-33	1.86E-04
		S-35	6.39E-03
		K-40	5.16E-05
		Sc-46	1.30E-06
		Cr-51	4.79E-07
		Fe-55	6.65E-07
		Fe-59	1.53E-06
		Mn-54	2.88E-06
		Co-56	2.01E-05
		Co-57	6.68E-03
		Co-58	2.14E-05
		Co-60	4.51E-05
		Zn-65	9.48E-07
		Ni-59	1.33E-06
		Ni-63	4.09E-06
		Y-88	2.12E-05
		Y-91	5.66E-06
		Sr-90	2.05E-01

ATTACHMENT A
SOURCE TERM BY BUILDING
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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
514 Tank Farm		Zr-95	1.40E-03
		Nb-95	3.08E-05
		Mo-99	7.99E-06
		Tc-99	2.76E-05
		Ru-103	2.54E-06
		Ru-106	4.35E-06
		Cd-109	8.97E-08
		Sn-113	4.66E-09
		Ag-110m	8.65E-07
		I-125	5.59E-05
		I-131	1.06E-05
		Sb-120m	7.32E-07
		Sb-124	6.25E-06
		Sb-125	9.93E-06
		Te-132	2.00E-07
		Ba-133	4.99E-05
		Ba-140	9.99E-07
		Cs-134	1.42E-05
		Cs-136	9.31E-07
		Cs-137	1.08E-01
		La-140	2.00E-08
		Ce-139	3.99E-09
		Ce-141	2.93E-05
		Ce-144	1.87E-04
		Nd-147	4.46E-06
		Pm-147	2.40E-06
		Gd-148	1.28E-05
		Sm-151	7.99E-08
		Eu-152	1.82E-04
		Eu-154	1.19E-04
		Eu-155	1.48E-05
		Eu-156	1.13E-07
		Tb-160	1.20E-08
		Hf-172	1.93E-06
		Hf-181	2.66E-06
		Lu-173	1.60E-06
		Lu-174	3.33E-07
		W-185	4.79E-09
		Au-195	4.26E-06
		Hg-203	3.06E-20
		Bi-207	1.04E-06
		Bi-210	5.06E-07
		Po-209	4.50E-06
		Po-210	5.06E-07
		Pb-210	1.36E-05
		Ra-226	1.55E-04
		Pa-233	1.60E-09
		Th-228	6.02E-03
		Th-229	1.28E-05
		Th-230	1.27E-05
		Th-232	1.14E-04
		U-232	1.31E-05
		U-233	4.44E-05
		U-234	1.63E-03
		U-235	7.36E-04
		U-236	3.33E-07
		U-237	3.46E-04

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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
514 Tank Farm		U-238	1.02E-02
		Pu-236	3.46E-08
		Pu-238	1.01E-04
		Pu-239	1.50E-03
		Pu-240	1.48E-04
		Pu-241	3.86E-05
		Pu-242	4.37E-05
		Pu-244	7.16E-08
		Np-237	2.31E-05
		Np-239	1.01E-04
		Am-241	1.02E-03
		Am-243	1.97E-05
		Cm-244	4.12E-05
		Cf-249	4.63E-06
612	Waste storage and repackaging	H-3	9.79E-01
		Be-7	1.22E-06
		C-14	7.04E-04
		Na-22	1.87E-04
		P-32	1.29E-02
		P-33	1.05E-08
		S-35	6.98E-06
		Cl-36	3.66E-11
		K-40	2.03E-05
		Sc-46	1.25E-06
		Cr-51	1.34E-06
612	Waste storage and repackaging	Fe-55	1.23E-06
		Mn-54	4.20E-06
		Co-56	7.33E-08
		Co-57	5.01E-06
		Co-58	1.34E-06
		Co-60	1.07E-03
		Ni-63	4.89E-08
		Zn-65	1.22E-08
		Se-75	2.88E-11
		Y-88	1.45E-07
		Y-91	1.05E-11
		Sr-85	8.72E-13
		Sr-89	3.93E-12
		Sr-90	6.02E-04
		Nb-94	5.50E-05
		Nb-95	1.34E-06
		Zr-90	1.48E-10
		Zr-95	1.28E-07
		Mo-99	1.55E-09
		Tc-99	1.60E-05
		Rh-102	2.01E-10
		Rh-103	1.66E-08
		Rh-103m	4.10E-13
		Rh-106	3.49E-11
		Ru-106	2.58E-08
		Cd-109	4.02E-05
		Cd-115	5.25E-09
		Ag-110m	2.18E-14
		I-125	2.45E-05
		I-131	3.15E-09
		Sb-124	4.45E-14
		Sb-125	4.99E-06

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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
612	Waste storage and repackaging	Sm-151	5.10E-11
		Ba-133	1.76E-05
		Ba-140	7.64E-09
		Cs-134	1.58E-05
		Cs-137	5.11E-04
		Ce-139	2.44E-13
		Ce-141	2.85E-08
		Ce-144	1.52E-04
		Nd-147	1.59E-09
		Pm-147	5.95E-10
		Pm-151	4.73E-10
		Sm-151	8.72E-13
		Gd-146	1.05E-05
		Gd-148	1.57E-05
		Eu-149	2.79E-12
		Eu-152	6.28E-05
		Eu-154	6.10E-05
		Eu-155	5.54E-06
		Tb-160	1.74E-13
		Hf-172	2.44E-06
		Lu-173	1.22E-06
		Lu-174	1.22E-06
		Ta-182	1.40E-11
		W-185	3.66E-09
		Ir-192	8.72E-14
		Au-195	5.41E-12
		Pt-195m	9.59E-10
		Hg-203	8.72E-17
		Bi-207	1.17E-06
		Bi-210	2.44E-07
		Po-209	3.30E-06
		Po-210	2.44E-07
		Pb-210	1.68E-05
		Ra-223	4.73E-12
		Ra-226	1.72E-06
		Ra-228	2.94E-09
		Th-228	1.45E-06
		Th-229	1.57E-05
		Th-230	1.56E-05
		Th-232	1.48E-05
		Th-234	1.13E-12
		U-232	1.58E-05
		U-233	2.08E-05
		U-234	4.93E-04
		U-235	1.85E-04
		U-237	3.39E-08
		U-238	2.01E-03
		U-239	9.60E-12
		Pu-238	1.15E-04
		Pu-239	3.89E-04
		Pu-240	3.54E-05
		Pu-241	1.28E-04
		Pu-242	2.60E-05
		Pu-244	3.56E-06
		Np-237	1.69E-05
		Np-239	6.09E-07
		Am-241	3.74E-04

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Table A-1 (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
612	Waste storage and repackaging	Am-242	6.81E-09
		Am-242m	1.57E-09
		Am-243	4.11E-04
		Am-244	4.45E-06
		Cm-244	1.05E-04
		Cf-249	3.39E-06
		Cf-250	2.24E-12
612 Yard		H-3	1.00E+00
		C-14	2.11E-06
		P-32	1.61E-07
		S-35	3.40E-08
		K-40	4.48E-11
		Cr-51	4.84E-11
		Mn-54	6.11E-13
		Co-57	6.38E-13
		Co-60	1.19E-10
		Ni-59	1.01E-12
		Ni-63	2.92E-11
		Se-75	2.45E-08
		Sr-90	9.84E-12
		Nb-95	3.19E-13
		Tc-99	2.44E-12
		Sb-125	4.09E-12
		Cs-134	1.02E-11
		Cs-137	3.60E-10
		Ce-144	4.25E-10
		Pm-147	1.70E-12
		Sm-151	5.26E-13
		Eu-152	5.45E-10
		Eu-154	2.89E-10
		Eu-155	6.11E-12
		Bi-207	1.81E-13
		Bi-214	4.52E-14
		Ra-226	3.65E-11
		Ra-228	1.22E-11
		Th-228	5.50E-10
		Th-230	1.17E-14
		Th-232	5.69E-10
		Th-234	1.17E-11
		U-233	5.40E-10
		U-234	1.87E-08
		U-235	2.47E-09
		U-238	1.87E-07
		Pu-238	2.43E-09
		Pu-239	5.46E-10
		Pu-240	2.12E-11
		Pu-241	4.43E-09
		Pu-242	1.02E-08
		Np-239	4.80E-11
		Am-241	1.45E-09
		Am-242	1.38E-12
		Am-243	4.22E-10
		Cm-243	4.89E-11
		Cm-244	3.35E-13
		Cm-245	3.03E-11

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Attachment A (Continued). Source term by building.[a]

(Current) building no.	Building activity	Radionuclide	Activity fraction
625	Waste operations	H-3	2.14E-01
		C-14	2.34E-04
		P-32	3.61E-10
		K-40	8.78E-05
		Mn-54	1.36E-06
		Co-57	5.74E-08
		Co-60	9.89E-06
		Sr-90	2.34E-06
		Y-88	1.70E-10
		Zr-95	2.55E-06
		Ru-106	7.01E-07
		Cd-109	4.40E-08
		Sb-125	9.78E-07
		Ba-133	1.01E-07
		Cs-134	1.11E-06
		Cs-137	1.05E-05
		Ce-141	4.46E-09
		Ce-144	1.57E-06
		Eu-152	4.47E-06
		Eu-154	2.55E-06
		Eu-155	2.55E-07
		Bi-214	2.98E-08
		Pb-212	3.83E-08
		Pb-214	4.89E-09
		Pa-231	4.89E-08
		Ra-226	1.51E-05
		Ra-228	6.59E-04
		Th-228	1.55E-06
		Th-230	5.53E-10
		Th-232	3.62E-06
		Th-234	4.89E-04
		U-233	4.46E-08
		U-234	2.76E-01
		U-235	4.89E-01
		U-238	2.32E-03
		U-239	2.55E-07
		Pu-238	7.68E-05
		Pu-239	3.40E-03
		Pu-240	3.83E-06
		Pu-241	1.30E-02
		Pu-242	4.46E-08
		Np-237	2.34E-07
		Am-241	2.87E-04
		Am-243	5.10E-06
		Cm-243	9.78E-09
		Cm-244	2.34E-09
		Cm-245	1.38E-09
2561		U-234	5.00E-01
		U-238	5.00E-01
		U-234	8.01E-02
		U-235	1.12E-02
		U-238	8.66E-01
Site 300-801		H-3	1
Site 300 Pit 7		H-3	1
Site 300-810A		U-234	8.38E-02
		U-235	1.16E-02
		U-238	9.05E-01

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Attachment A (Continued). Source term by building.[a]

Site 300-810B		U-234	8.47E-02
		U-235	1.13E-02
		U-238	9.04E-01
Site 300-850		H-3	9.6E-01
		U-234	3.2E-03
		U-235	4.4E-04
		U-238	3.4E-02
Site 300-851		H-3	9.57E-01
		U-234	9.57E-04
		U-235	1.34E-04
		U-238	1.02E-02
Site 300 Well 8 Spring		H-3	1

a. This table was derived from data reported for calendar years 1992 through 2001 as part of the National Emission Standards for Hazardous Air Pollutants (NESHAPs; 40 CFR Part 61, Subpart H) reporting process (LLNL 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003). As part of its required reporting under NESHAPs, LLNL must monitor emissions by radionuclide and total activity at all building release points. This table only lists buildings for which NESHAPS data was reported; this is not a complete list of all buildings. For a listing of major buildings and activities see Lawrence Livermore National Laboratory- Site Description (NIOSH, 2005.) While the emissions identified over the years might not be fully representative of the source term in each building, they do provide a reasonable basis, in the absence of claimant-specific monitoring results, for determining the types of radioactive materials to which employees might have been exposed. To develop the table, the isotopic listing of each building in the relevant NESHAPs reports was captured in a building-specific spreadsheet. The annual emissions were totaled for each isotope and then for all isotopes in the listing. Activity fractions were obtained by dividing the Activity total by the "all isotopes" total (Berger 2005). The Activity fraction for each radionuclide in the table is that fraction of the total source term present (i.e., the sum of the fractions for each building is equal to "1" or 100% of the mixture). However, those radionuclides with Activity fractions equal to "zero", those with half-lives too short to contribute significant dose (i.e., isotopes of nitrogen and oxygen), and those that contribute submersion dose only were subsequently deleted from the listing.

b. LLNL (1987a).