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## 4. NATURE AND EXTENT OF CONTAMINATION

The purpose of this section is to assess available monitoring data to identify the distribution of COPCs in the RWMC environment. The emphasis in Section 4 is on the human health COPCs identified in the IRA (Becker et al. 1998), but some discussion also is provided about the occurrence of ecological COPCs that are not human health risk drivers (Hampton and Becker 2000). The discussions focus on the results from routine aquifer and vadose zone monitoring conducted by the INEEL and the USGS. The INEEL subsurface data used for this analysis were compiled from limitations and validation reports generated from laboratory analyses, with the exception of the data used for the analysis of carbon tetrachloride. Carbon tetrachloride data were assembled from several sources as cited in Section 4.8.1. The INEEL surface monitoring data (e.g., surface soil, vegetation, and runoff) were primarily obtained from the INEEL annual monitoring reports (as cited). The USGS data were obtained from the USGS.

The occurrence of each human health COPC in the following regions is discussed in subsequent sections, as indicated below and shown in Figure 4-1:

- Waste zone—contaminant inventories contained in waste at the time of disposal; waste streams that give rise to additional COPC inventories through radioactive decay and ingrowth, and waste zone nuclear logging data
- Surface—environmental monitoring data for soil, runoff water, and vegetation
- Vadose zone—environmental monitoring data for soil moisture, perched water, interbed sediments, or subsurface basalt samples
- Aquifer—environmental monitoring data for the aquifer.

Discussions are tailored to address any trends or patterns in the data. Graphs, tables, and illustrations of the patterns of COPCs in the environment are presented when data sets are large enough.

### 4.1 Waste Zone Data

The waste zone is generally defined by the boundaries of the disposal units (e.g., pits and trenches) within the SDA, with a vertical profile extending to the first basalt layer beneath the SDA. Waste zone data include disposal and inventory records of waste buried in the SDA and shallow nuclear logging data collected within the SDA from the Type A probe network. Data collected outside the pits and trenches are discussed in Section 4.3 as components of the vadose zone data set.

#### 4.1.1 Inventory Data and Disposal Information

The two primary databases maintained for disposal information are CIDRA and WasteOScope. The CIDRA contains the inventory information reflected in the tables for each COPC. The database was originally based on the HDT (LMITCO 1995a) and RPDT (LMITCO 1995b) reports, which contained inventory estimates and waste characteristics developed in cooperation with the waste generators (e.g., RFP and INEEL facilities). Several corrections and updates have been incorporated into CIDRA since the HDT and RPDT reports were published. The best-estimate SDA inventories currently contained in CIDRA are presented in Table 4-1 for radionuclides and Table 4-2 for nonradionuclides.

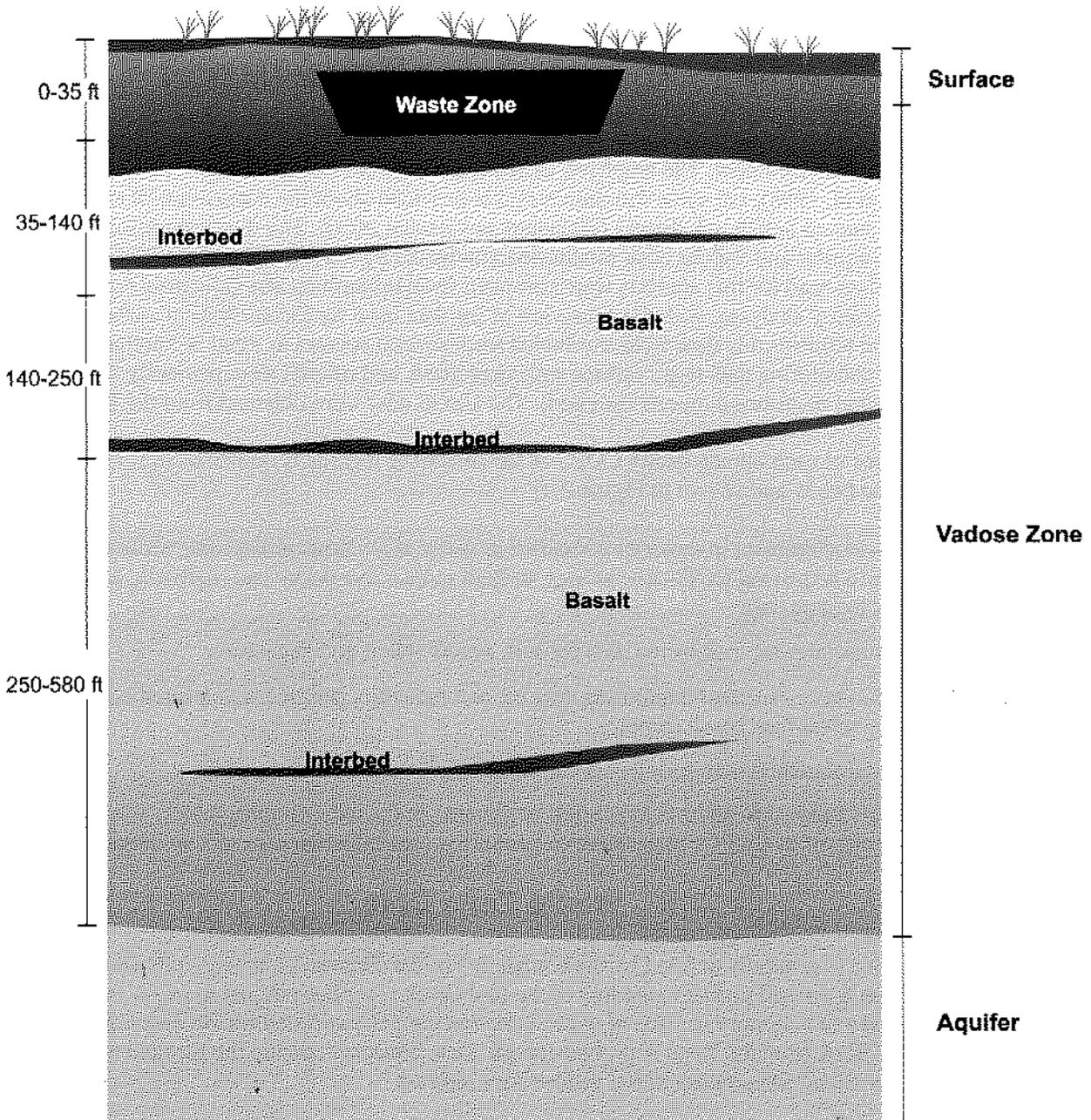


Figure 4-1. Depth intervals analyzed in the evaluation of the nature and extent of contamination for Waste Area Group 7.

The WasteOScope database reflects the information provided on the shipping manifests, including numbers of containers, disposal location, and contact dose rate. For waste generated at the RFP, WasteOScope contains waste types and drum weights taken from the RFP shipping manifests and trailer load lists. Though work continues to refine the contents of WasteOScope, the database is as complete as practicable for RFP. Continued refinements focus primarily on INEEL waste shipments to the SDA.

To model the release of contaminants from the waste, the inventory information within CIDRA was combined with the disposal location information in the WasteOScope database to determine where COPCs had been disposed of. The details of this process are provided in Section 3.

Table 4-1. Annual inventories (curies) of radionuclide contaminants of potential concern and associated long-lived decay chain products at the time of disposal in the Subsurface Disposal Area from 1952 to 1999.

Contaminant <sup>a</sup>	1952	1953	1954	1955	1956	1957	1958	1959
Ac-227	1.49E-10							
Am-241 <sup>b</sup>	1.09E+00	1.09E+00	3.64E+02	1.13E+03	2.26E+03	3.37E+03	8.23E+03	8.98E+03
Am-243 <sup>c</sup>	3.06E-06	3.06E-06	3.06E-06	3.06E-06	2.43E-04	1.97E-04	2.52E-04	1.36E-02
C-14	5.99E+00	5.99E+00	5.99E+00	6.61E+00	6.61E+00	6.61E+00	6.61E+00	6.61E+00
Cl-36	0.00E+00	0.00E+00	0.00E+00	5.09E-08	5.09E-08	5.09E-08	5.09E-08	5.09E-08
Cs-137	7.47E+01	7.47E+01	7.47E+01	4.72E+03	4.72E+03	4.72E+03	6.08E+03	6.20E+03
I-129	1.25E-05	1.25E-05	1.25E-05	1.25E-05	4.12E-03	3.34E-03	4.04E-03	4.07E-03
Nb-94	1.32E+00	1.32E+00	1.32E+00	8.13E+00	8.13E+00	8.13E+00	8.13E+00	8.13E+00
Np-237	8.20E-04	8.20E-04	8.20E-04	8.20E-04	2.36E-02	1.92E-02	3.57E-02	3.50E-02
Pa-231	4.08E-09							
Pb-210	9.88E-15							
Pu-238 <sup>d</sup>	3.20E-01	3.20E-01	3.09E+00	1.41E+01	6.73E+01	7.21E+01	1.35E+02	1.43E+02
Pu-239	1.34E-02	1.34E-02	9.45E+01	4.72E+02	9.52E+02	1.38E+03	3.20E+03	3.51E+03
Pu-240 <sup>e</sup>	8.67E-03	8.67E-03	2.11E+01	1.06E+02	2.13E+02	3.08E+02	7.16E+02	7.86E+02
Ra-226	7.28E-14							
Sr-90	5.12E+01	5.12E+01	5.12E+01	5.12E+01	1.90E+04	1.54E+04	1.86E+04	1.88E+04
Tc-99	4.73E-02	4.73E-02	4.73E-02	5.37E-02	2.65E+00	2.15E+00	2.59E+00	2.61E+00
Th-229	1.71E-12							
Th-230	1.43E-10							
Th-232	3.32E-14							
U-233	1.37E-08							
U-234	1.02E-03	1.02E-03	2.01E+00	2.01E+00	2.03E+00	2.01E+00	2.03E+00	2.03E+00
U-235	1.61E-04	1.61E-04	1.02E-01	1.02E-01	1.34E-01	1.28E-01	1.34E-01	1.33E-01
U-236	9.22E-04	9.22E-04	5.57E-02	5.57E-02	1.45E-01	1.28E-01	1.54E-01	1.51E-01
U-238 <sup>f</sup>	2.74E-06	2.74E-06	4.24E+00	4.24E+00	4.24E+00	4.24E+00	4.24E+00	4.24E+00

a. Green shading indicates a contaminant of potential concern identified in the Interim Risk Assessment (Becker et al. 1998); yellow shading indicates a long-lived decay chain product of a contaminant of potential concern; and blue shading indicates a long-lived parent of a contaminant of potential concern.

b. Am-241 inventories include the annual contributions from its short-lived parent, Pu-241, which total 9.74E+05 Ci.

c. Am-243 is the long-lived parent of Pu-239 and is explicitly modeled (see Section 5).

d. Pu-238 is the long-lived parent of U-234 and is explicitly modeled (see Section 5).

e. Pu-240 inventories include the annual contributions from its short-lived parent, Cm-244, which total 5.24E+04 Ci.

f. U-238 inventories include the annual contributions from its parent, Pu-242, which total 1.65E+01 Ci.

Table 4-1. (continued).

Contaminant <sup>a</sup>	1960	1961	1962	1963	1964	1965	1966	1967
Ac-227	1.49E-10							
Am-241 <sup>b</sup>	1.05E+04	9.74E+03	1.24E+04	1.54E+04	1.31E+04	1.87E+04	2.28E+04	8.99E+03
Am-243 <sup>c</sup>	7.98E-02	1.34E-02	2.34E-02	1.53E-01	1.39E-02	1.34E-02	2.34E-02	1.39E-02
C-14	6.62E+00	6.78E+00	6.92E+00	6.79E+00	7.93E+00	7.84E+00	7.85E+00	7.78E+00
Cl-36	5.09E-08	1.57E-01	1.57E-01	5.09E-08	1.47E-07	1.47E-07	1.47E-07	1.47E-07
Cs-137	1.53E+04	2.63E+04	7.02E+04	2.56E+04	8.72E+03	2.77E+04	1.22E+04	8.23E+03
I-129	1.20E-04							
Nb-94	8.13E+00	8.13E+00	8.14E+00	8.13E+00	2.09E+01	2.09E+01	2.09E+01	2.09E+01
Np-237	2.34E-02	9.47E-02	3.80E-01	1.34E-01	2.65E-02	1.51E-01	4.16E-02	1.53E-02
Pa-231	4.08E-09							
Pb-210	9.88E-15							
Pu-238 <sup>d</sup>	1.52E+02	1.18E+02	2.01E+02	5.90E+02	1.58E+02	2.26E+02	3.10E+02	1.08E+02
Pu-239	4.17E+03	3.82E+03	5.20E+03	6.24E+03	5.16E+03	7.42E+03	9.08E+03	3.52E+03
Pu-240 <sup>e</sup>	9.30E+02	8.52E+02	1.33E+03	1.57E+03	1.16E+03	1.66E+03	2.04E+03	7.87E+02
Sr-90	5.11E+02	1.15E+03	1.92E+03	1.79E+03	1.07E+03	9.40E+02	3.40E+03	3.27E+03
Tc-99	1.09E-01	1.09E-01	1.09E-01	1.09E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01
Th-229	1.71E-12							
Th-230	1.43E-10							
Th-232	2.10E-03	5.49E-01	5.30E-01	2.16E-01	5.00E-10	3.32E-14	2.00E-02	3.32E-14
U-233	1.37E-08	5.40E-01						
U-234	3.69E+00	5.28E+00	9.27E+00	2.22E+00	2.05E+00	2.26E+00	2.08E+00	2.03E+00
U-235	1.96E-01	2.78E-01	4.08E-01	1.66E-01	1.11E+00	1.15E-01	1.11E-01	1.10E-01
U-236	7.12E-02	1.15E-01	2.95E-01	1.38E-01	7.29E-02	1.50E-01	8.61E-02	6.60E-02
U-238 <sup>f</sup>	4.70E+00	5.44E+00	5.33E+00	4.28E+00	4.26E+00	4.26E+00	4.29E+00	4.92E+00

a. Green shading indicates a contaminant of potential concern identified in the Interim Risk Assessment (Becker et al. 1998); yellow shading indicates a long-lived decay chain product of a contaminant of potential concern; and blue shading indicates a long-lived parent of a contaminant of potential concern.

b. Am-241 inventories include the annual contributions from its short-lived parent, Pu-241, which total 9.74E+05 Ci.

c. Am-243 is the long-lived parent of Pu-239 and is explicitly modeled (see Section 5).

d. Pu-238 is the long-lived parent of U-234 and is explicitly modeled (see Section 5).

e. Pu-240 inventories include the annual contributions from its short-lived parent, Cm-244, which total 5.24E+04 Ci.

f. U-238 inventories include the annual contributions from its parent, Pu-242, which total 1.65E+01 Ci.

Table 4-1. (continued).

Contaminant <sup>a</sup>	1968	1969	1970	1971	1972	1973	1974	1975
Ac-227	1.49E-10	1.08E-07	1.63E-07	1.49E-10	5.78E-08	1.49E-10	1.49E-10	1.49E-10
Am-241 <sup>b</sup>	1.81E+04	1.13E+04	8.68E+03	4.85E+01	5.43E+01	4.78E+01	4.76E+01	7.15E+03
Am-243 <sup>c</sup>	1.34E+01	1.98E-02	2.30E-02	1.34E-02	1.68E-02	1.34E-02	1.34E-02	6.64E+01
C-14	7.78E+00	2.52E+01	3.40E+01	7.78E+00	1.71E+01	5.08E+01	7.78E+00	7.78E+00
Cl-36	1.47E-07	1.22E-01	1.84E-01	1.47E-07	6.53E-02	1.47E-07	1.47E-07	1.47E-07
Cs-137	1.11E+04	4.52E+04	9.45E+03	8.84E+03	1.30E+04	8.85E+03	8.92E+03	1.10E+04
I-129	8.61E-02	1.26E-04	1.29E-04	1.20E-04	1.23E-04	1.20E-04	1.20E-04	4.28E-02
Nb-94	2.09E+01	2.09E+01	2.09E+01	2.09E+01	2.09E+01	6.79E+01	2.09E+01	2.09E+01
Np-237	4.49E-01	2.28E-01	2.28E-02	2.37E-02	5.08E-02	2.44E-02	2.37E-02	2.31E-01
Pa-231	4.08E-09	1.41E-06	2.12E-06	4.08E-09	7.54E-07	4.08E-09	4.08E-09	4.08E-09
Pb-210	9.88E-15	1.07E-10	1.62E-10	9.88E-15	5.72E-11	9.88E-15	9.88E-15	9.88E-15
Pu-238 <sup>d</sup>	8.31E+03	1.41E+02	1.04E+02	3.83E+00	5.09E+00	3.86E+00	3.85E+00	4.11E+03
Pu-239	2.38E+03	4.41E+03	3.42E+03	2.01E+00	3.21E+00	1.27E+00	1.25E+00	4.12E+02
Pu-240 <sup>e</sup>	1.90E+03	9.89E+02	7.65E+02	1.02E+00	1.22E+00	1.01E+00	1.10E+01	7.72E+02
Ra-226	6.25E-02	5.50E-02	3.42E-02	1.71E-03	2.50E+00	2.31E-01	1.00E+00	1.71E-03
Sr-90	9.88E+04	7.46E+03	3.29E+03	1.87E+03	1.81E+03	1.80E+03	1.95E+03	4.95E+04
Tc-99	2.79E+01	1.23E-01	1.24E-01	1.21E-01	1.22E-01	1.51E-01	1.21E-01	1.39E+01
Th-229	1.71E-12	5.01E-08	7.55E-08	1.71E-12	2.67E-08	1.71E-12	1.71E-12	1.71E-12
Th-230	1.43E-10	6.08E-09	9.09E-09	1.43E-10	3.31E-09	1.43E-10	1.43E-10	1.43E-10
Th-232	1.00E-05	5.61E-08	1.11E-04	1.09E-04	4.02E-06	3.99E-06	2.31E-05	2.58E-05
U-233	1.37E-08	1.79E-04	6.00E-01	1.37E-08	9.52E-05	1.37E-08	1.37E-08	1.37E-08
U-234	2.23E+00	7.07E+00	1.26E+00	1.42E+00	2.08E+00	7.30E-01	7.11E-01	7.11E-01
U-235	1.30E-01	2.68E-01	3.51E-01	8.00E-02	1.83E-01	5.41E-02	5.34E-02	5.64E-02
U-236	2.33E-01	1.97E-01	4.97E-02	5.46E-02	6.97E-02	1.74E-02	1.69E-02	9.45E-02
U-238 <sup>f</sup>	5.43E+00	4.36E+00	2.64E+00	4.14E+00	6.40E+00	3.60E+00	3.61E+00	4.01E+00

a. Green shading indicates a contaminant of potential concern identified in the Interim Risk Assessment (Becker et al. 1998); yellow shading indicates a long-lived decay chain product of a contaminant of potential concern; and blue shading indicates a long-lived parent of a contaminant of potential concern.

b. Am-241 inventories include the annual contributions from its short-lived parent, Pu-241, which total 9.74E+05 Ci.

c. Am-243 is the long-lived parent of Pu-239 and is explicitly modeled (see Section 5).

d. Pu-238 is the long-lived parent of U-234 and is explicitly modeled (see Section 5).

e. Pu-240 inventories include the annual contributions from its short-lived parent, Cm-244, which total 5.24E+04 Ci.

f. U-238 inventories include the annual contributions from its parent, Pu-242, which total 1.65E+01 Ci.

Table 4-1. (continued).

Contaminant <sup>a</sup>	1976	1977	1978	1979	1980	1981	1982	1983
Ac-227	1.49E-10	4.11E-08	1.49E-10	1.49E-10	1.49E-10	1.49E-10	1.49E-10	1.49E-10
Am-241 <sup>b</sup>	1.38E+03	8.72E+01	3.91E+01	3.91E+01	3.91E+01	1.67E+01	1.60E+01	2.96E-02
Am-243 <sup>c</sup>	5.42E+01	3.15E-03	1.25E-05	1.25E-05	1.48E-05	1.48E-05	1.48E-05	1.48E-05
C-14	1.22E+01	3.26E+01	1.22E+01	1.22E+01	1.22E+01	9.52E+00	9.52E+00	9.35E+00
Cl-36	2.27E-07	1.40E-01	2.27E-07	2.27E-07	2.27E-07	1.36E-07	1.36E-07	1.36E-07
Cs-137	2.98E+04	7.37E+04	3.15E+04	3.13E+04	3.11E+04	2.72E+04	2.65E+04	2.54E+04
I-129	5.31E-03	9.65E-05	8.83E-05	8.83E-05	8.83E-05	8.83E-05	8.83E-05	8.83E-05
Nb-94	3.17E+01	3.17E+01	3.17E+01	3.17E+01	3.17E+01	1.97E+01	1.97E+01	2.15E+01
Np-237	1.89E-01	2.98E-01	2.38E-02	2.35E-02	2.37E-02	1.42E-02	1.04E-02	1.15E-03
Pa-231	4.08E-09	5.82E-07	4.08E-09	4.08E-09	4.08E-09	4.08E-09	4.08E-09	4.08E-09
Pb-210	9.88E-15	5.12E-11	9.88E-15	9.88E-15	9.88E-15	9.88E-15	9.88E-15	9.88E-15
Pu-238 <sup>d</sup>	2.08E+03	1.49E+01	3.41E+00	3.40E+00	3.40E+00	2.43E+00	2.25E+00	1.61E+00
Pu-239	5.55E+01	1.21E+01	7.00E-01	5.89E-01	6.32E-01	4.62E-01	2.90E-01	1.26E-01
Pu-240 <sup>e</sup>	1.66E+02	1.54E+00	2.87E-01	2.54E-01	3.13E-01	1.82E-01	1.65E-01	6.47E-02
Ra-226	1.71E-03	1.71E-03	4.58E-03	4.58E-03	2.53E-01	2.53E-01	2.51E-01	2.51E-01
Sr-90	1.66E+05	3.18E+04	3.17E+04	3.18E+04	3.19E+04	3.15E+04	3.13E+04	3.13E+04
Tc-99	3.26E+00	1.23E-01	1.20E-01	1.20E-01	1.20E-01	1.09E-01	1.09E-01	1.09E-01
Th-229	1.71E-12	1.94E-08	1.71E-12	1.71E-12	1.71E-12	1.71E-12	1.71E-12	1.71E-12
Th-230	1.43E-10	2.59E-09	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03
Th-232	3.99E-06	4.17E-06	6.07E-05	2.37E-04	1.35E-04	1.35E-04	1.35E-04	1.35E-04
U-233	9.47E-03	7.38E-05	1.37E-08	1.37E-08	1.05E-05	1.05E-05	1.05E-05	1.05E-05
U-234	1.07E+00	1.35E+00	9.07E-01	2.32E-01	2.04E-01	1.56E-01	1.50E-01	1.35E-01
U-235	4.61E-01	7.17E-02	6.19E-02	1.56E-02	2.52E-02	2.33E-02	2.32E-02	2.28E-02
U-236	1.03E-01	1.86E-01	1.80E-02	1.78E-02	1.78E-02	1.04E-02	8.05E-03	2.02E-03
U-238 <sup>f</sup>	4.05E+00	4.15E+00	4.07E+00	5.22E-01	4.41E-01	4.41E-01	4.40E-01	4.40E-01

a. Green shading indicates a contaminant of potential concern identified in the Interim Risk Assessment (Becker et al. 1998); yellow shading indicates a long-lived decay chain product of a contaminant of potential concern; and blue shading indicates a long-lived parent of a contaminant of potential concern.

b. Am-241 inventories include the annual contributions from its short-lived parent, Pu-241, which total 9.74E+05 Ci.

c. Am-243 is the long-lived parent of Pu-239 and is explicitly modeled (see Section 5).

d. Pu-238 is the long-lived parent of U-234 and is explicitly modeled (see Section 5).

e. Pu-240 inventories include the annual contributions from its short-lived parent, Cm-244, which total 5.24E+04 Ci.

f. U-238 inventories include the annual contributions from its parent, Pu-242, which total 1.65E+01 Ci.

Table 4-1. (continued).

Contaminant <sup>a</sup>	1984	1985	1986	1987	1988	1989	1990	1991
Ac-227	1.49E-10	1.49E-10	7.09E-08	6.45E-08	1.49E-10	1.49E-10	1.49E-10	1.49E-10
Am-241 <sup>b</sup>	1.91E-01	1.34E-01	1.14E+00	1.64E+00	7.96E-02	7.79E-02	4.10E-02	3.12E+00
Am-243 <sup>c</sup>	1.25E-05	1.23E-05	1.48E-02	1.35E-02	1.23E-05	1.23E-05	1.23E-05	1.23E-05
C-14	4.89E+00	4.89E+00	1.92E+01	4.89E+00	4.89E+00	1.36E+01	1.36E+01	1.36E+01
Cl-36	1.67E-07	1.67E-07	9.60E-02	1.67E-07	1.67E-07	4.41E-07	4.41E-07	4.41E-07
Cs-137	1.59E+02	3.12E+02	1.77E+02	7.34E+02	4.02E+01	5.88E+01	1.31E+03	8.03E+01
I-129	8.90E-05	8.90E-05	9.43E-05	8.90E-05	8.90E-05	8.90E-05	3.58E-04	8.90E-05
Nb-94	2.26E+01	2.26E+01	2.26E+01	2.26E+01	2.26E+01	5.92E+01	5.92E+01	5.92E+01
Np-237	1.01E-03	9.83E-04	9.38E-04	4.43E-03	9.19E-04	9.15E-04	9.14E-04	9.13E-04
Pa-231	4.08E-09	4.08E-09	6.70E-07	6.10E-07	4.08E-09	4.08E-09	4.08E-09	4.08E-09
Pb-210	9.88E-15	9.88E-15	2.30E-10	2.10E-10	9.88E-15	9.88E-15	9.88E-15	9.88E-15
Pu-238 <sup>d</sup>	1.65E+00	1.62E+00	2.08E+00	2.19E+00	1.62E+00	1.58E+00	1.58E+00	1.58E+00
Pu-239	3.01E-01	3.01E-01	3.45E-01	4.86E-01	2.89E-01	1.70E-01	1.63E-01	1.62E-01
Pu-240 <sup>e</sup>	1.43E-02	1.40E-02	6.12E-02	7.25E-02	8.49E-03	4.46E-03	4.57E-03	4.43E-03
Ra-226	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	7.28E-14	7.28E-14	7.28E-14
Sr-90	4.41E+02	4.03E+02	4.03E+02	4.94E+02	4.01E+02	4.18E+02	4.31E+02	3.99E+02
Tc-99	1.65E-01	1.65E-01	1.67E-01	1.65E-01	1.65E-01	2.00E-01	2.03E-01	2.00E-01
Th-229	1.71E-12	1.71E-12	5.08E-08	4.62E-08	1.71E-12	1.71E-12	1.71E-12	1.71E-12
Th-230	1.43E-10	1.43E-10	5.14E-09	4.69E-09	1.43E-10	1.43E-10	1.43E-10	1.43E-10
Th-232	3.32E-14	3.32E-14	2.09E-08	1.91E-08	3.32E-14	3.32E-14	3.32E-14	3.32E-14
U-233	1.37E-08	1.37E-08	8.52E-05	7.75E-05	1.37E-08	1.37E-08	1.37E-08	1.37E-08
U-234	3.96E-01	3.96E-01	3.98E-01	4.24E-01	5.16E-01	3.13E-01	2.54E-01	3.24E-01
U-235	2.29E-02	1.71E-02	1.72E-02	1.84E-02	2.26E-02	1.38E-02	1.14E-02	1.43E-02
U-236	2.07E-03	2.03E-03	2.00E-03	4.15E-03	1.99E-03	1.98E-03	1.98E-03	1.98E-03
U-238 <sup>f</sup>	8.22E-02	7.79E-02	8.28E-02	1.56E-01	4.98E-01	2.62E-01	5.32E-02	3.00E-01

a. Green shading indicates a contaminant of potential concern identified in the Interim Risk Assessment (Becker et al. 1998); yellow shading indicates a long-lived decay chain product of a contaminant of potential concern; and blue shading indicates a long-lived parent of a contaminant of potential concern.

b. Am-241 inventories include the annual contributions from its short-lived parent, Pu-241, which total 9.74E+05 Ci.

c. Am-243 is the long-lived parent of Pu-239 and is explicitly modeled (see Section 5).

d. Pu-238 is the long-lived parent of U-234 and is explicitly modeled (see Section 5).

e. Pu-240 inventories include the annual contributions from its short-lived parent, Cm-244, which total 5.24E+04 Ci.

f. U-238 inventories include the annual contributions from its parent, Pu-242, which total 1.65E+01 Ci.

Table 4-1. (continued).

Contaminant <sup>a</sup>	1992	1993	1994	1995	1996	1997	1998	1999	Total
Ac-227	1.49E-10	5.12E-07							
Am-241 <sup>b</sup>	2.95E-02	3.71E-02	1.20E+00	1.24E-01	3.04E-02	3.48E-01	2.88E-01	1.09E-01	1.83E+05
Am-243 <sup>c</sup>	1.23E-05	1.23E-05	3.06E-06	4.50E-06	3.33E-06	4.91E-06	3.09E-06	6.23E-06	1.34E+02
C-14	1.36E+01	1.36E+01	8.62E+00	1.47E+00	1.60E+00	1.46E+00	1.59E+00	1.47E+00	5.00E+02
Cl-36	4.41E-07	4.41E-07	8.37E-02	3.22E-02	2.78E-02	2.39E-02	1.16E-02	4.95E-03	1.11E+00
Cs-137	1.97E+02	1.75E+01	5.39E+00	1.40E+01	8.06E+00	8.82E+00	1.59E+01	2.28E+01	6.17E+05
I-129	8.90E-05	8.90E-05	1.57E-03	4.57E-05	2.65E-05	9.34E-04	2.06E-03	4.21E-05	1.58E-01
Nb-94	5.92E+01	5.92E+01	3.86E-01	1.13E-01	1.98E-01	1.30E-01	2.75E-02	3.79E-04	1.00E+03
Np-237	9.13E-04	9.13E-04	8.41E-03	7.70E-04	2.06E-04	2.79E-04	6.06E-04	2.47E-04	2.64E+00
Pa-231	4.08E-09	4.08E-09	6.77E-09	4.18E-09	4.21E-09	7.75E-09	7.32E-08	8.58E-04	8.64E-04
Pb-210	9.88E-15	9.88E-15	9.88E-15	9.88E-15	9.88E-15	2.73E-08	4.81E-07	1.05E-09	5.10E-07
Pu-238 <sup>d</sup>	1.58E+00	1.58E+00	3.26E-01	2.93E-01	2.87E-01	3.33E-01	2.97E-01	2.99E-01	1.71E+04
Pu-239	1.62E-01	1.62E-01	2.02E-02	3.13E-02	5.33E-03	5.12E-02	5.03E-02	3.20E-02	6.49E+04
Pu-240 <sup>e</sup>	4.43E-03	4.43E-03	8.50E-03	5.96E-03	2.78E-03	5.13E-02	2.37E-02	1.98E-02	1.71E+04
Ra-226	7.28E-14	7.28E-14	7.28E-14	7.28E-14	1.20E-03	3.95E-03	5.57E-02	1.83E-02	6.00E+01
Sr-90	5.04E+02	3.89E+02	4.15E+00	6.43E+00	8.58E+00	1.09E+01	1.79E+01	1.04E+01	6.44E+05
Tc-99	2.00E-01	2.00E-01	7.10E-03	2.29E-01	8.00E-03	3.98E-02	4.78E-01	1.34E-01	6.05E+01
Th-229	1.71E-12	1.71E-12	6.17E-11	1.71E-12	3.93E-06	8.38E-08	2.52E-06	9.94E-09	6.81E-06
Th-230	1.43E-10	1.43E-10	5.66E-07	1.33E-05	7.57E-06	2.47E-03	1.08E-02	9.21E-05	3.13E-02
Th-232	3.32E-14	3.32E-14	1.70E-05	9.43E-03	2.42E-04	1.42E-02	1.85E-03	8.00E-05	1.34E+00
U-233	1.37E-08	1.37E-08	2.59E-01	6.81E-02	4.50E-04	1.19E-03	2.05E-02	7.24E-03	1.51E+00
U-234	2.55E-01	2.54E-01	4.39E-01	1.04E-01	3.96E-04	1.83E+00	5.26E-02	6.74E-02	6.74E+01
U-235	1.11E-02	1.11E-02	2.92E-02	7.22E-03	4.20E-04	4.70E-02	1.86E-01	5.89E-03	5.54E+00
U-236	1.98E-03	1.98E-03	3.85E-02	1.04E-02	9.31E-04	5.57E-04	3.20E-03	5.17E-03	2.86E+00
U-238 <sup>f</sup>	5.54E-02	5.43E-02	2.00E+00	5.41E-01	6.93E-04	8.00E-01	3.00E-01	2.56E-01	1.17E+02

a. Green shading indicates a contaminant of potential concern (COPC) identified in the Interim Risk Assessment (Becker et al. 1998); yellow shading indicates a long-lived decay chain product of a COPC; and blue shading indicates a long-lived parent of a COPC.

b. Am-241 inventories include the annual contributions from its short-lived parent, Pu-241, which total 9.74E+05 Ci.

c. Am-243 is the long-lived parent of Pu-239 and is explicitly modeled (see Section 5).

d. Pu-238 is the long-lived parent of U-234 and is explicitly modeled (see Section 5).

e. Pu-240 inventories include the annual contributions from its short-lived parent, Cm-244, which total 5.24E+04 Ci.

f. U-238 inventories include the annual contributions from its parent, Pu-242, which total 1.65E+01 Ci.

Table 4-2. Annual inventories (grams) of nonradionuclide contaminants of potential concern buried in the Subsurface Disposal Area from 1952 to 1999.

Contaminant	1952	1953	1954	1955	1956	1957	1958	1959
Carbon tetrachloride	0.00E+00	0.00E+00	4.99E+04	2.06E+05	4.05E+05	5.81E+05	1.33E+06	1.46E+06
Methylene chloride	0.00E+00	0.00E+00	2.11E+04	1.06E+05	2.13E+05	3.08E+05	7.16E+05	7.86E+05
Tetrachloroethylene	0.00E+00							
Nitrates	0.00E+00	0.00E+00	2.92E+06	2.92E+06	2.92E+06	2.92E+06	2.92E+06	2.92E+06

Contaminant	1960	1961	1962	1963	1964	1965	1966	1967
Carbon tetrachloride	1.73E+06	1.58E+06	2.06E+06	2.50E+06	2.15E+06	3.08E+06	1.76E+08	1.74E+08
Methylene chloride	9.30E+05	8.51E+05	1.11E+06	1.35E+06	1.16E+06	1.66E+06	2.03E+06	7.80E+05
Tetrachloroethylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.12E+07	2.12E+07
Nitrates	2.92E+06	2.94E+06	2.94E+06	2.94E+06	3.49E+06	2.88E+06	2.88E+06	3.45E+07

Contaminant	1968	1969	1970	1971	1972	1973	1974	1975
Carbon tetrachloride	1.73E+08	1.74E+08	1.06E+08	8.61E+00	8.61E+00	8.61E+00	8.61E+00	8.61E+00
Methylene chloride	3.37E+05	9.80E+05	7.60E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tetrachloroethylene	2.12E+07	2.12E+07	1.30E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nitrates	3.45E+07	3.45E+07	2.21E+07	2.18E+07	5.35E+07	3.26E+07	3.26E+07	3.26E+07

Contaminant	1976	1977	1978	1979	1980	1981	1982	1983
Carbon tetrachloride	8.61E+00	8.61E+00	8.61E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methylene chloride	0.00E+00							
Tetrachloroethylene	0.00E+00							
Nitrates	3.26E+07	3.26E+07	3.26E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 4-2. (continued).

Contaminant	1984	1985	1986	1987	1988	1989	1990	1991
Carbon tetrachloride	0.00E+00							
Methylene chloride	0.00E+00							
Tetrachloroethylene	0.00E+00							
Nitrates	0.00E+00							

Contaminant	1992	1993	1994	1995	1996	1997	1998	1999	Total
Carbon tetrachloride	0.00E+00	8.21E+08							
Methylene chloride	0.00E+00	1.41E+07							
Tetrachloroethylene	0.00E+00	9.78E+07							
Nitrates	0.00E+00	4.35E+08							

#### 4.1.2 Ingrowth

Waste in the SDA contributes radionuclides to the source term inventory either directly through disposals (see Table 4-1) or over time through ingrowth. Ingrowth is incremental accumulation of daughter products generated by decay of the parent. Of the 25 radionuclides listed in Table 4-1, 11 of them are members of decays chains: Am-241, Ac-227, Np-237, Pa-231, Pb-210, Ra-226, U-233, U-234, U-235, U-236, and U-238. Three decay chain series, named after the initiating nuclide, occur naturally: the thorium, uranium, and actinium series. A fourth decay chain, the neptunium series, has not occurred naturally since the creation of the cosmos.

Decay chain members for the four series are listed in the sequences they occur in Table 4-3 for the thorium series, Table 4-4 for the neptunium series, Table 4-5 for the uranium series, and Table 4-6 for the actinium series, as documented by Shleien (1992). Two nuclides in the same row of the table indicate that both can emanate from the parent nuclide listed above. Typically, the first decay product is common and the second is rare. The exception is the Po-211 and Tl-207 pair near the termination of the actinium series. Half-lives also are listed. The COPCs identified in Becker et al. (1998) and discussed in this report are shaded green in Tables 4-3 through 4-6. The inventories of these COPCs are significantly affected over time as the parent nuclides decay and daughters accumulate. For some COPCs, such as Np-237, the inventory from ingrowth exceeds the inventory from disposal, while other COPCs such as Am-241 generate risk through radioactive decay. Throughout Section 4, the contributions to COPCs from parents via ingrowth are identified in the waste stream tables for the affected nuclides. The ingrowth amounts identified in the tables were calculated by assuming that the contributing parent isotope completely decays away and the daughter COPC only accumulates.

Table 4-3. Decay chain for the thorium decay series, including anthropic predecessors from weapons manufacturing or reactor operations.

Anthropic Predecessor (Half-Life)		Decay Chain Series Isotope (Half-Life)
Pu-240 (6560 years)	U-236 (2.342E+07 years)	Th-232 (1.4E+10 years)
		Ra-228 (5.75 years)
		Ac-228 (6.13 hours)
		Th-228 (1.913 years)
		Ra-224 (3.66 days)
		Rn-220 (56.6 seconds)
		Po-216 (0.15 seconds)
		Pb-212 (10.64 hours)
		Bi-212 (1.009 hours)
		Po-212 (305 nanoseconds)
		Tl-208 (3.07 minutes)
		Pb-208 Stable

Table 4-4. Decay chain for the neptunium series.

Nuclide (Half-Life)	
Pu-241 (14.4 years)	
Am-241 (432.2 years)	U-237 (6.75 days)
Np-237 (2.14E+06 years)	
Pa-233 (27.0 days)	
U-233 (1.59E+05 years)	
Th-229 (7.34E+03 years)	
Ra-225 (14.8 days)	
Ac-225 (10.0 days)	
Fr-221 (4.8 minutes)	
At-217 (0.03 seconds)	
Bi-213 (45.7 minutes)	
Po-213 (4.2 microseconds)	Tl-209 (2.2 minutes)
Pb-209 (3.25 hours)	
Bi-209	
Stable	

Table 4-5. Decay chain for the uranium series and anthropic predecessors from weapons manufacturing or reactor operations.

Anthropic Predecessor (Half-Life)	Decay Chain Series Isotope (Half-Life)
	U-238 (4.47E+09 years)
	Th-234 (24.1 days)
	Pa-234m (1.17 minutes)
	Pa-234 (6.7 hours)
Pu-238 (87.7 years)	U-234 (2.45E+05 years)
	Th-230 7.7E+04 years
	Ra-226 (1,600 years)
	Rn-222 (3.823 days)
	Po-218 (3.05 minutes)
	Pb-214 (26.8 minutes)      At-218 (2 seconds)
	Bi-214 (19.9 minutes)
	Po-214 (164 microseconds)      Tl-210 (1.3 minutes)
	Pb-210 (22.3 years)
	Bi-210 (5.01 days)
	Po-210 (138.4 days)      Tl-206 (4.20 minutes)
	Pb-206 Stable

Table 4-6. Decay chain for the actinium series, including predecessors from weapons production or reactor operations.

Anthropic Predecessor (Half-Life)		Decay Chain Series Isotope (Half-Life)	
Am-243 (7.37E+03 years)	Np-239 (2.355 days)	Pu-239 (2.41E+04 years)	U-235 (7.04E+08 years)
			Th-231 (25.5 hours)
			Pa-231 (3.276E+04 years)
			Ac-227 (21.44 years)
		Th-227 (18.72 days)	Fr-223 (21.8 minutes)
			Ra-223 (11.43 days)
			Rn-219 (3.96 seconds)
			Po-215 (1.78 milliseconds)
		Pb-211 (36.1 minutes)	At-215 (0.10 milliseconds)
			Bi-211 (2.14 minutes)
		Po-211 (0.516 seconds)	Tl-207 (4.77 minutes)
			Pb-207 Stable

### 4.1.3 Nuclear Logging of the Waste Zone

Nuclear logging data were gathered to provide information on the physical, chemical, and radiological conditions within the SDA waste zone. Beginning in December 1999, 142 cased steel probeholes were installed in waste-bearing portions of Pits 4, 5, 9, and 10 of the SDA (see Figure 4-2). Type A probes within these probeholes provide the ability to conduct in situ characterization of subsurface soil and waste material by lowering nuclear logging tools into the probehole. The nuclear logging tools measure soil moisture, gamma radiation flux, neutron radiation flux, and chemical characteristics within the soil and waste surrounding the probeholes. Table 4-7 gives a brief description of the logging tool suite.

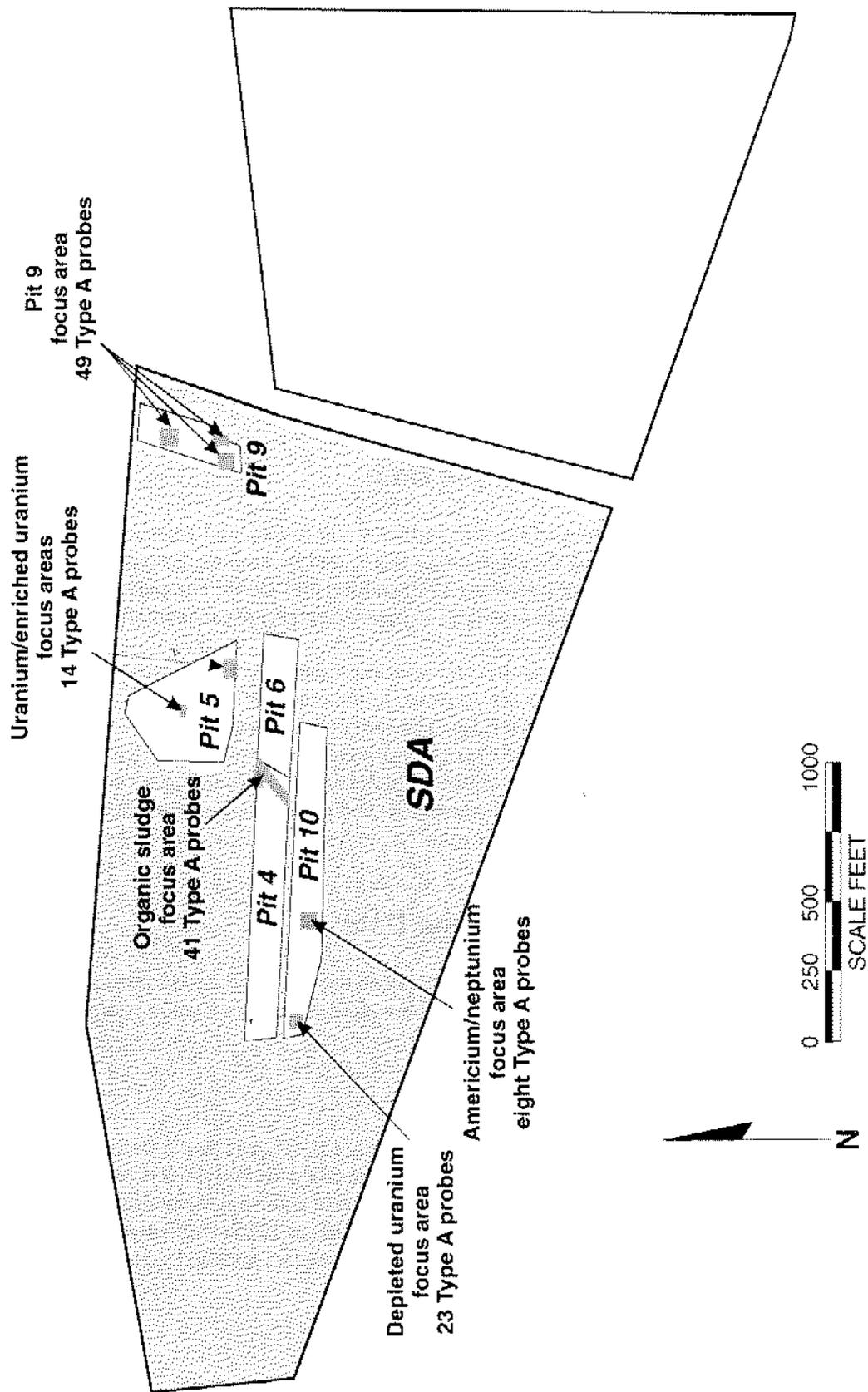


Figure 4-2. Locations of the Type A probes from which nuclear logging data were obtained.

Table 4-7. Description of Type A probe logging tools.

Tool	Detector Type	Detection Capabilities
Spectral gamma log	Germanium gamma detector.	Gamma-emitting radionuclides.
Passive neutron log	He-3 neutron detector.	Fissile radionuclides.
Moisture log	Americium/beryllium neutron source combined with neutron detector.	Total hydrogen.
Activated gamma (n-gamma) log	Cf-252 neutron source combined with germanium gamma detector.	High neutron capture cross-section elements such as chlorine, iron, silicon, and calcium.
Azimuthal spectral gamma log	Germanium gamma detector with slotted shield.	Rotated in probes to determine direction of maximum gamma flux.

## 4.2 Surface Sample Data

Samples of the SDA overburden, nearby surface soil, surface water runoff, and vegetation in the RWMC area are classified as surface data. Only the top 6 cm (2 in.) of soil is sampled. Because the SDA has been recontoured with clean soil several times between 1986 and the mid 1990s, comparison of recent surface soil data (1997 to 2000) to data collected before 1997 to assess trends is not meaningful.

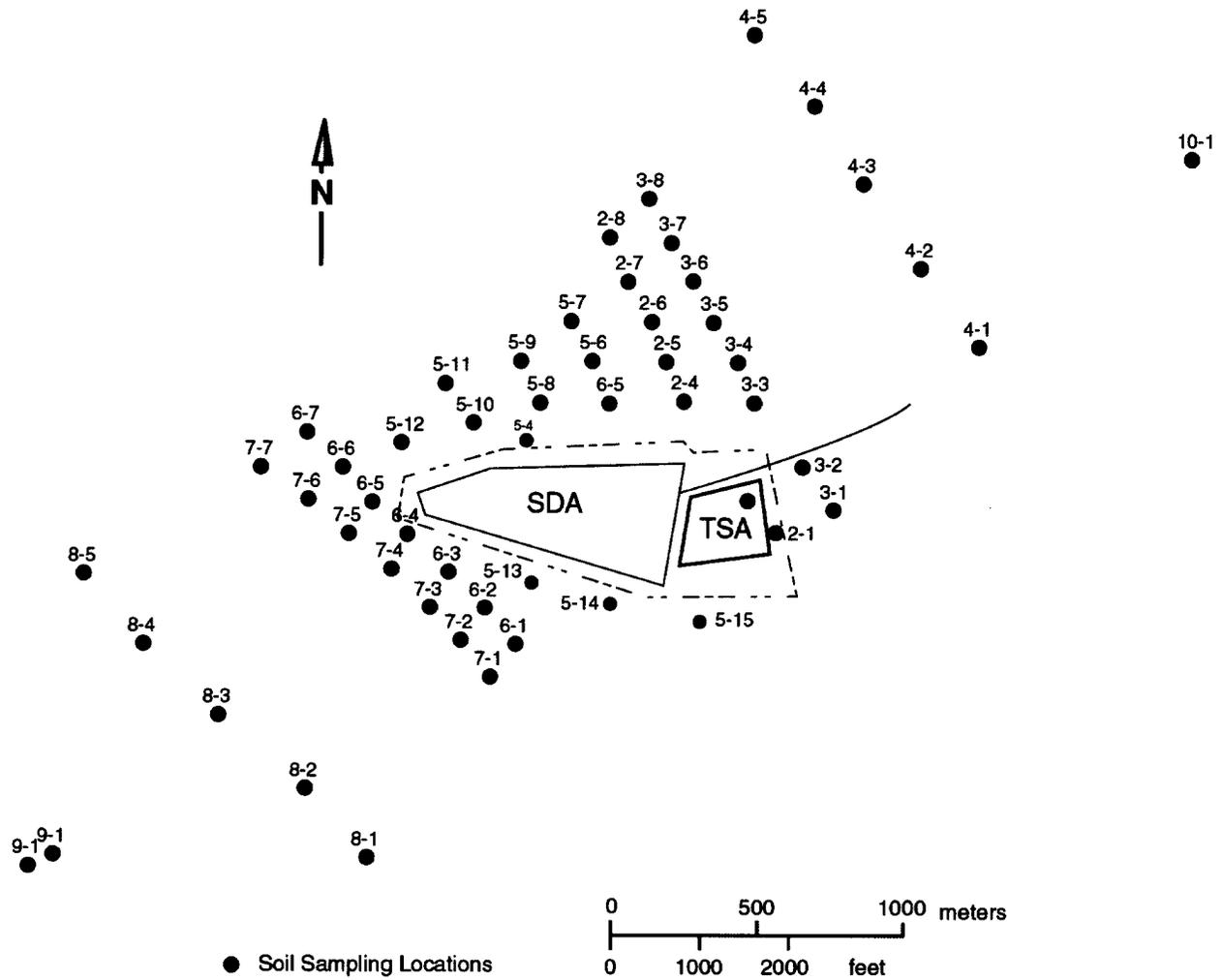
All samples are analyzed by gamma spectroscopy, and selected samples based on activity are analyzed using radiochemistry. Surface soil samples are collected around the RWMC every 3 years and analyzed by gamma spectroscopy for selected radionuclides. The sample locations for the RWMC soil samples are shown in Figure 4-3, with the SDA-specific samples shown in Figure 4-4 and TSA-specific locations shown in Figure 4-5. Vegetation samples are collected in the areas shown in Figure 4-6. Vegetation samples are collected annually, with crested wheatgrass and perennials collected in odd years and Russian thistle collected in even years. Surface water runoff samples, if available, are collected quarterly in the locations shown in Figure 4-7.

## 4.3 Vadose Zone Data

The vadose zone is defined as the unsaturated interval between the land surface and the aquifer. The primary sources of data used to describe contaminants in the vadose zone were suction lysimeter network samples, perched water samples, and soil and rock core.

### 4.3.1 Suction Lysimeter Network

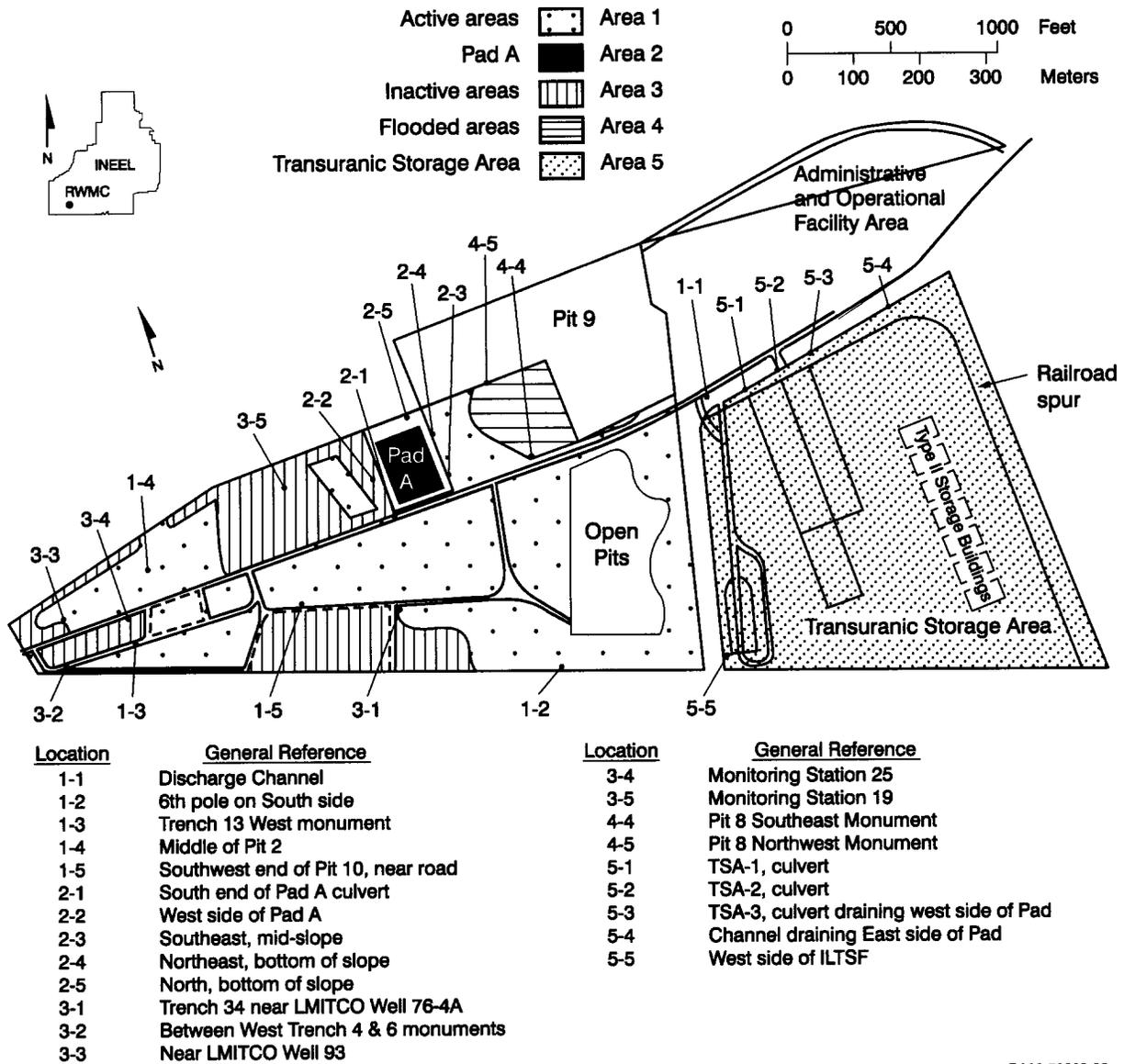
Lysimeter sampling is conducted to characterize the soil moisture (i.e., water that accumulates in soil pores) in the vadose zone. A network of suction lysimeters was installed around the RWMC to allow repeated samples to be collected from the sediments near the buried waste and from the underlying interbeds. Though the first lysimeter samples were collected at the INEEL in 1985 (Hubbell et al. 1985), routine lysimeter sampling did not begin until 1997. The network of lysimeters installed within the vadose zone around the RWMC is shown in Figures 4-8 and 4-9.



GE99 0136

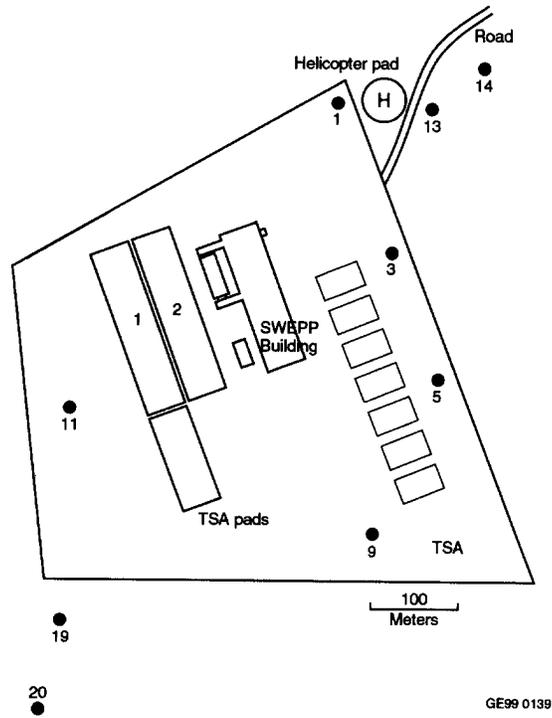
**RWMC Soil Sampling Grid**

Figure 4-3. Surface soil sampling locations around the Radioactive Waste Management Complex.



GA02-50283-02

Figure 4-4. Surface soil sampling locations at the Subsurface Disposal Area.



GE99 0139

Figure 4-5. Surface soil sampling locations at the Transuranic Storage Area.

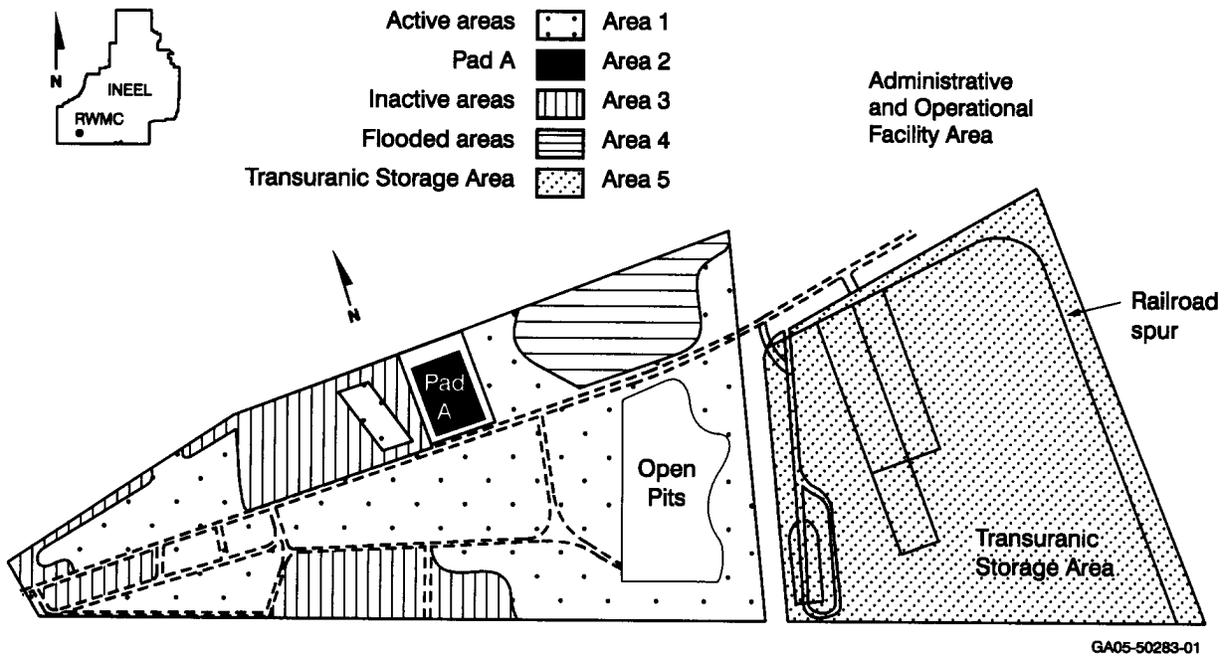


Figure 4-6. Vegetation sampling areas at the Radioactive Waste Management Complex.

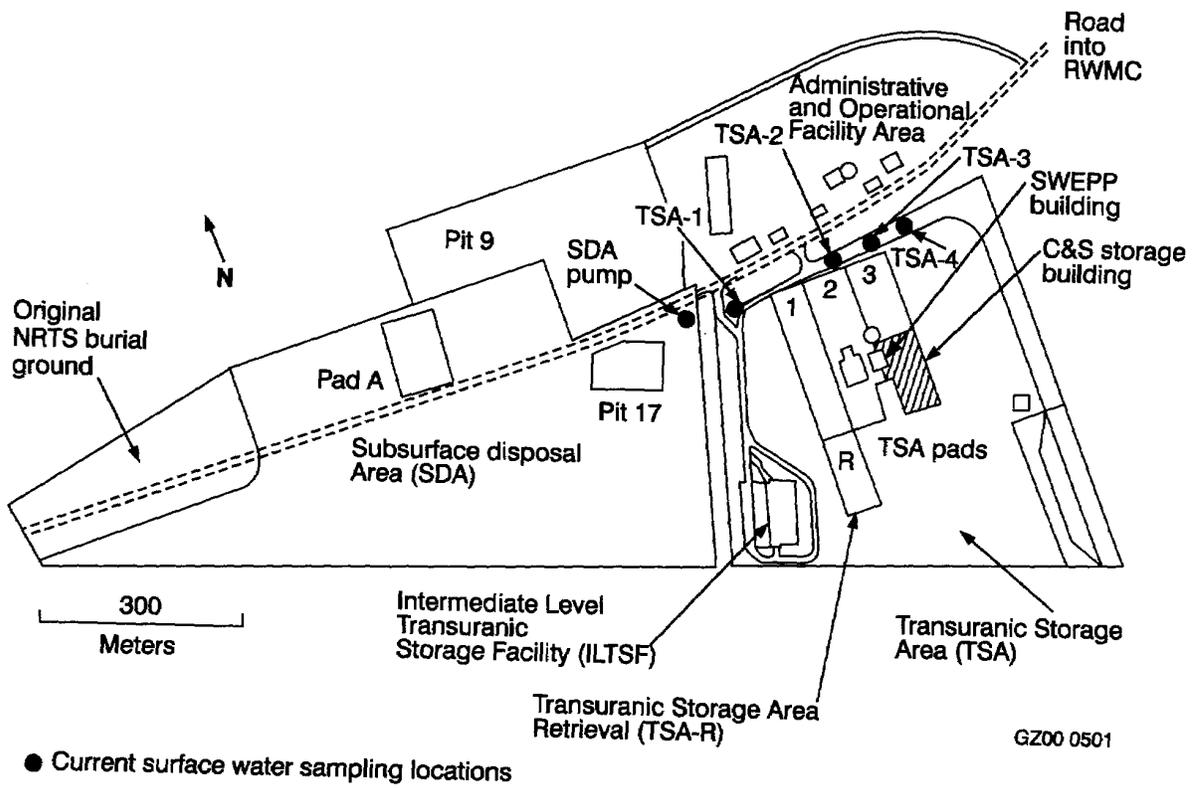


Figure 4-7. Surface water runoff sampling locations at the Radioactive Waste Management Complex.

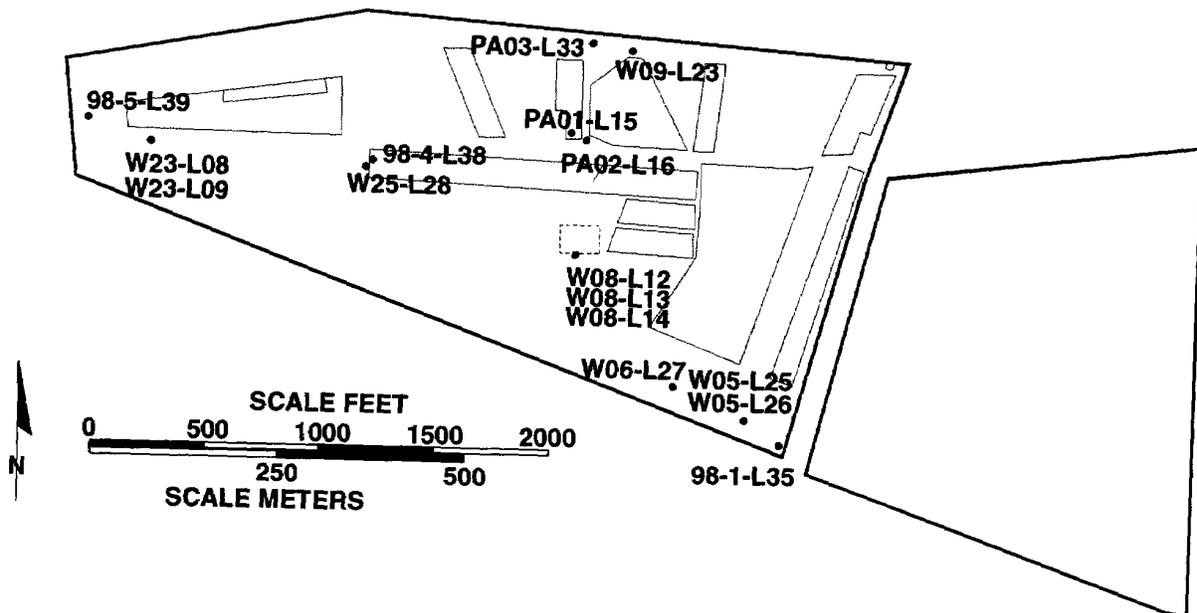


Figure 4-8. Shallow lysimeters located at depths from 0 to 35 ft.

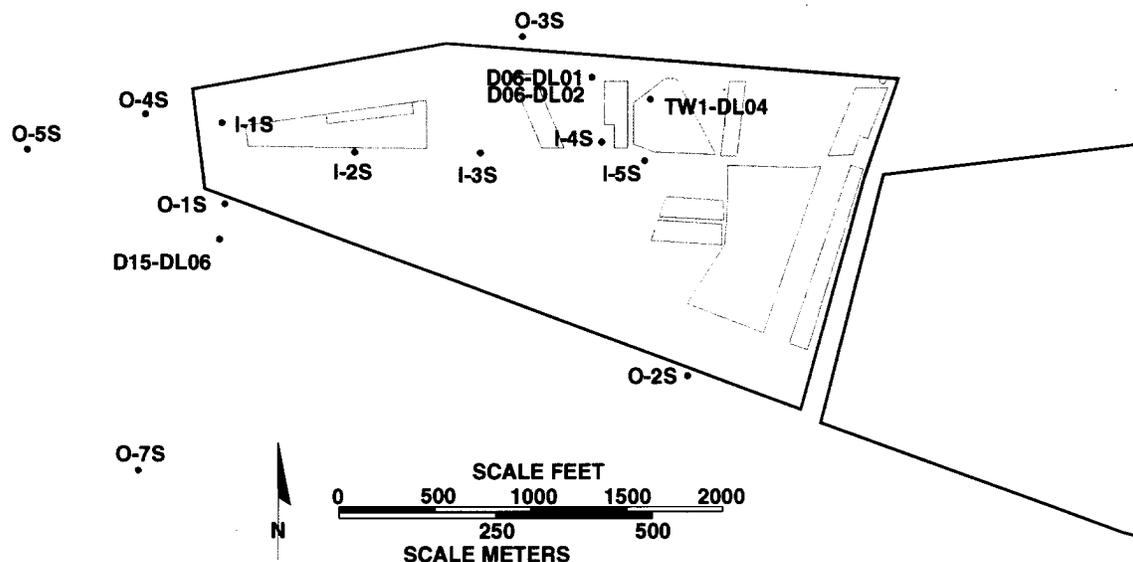


Figure 4-9. Lysimeters located in the intermediate vadose zone at depths ranging from 35 to 140 ft.

Very small volumes of soil moisture, typically 0 to 200 mL, are usually obtained from lysimeters, and 50 mL of that total volume is generally allotted for each separate analysis. The detection limits vary with the sample volume available for analysis. Detection limits increase (i.e., are less sensitive) as sample volumes decrease because of the difficulty associated with precision measurement of small amounts of sample matrix. When the soil is relatively dry, a soil moisture sample cannot be collected from the lysimeter. Analyses are prioritized to obtain the most essential data first.

Though risk-based standards and regulatory limits do not apply to the soil moisture data, comparison to such limits provides a frame of reference, particularly for radionuclides that are naturally occurring. Therefore, results from soil moisture analyses are evaluated against one of the parameters listed below:

- Maximum contaminant levels (MCLs) for groundwater
- When MCLs were not available (e.g., Am-241), or were not specific to an isotope (e.g., plutonium and uranium isotopes) data were compared to the aquifer risk-based concentrations (RBCs) equivalent to an increased cancer risk of 1E-05
- Background concentrations when available.

The soil moisture results are discussed by depth interval as follows:

- Shallow vadose zone with depths ranging from 0 to 35 ft (0 to 10.9 m) (see Figure 4-8).
- Intermediate interval from 35 to 140 ft (10.9 to 42.7 m) corresponding roughly to the interval between the A-B and B-C interbeds (see Figure 4-9).
- Deep vadose zone at depths greater than 140 ft (42.7 m). The deep vadose zone is sampled by bailers and suction lysimeters at the locations shown in Figure 4-10.

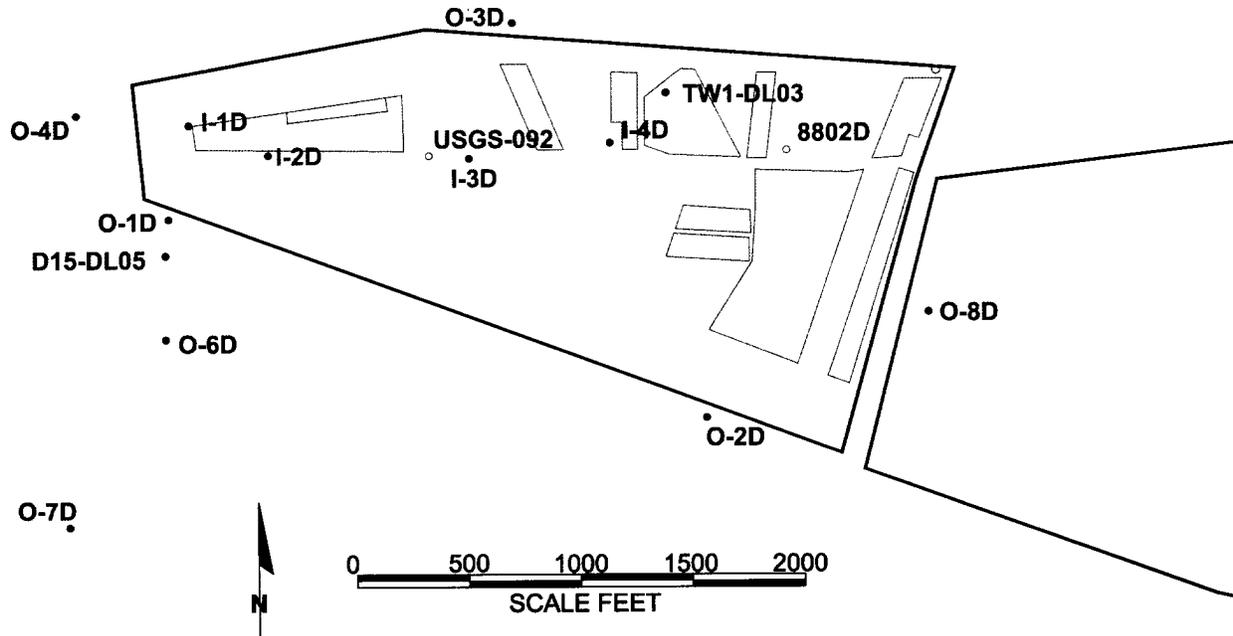


Figure 4-10. Lysimeters and bailers located in the deep vadose zone at depths greater than 140 ft.

#### 4.3.2 Perched Water Sampling with a Bailer

Perched water is present in isolated lenses above the sediments comprising the B-C and C-D interbeds. Samples from the water perched above the C-D interbed are obtained with a bailer from Wells USGS-92 and 8802D. Well USGS-92 was installed in 1972 and Well 8802D in 1988. These perched water wells have slow recharge rates and thin depths of water, often limiting the volume of water sample that can be collected in the bailer. Generally, samples can be collected at Well USGS-92, but success is sporadic at Well 8802D.

#### 4.3.3 Core Sampling

Nine core investigations have been conducted at the RWMC between 1971 and 2000. The investigations were conducted by the USGS (1971 to 1972), the DOE (1975), and various INEEL contractors (1976 to 1977, 1978, 1979, 1986 to 1987, 1993, 1994, and 1999 to 2000). Cores were extracted from numerous locations around the RWMC (see Figure 4-11). Many cores extend to the aquifer, with several depth intervals per core targeted for analyses. Core results are compared with calculated  $1E-05$  RBC for soil.

### 4.4 Aquifer Data

Most of the aquifer data come from INEEL and USGS sampling around the RWMC. Fifteen aquifer monitoring wells are monitored by the INEEL and eight additional aquifer wells are monitored by the USGS. The locations of the aquifer monitoring wells are shown in Figure 4-12. The INEEL wells around the RWMC were installed between 1992 and 2000. The USGS wells near the RWMC were installed between 1971 and 1987.

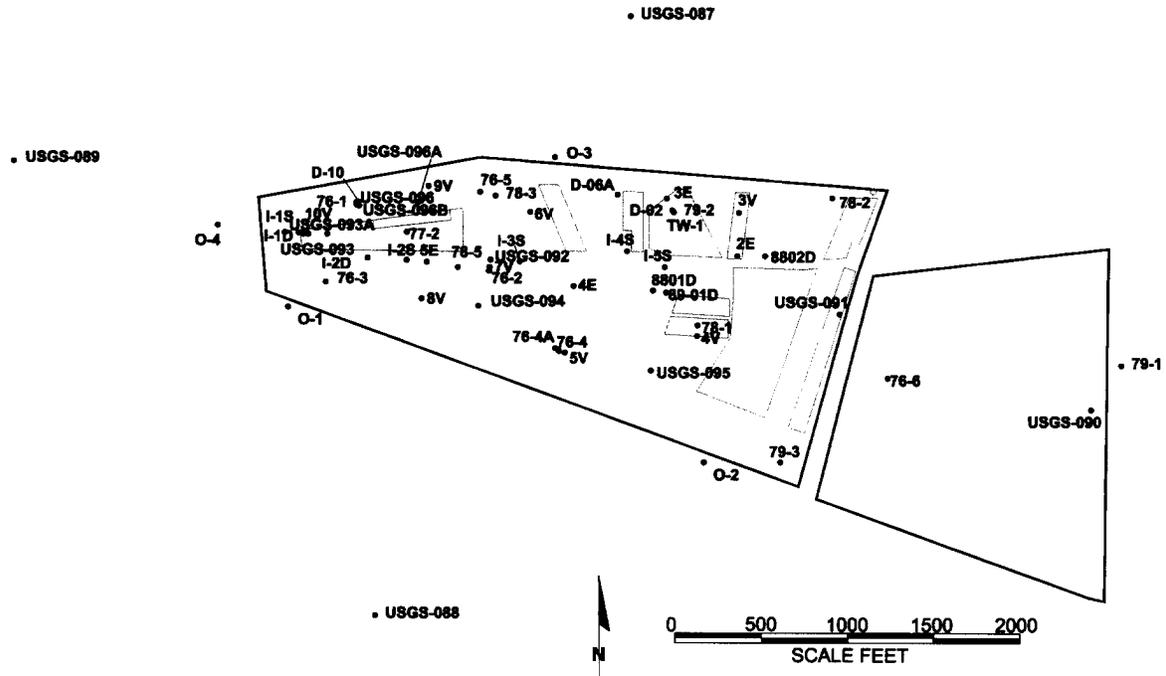


Figure 4-11. Locations of core samples collected at the Radioactive Waste Management Complex.

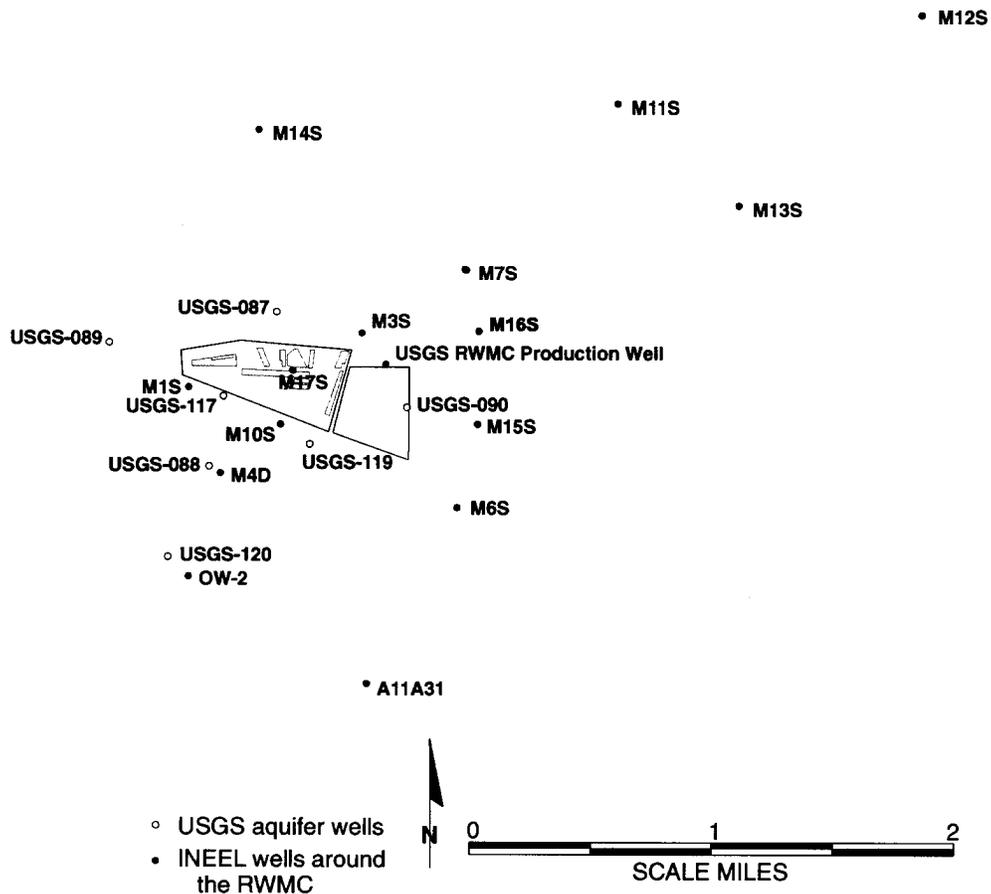


Figure 4-12. Radioactive Waste Management Complex aquifer monitoring wells.

Quarterly monitoring is typically planned for the INEEL and USGS wells each year, though sometimes only three rounds of samples are collected from the RWMC wells by the INEEL in any given year because of funding constraints. When the INEEL performs its quarterly sampling, the USGS and state oversight program also sample a few specified RWMC wells. Typically, the USGS and state oversight program sample Wells M1S and M3S in conjunction with the INEEL. Recently the USGS began cosampling Wells M7S, M11S, M12S, M13S, and M14S with the INEEL. The USGS shares their analytical data with the INEEL. The state oversight program also shares its analytical data with the INEEL when detections occur. The INEEL does not maintain records of state oversight program analytical data. When detections occur, the INEEL, USGS and state oversight program generally corroborate to confirm detections and to resolve analytical anomalies.

## 4.5 Data Interpretation Considerations

Accurate interpretation of analytical data requires an understanding of the limitations of analytical methods, such as the impact of sample preparation and potential errors associated with the measurements. Some of the key issues affecting data interpretation for the aquifer monitoring samples are discussed in the following sections.

### 4.5.1 Quality Assurance

Several quality assurance steps are implemented to ensure that aquifer data are of the highest possible quality and that the reported concentrations are representative of the concentrations in the samples. These steps include the following:

- **Laboratory subcontracting**—Laboratories analyzing INEEL samples undergo a very rigorous evaluation, certification, qualification, and approval process. The laboratory must satisfy the requirements of the national integrated contractor purchasing team and audits by the DOE national environmental monitoring and consolidated auditing program.
- **Intercomparison quality control performance programs**—Subcontracted laboratories are required to routinely participate in national intercomparison program quality control testing. The test results provide an indicator of a laboratory's analytical abilities, performance, and reliability.
- **Performance evaluation samples**—Blind performance evaluation samples are prepared with each quarterly round of aquifer samples by a separate certified and authorized laboratory and submitted to the laboratory analyzing the INEEL aquifer samples. The prepared samples are spiked with known concentrations to assess the accuracy and precision being achieved by the laboratory for routine analytical measurements. If the results do not agree with the known concentrations, all results for the affected analyte are flagged in accordance with data validation procedures as either questionable or rejected.
- **Laboratory control sample**—The laboratory is required to prepare and analyze a laboratory control sample concurrently with each batch of aquifer samples. The control sample is a spike containing known quantities of the analyte of interest prepared by the laboratory, and the control sample is processed with each batch of field samples. This sample provides a means of measuring laboratory performance and the accuracy of the analytical method. The results also are used to indicate whether the laboratory's radiochemical procedure is capable of recovering the contaminant of interest. If the percent recovery for the control samples is unsatisfactory, the rest of the aquifer sample results for the affected analyte are flagged as either questionable or rejected, in accordance with the percent recovery test criterion defined in the data validation procedures.

- **Matrix spikes**—The laboratory is required to prepare a matrix spike and matrix-spike duplicate from an aliquot of an INEEL aquifer sample. The aliquot is spiked by the laboratory with known quantities of pertinent analytes and is processed with each batch of aquifer samples. The results provide information about the effect of the sample matrix on the sample preparation and analytical processes. If the percent recovery for the matrix spike is unsatisfactory, the rest of the results for that particular analyte are flagged as either questionable or rejected, in accordance with data validation procedures.
- **Method blank**—The laboratory is required to run a laboratory-generated blank sample (i.e., method blank) with each round and batch of aquifer samples. This test is used as a means of determining the existence and magnitude of contamination resulting from the sample preparation and analysis process (e.g., from chemical reagents, laboratory glassware, laboratory equipment, or instruments). If the method blank has detectable contamination, the rest of the aquifer sample results for that particular analyte are flagged as either questionable or rejected, with consideration given to the magnitude of the difference between the blank result and the field sample results.
- **Laboratory duplicate**—The laboratory is required to prepare a laboratory-generated duplicate (i.e., split) from one of the INEEL field samples. Duplicate analyses can indicate analytical variability and laboratory precision or the homogeneity of the sample. The duplicate results must satisfy relative percent difference criteria and mean-difference criteria. If the criteria are not satisfied, either the duplicate sample results or the rest of the aquifer sample results for that particular analyte are flagged as either questionable or rejected, in accordance with the mean-difference test criterion defined in data validation procedures, which depends on the sample matrix and known sample homogeneity for that particular matrix.
- **Field duplicate**—A field duplicate is a second sample collected in the field from the same well as each quarterly round of samples. The field duplicate provides information about the representativeness, homogeneity, and variances associated with each field sampling and monitoring event. If the relative percent difference and mean-difference criteria are not satisfied, the rest of the aquifer sample results or only the duplicate sample results (for that particular analyte) are flagged as questionable or rejected, in accordance with the mean difference test criterion defined in data validation procedures, which depends on the sample matrix and known sample homogeneity for the particular matrix.
- **Field blank**—A field blank is a container of clean deionized water that is prepared and collected in the field. The field blank container accompanies the samplers throughout the entire sampling event. At each wellhead, the container is opened, and a small amount of the clean deionized water is poured into the blank container. The field blank is submitted to the laboratory and analyzed with each set of aquifer samples. The field blank provides information that is used to assess whether any sample contamination was introduced by field operations and conditions. If the field blank has detectable contamination, the rest of the aquifer samples for the detected contaminant are flagged as questionable or rejected, depending on the magnitude of the difference between the blank result and the field sample results. The mean difference test criteria are defined in data validation procedures.
- **Performance evaluation blank**—A performance evaluation blank is prepared by a certified and authorized performance evaluation sample laboratory. The blank is sealed at the preparation laboratory and never opened until it is received by the analyzing laboratory for INEEL aquifer samples. The blank provides information that is used to assess whether any sample contamination was introduced at the laboratory. If the blank has detectable contamination, then the rest of the aquifer samples for the detected contaminant are flagged as either questionable or rejected,

depending on the magnitude of the difference between the blank result and the field sample results. The mean-difference test criteria are defined in the data validation procedures.

- **Equipment rinsate**—Water is poured over, around, and through the sampling equipment after use. This sample is analyzed with each set of aquifer samples. It provides information used to assess whether any sample contamination was introduced by the sampling equipment. If the rinsate blank has detectable contamination, the rest of the aquifer samples for the detected contaminant are flagged as either questionable or rejected, depending on the magnitude of the difference between the blank result and the field sample results. The mean difference test criteria are defined in the data validation procedures.
- **Reanalysis**—When an aquifer sample contains a concentration of a radionuclide greater than  $2\sigma$  (see Section 4.5.2), the laboratory is required to pull another aliquot from the sample container and analyze it. Reanalysis of the same sample can confirm a detection and also can provide information about sample inhomogeneity. Both results are reported. If the reanalysis result is a nondetect, the sample result is not considered a confirmed detection.
- **U.S. Geological Survey sampling**—The USGS routinely collects samples from a subset of wells that are simultaneously sampled by the INEEL. The USGS validates their results and provides them to the INEEL. The two sets are compared to help assess and confirm low-level detections.
- **Laboratory performance evaluation program**—The performance of each subcontracted laboratory using various performance indicators is continually assessed and tracked by the INEEL using a formalized and documented plan (PLN) -491, "Laboratory Performance Evaluation Program Plan, INEEL Sample Management Office." This program ensures that INEEL project sample analyses are performed by the best performing subcontracted laboratories.

#### 4.5.2 Radiological Uncertainty

When radioactive materials decay, they emit alpha particles, beta particles, or photons (i.e., X-rays and gamma-rays). Emissions from the parent atoms are random and erratic and cannot be precisely measured. If the rate of radioactive decay is fast, then many particles or photons are being emitted and the radioisotope has a short half-life. Conversely, if the emission rate is slow, few particles are emitted and the radioisotope has a long half-life. The lower the emission rate, the longer the half-life and the higher the measurement uncertainty. For environmental level radioactivity, where the emissions typically occur less frequently, a much longer measurement interval is required to obtain an accurate count of the emissions and quantify the amount of radioactivity present.

Radiological uncertainty is a reported value that accompanies the reported concentration, and also follows a known probability distribution. The uncertainty value reported with each measured result is a total of all the recognized errors in the entire analytical process and is referred to as the total propagated uncertainty. The laboratory-reported uncertainty for each sample is given by the statistical standard deviation symbol, the Greek lower-case sigma ( $\sigma$ ). All laboratories subcontracted through the INEEL are required to report uncertainties at the  $1\sigma$  confidence level. Radioanalytical results are reported as a measured concentration plus or minus its uncertainty. The uncertainty measure is a function of the standard deviation and identifies a range of values that bracket the true sample value with a specified level of confidence. The standard deviation associated with each radioanalytical measurement is a very predictable value because the statistical probabilities associated with the radioactive decay processes are very well understood.

The reported uncertainty value is used to define the confidence interval for the measurement. The confidence interval for a single measured value simply defines where a specified percentage of the data would occur on repeated measurements. The 68.3% confidence interval for a value is formed by plus or minus  $1\sigma$ .

Examples for  $1\sigma$ ,  $2\sigma$ , and  $3\sigma$  are shown in Table 4-8. For example, a value of 10 with  $\sigma = 3$  (i.e.,  $10 \pm 3$ ) indicates that, upon repeated measurements, 68.3% of the results would fall between 7 and 13. Another way of looking at a value of  $10 \pm 3$  is that it specifies with 68.3% certainty that the true value lies somewhere between 7 and 13. Similarly,  $\pm 2\sigma$  defines the 95.4% confidence interval, while the 99.7% confidence interval is defined by  $\pm 3\sigma$ . For the example above, 1 to 19 (i.e.,  $10 \pm 9$ ) is the 99.7% result. The result would be considered a positive detection because the measured value (10) is greater than  $3\sigma$  (9), and the entire confidence interval, 1 to 19, is greater than 0. The second example has a larger uncertainty value of 4, indicating a statistical detection at the 95.4% confidence interval but not a positive detection at the 99.7% confidence interval. The 95.4% confidence interval is greater than 0, but the 99.7% confidence interval is not. Thus, confidence that the value is greater than 0, indicating a positive detection, is low.

Table 4-8. Example of the application of uncertainty measurements to radiological data.

Measured Value	Uncertainty ( $1\sigma$ )	Uncertainty Level	Measured Value $\pm$ Uncertainty Range	Confidence Level	Confidence Interval
10 pCi/L	3 pCi/L	$1\sigma$	$10 \pm 3$	68.3%	7 to 13 pCi/L
		$2\sigma$	$10 \pm 6$	95.4%	4 to 16 pCi/L
		$3\sigma$	$10 \pm 9$	99.7%	1 to 19 pCi/L
10 pCi/L	4 pCi/L	$1\sigma$	$10 \pm 4$	68.3%	6 to 14 pCi/L
		$2\sigma$	$10 \pm 8$	95.4%	2 to 18 pCi/L
		$3\sigma$	$10 \pm 12$	99.7%	-2 to 22 pCi/L
10 pCi/L	6 pCi/L	$1\sigma$	$10 \pm 6$	68.3%	4 to 16 pCi/L
		$2\sigma$	$10 \pm 12$	95.4%	-2 to 22 pCi/L
		$3\sigma$	$10 \pm 18$	99.7%	-8 to 28 pCi/L

The result from a sample measurement is declared as (a) a nondetection, (b) a statistical detection, or (c) a positive detection, depending on its magnitude relative to its uncertainty. If the measured value is between  $2\sigma$  and  $3\sigma$ , it is a statistical detection and qualified with a “J” validation flag to indicate the detections are questionable and should only be used as estimated quantities. If the measured value is greater than the sample-specific minimum detectable activity and is more than three times greater than its uncertainty, it is a positive detection. Otherwise, the result is a nondetection. The data quality associated with statistical detections (i.e.,  $2\sigma < x < 3\sigma$ ) does not satisfy criteria for reportable detections; however, statistical detections are evaluated closely for early indication of developing trends or sudden changes.

One of the misconceptions of confidence level is that it expresses a 68.3%, 95.4%, or 99.7% certainty that the measured value is correct. This is not what confidence level implies. Confidence level only implies that we are 68.3%, 95.4%, or 99.7% certain that the true value lies somewhere between the defined confidence intervals.

The confidence level also defines the percentage of results that are expected to be outside the defined confidence interval. For example, at the 99.7% confidence level, 0.3% of the results are expected to fall outside the  $3\sigma$  confidence interval when the measurement is repeated. Therefore, the probability that a positively identified result is actually a false positive result is 0.3%. The opposite can also occur, where the reported value is not a positive detection at the 99.7% confidence interval, but the probability is 0.3% that such a results could be incorrect (i.e., false negative).

Before 1998, Technical Procedure (TPR) -80, "Radioanalytical Data Validation," defined a radionuclide detection as a result that was greater than the sample-specific minimum detectable activity (MDA) and greater than  $2\sigma$ . After a comparison was made to the detection standards used by other agencies (i.e., USGS, IDEQ, and the INEEL Oversight Program), the detection criteria were changed to greater than the minimum detectable activity and greater than  $3\sigma$  to be consistent with the results reported by other agencies. All results identified as positive detections in this ABRA were assessed with the  $3\sigma$  criterion.

The MDA is defined as the minimum amount of radioactivity in a sample that can be detected with confidence given a defined set of background, sample, instrument, analytical and measurement conditions. The MDA is a probabilistic approach to determine whether radioactive material is present in a sample. The MDA is derived from the sample measurement, and represents the 95% probability that radioactivity is present in a sample. The MDA is defined as  $2.71 + 4.65 (B)^{1/2}$ , where B is the instrument/ambient background, and 2.71 and 4.65 are probabilistic based values. This equation was derived by Currie (1968), and is a standard method for computing the MDA throughout the analytical industry. All laboratories subcontracted through the INEEL Sample Management Office use this method of computing the MDA.

Beginning in 2002, statistical hypothesis testing to compare sample results to background levels is a planned addition to the radioanalytical data validation process. The hypothesis testing will provide additional information for determining the presence or absence of radioactivity in aquifer samples and will expedite early identification of significant changes or potential developing trends.

#### **4.5.3 Nitrogen Species**

Nitrogen is a redox element, and its chemical form in the environment is dependent on the presence or absence of electrons. In reducing environments (e.g., swamps), nitrite ( $\text{NO}_2^-$ ) is most common, and nitrate ( $\text{NO}_3^-$ ) prevails in oxidized environments. Although nitrite might be present in notable quantities in some waste environments, nitrate is the predominant species in INEEL soil, soil moisture, and aquifer samples.

Nitrogen analyses are generally accomplished by ion chromatography (EPA Method 9056), colorimetry (EPA Method 353.1 or 353.2), or spectrophotometry (EPA Method 353.3 or 354.1). When samples are analyzed by ion chromatography, nitrite and nitrate species are individually quantified. When samples are analyzed by spectrophotometry or colorimetry, the samples are generally treated with a reducing agent (e.g., cadmium or hydrazine) to reduce nitrate to nitrite, and the analysis is run on the nitrite. If requested, the laboratory will run a nitrite analysis before reducing the nitrate, then quantify the nitrate species by subtraction, but generally the combined nitrate/nitrite results are reported.

Historically, nitrogen reporting requirements for the INEEL-contracted analytic laboratories were project-specific. Generally, the laboratory reported the combined nitrite/nitrate results as nitrogen, which were input into the Environmental Restoration Information System (ERIS) database as it appeared on the laboratory forms. Sometimes, in cases where it was unclear what the species were, the result may have

been assigned one or more nitrogen codes in ERIS. For example, a sample with 4.2 µg/L nitrate result may have been archived as 4.2 µg/L nitrate, 4.2 µg/L ammonia, and 4.2 µg/L total nitrogen.

All the nitrogen data used for this report were reviewed against the original supporting documentation (e.g., laboratory reports), and only the nitrogen species reported by the laboratories are presented in the tables. However, it is unclear if the results have been converted to total nitrogen or are reported as nitrogen species in ERIS.

The consequences of this issue on the risk assessment are insignificant. Nitrate is ubiquitous in the environment, and reliable background concentrations have not been established. Therefore, discriminating the possible contribution from the SDA from other sources (e.g., fertilizer) would be problematic even if RWMC monitoring data were more certain. In addition, the quantities of nitrogen-bearing compounds in the buried waste were converted as described in Section 5 for modeling and risk assessment. The concentrations detected in the environment were not used to assess risk.

#### **4.5.4 Nuclear Logging Data**

Waste zone data are being collected from a network of probeholes in selected locations throughout the SDA. The probeholes are equipped with up to five different detectors shown in Table 4-7. The spectral gamma and neutron-neutron moisture logging tools were calibrated for a set of standard conditions corresponding to soil having a moisture content, bulk density, average atomic number, and average mass number similar to typical SDA soil (Beitel et al. 2000; Josten and Okeson 2000). The results are based on an assumed homogenized, large volume sample (approximately 10 to 15 L [2.6 to 3.9 gal]) and are representative to the extent that the probehole environment meets these conditions. If it is confirmed that these conditions are met, then these tools will be able to provide a quantitative estimate of soil moisture content and radionuclide concentration to assess source term estimates and support remedial design for the SDA. The passive neutron, n-gamma, and azimuthal tools were not quantitatively calibrated and provided only a relative measure of the targeted subsurface characteristics.

For all the tools, measurements are influenced not only by the amount of the contaminant of interest but also by the uniformity of the distributions of the contaminant, the soil, and other waste in the vicinity of the probehole. Therefore, interpretation of the logging response is subject to uncertainty, because the medium characteristics are typically heterogeneous. Nonetheless, the logging data reveal useful information that inventory records cannot provide about the physical, chemical, and radiological conditions at specific locations.

#### **4.5.5 Early 1970s Data**

In the early 1970s, the Atomic Energy Commission sponsored a hydrogeologic study of the RWMC area to determine whether waste buried in the SDA threatened the quality of the SRPA. The objectives of the study were to (a) evaluate the geologic, hydrologic, and geochemical variables that control the potential for subsurface migration of radionuclides from burial trenches to the water table, (b) determine the amount and reach of past radionuclide migration, and (c) construct wells to monitor the groundwater in the SRPA in the vicinity of the burial ground (Barracough et al. 1976). The study incorporated sampling of sediments, cores, and water.

Core data from this study contained numerous inexplicable detections, which have not been corroborated by subsequent sampling events nearby. Barracough et al. (1976) discuss the perplexity of the data, and identify the potential for “artificial contamination” at the borehole or elsewhere. The report indicates a “possibility that artificial contamination, analytical error, and statistical error are responsible

for some of the positive results. However, there are no apparent artificial contamination mechanisms that could reasonably account for all the observed values." The report also indicates that the detection of multiple contaminants in a single sample discounts the likelihood that the detections were attributable to analytical or statistical error, and stressed that the contaminant levels measured were too high to be artificial contamination.

Most perplexing was that some of the exterior borehole samples unexpectedly contained elevated Cs-137 and Sr-90, as well as detectable plutonium. The authors indicated that a portion of the detected concentrations might have been artificially introduced by the drilling method used (cable-tool method, discussed below). However, the authors also indicated that it was unlikely that the detected contamination could have been accounted for solely by the contamination introduced by drilling or sampling methods, citing that a substantial amount of contamination down hole would have been required to attain the concentrations that were actually measured. Barraclough et al. (1976) state that for the Well 93 air-blown samples from 97 to 105 ft, the 50 pounds of sediment blown up through the annular well space would have to be mixed with at least 5 lb of soil with a Pu-239/240 concentration of 2.4 pCi/g, or 0.5 lb soil with Pu-239/240 concentrations of 24.0 pCi/g, to acquire the average contaminant levels measured (0.24 pCi/g). It is also unlikely that the contamination is real, because there is no plausible source of such levels of contamination in the immediate vicinity.

A fraction of the measured contamination could have been attributable to artificial contamination introduced by the sampling method, samplers, or surface contamination blown into the hole. The four boreholes drilled outside the SDA (USGS-87, -88, -89, and -90) were drilled using the cable-tool method. The cable-tool method is a percussion technique where a heavy bit of hard steel is suspended on a cable and rhythmically raised a few feet and dropped on the formation at the bottom of the borehole. Repeated hammering breaks up the formation. Usually, a couple feet of water is maintained in the bottom of the borehole to cool the bit. Every several feet the tool is retracted to the surface and a bailing tool (hollow cylinder) is lowered to the bottom of the hole on a cable. The bailer is surged up and down in the slurry (water and cuttings) at the bottom of the hole, and a trap door valve on the bottom of the bailer allows the water and suspended rock cuttings to enter. The cuttings are removed from the hole by bringing the bailer to the surface and dumping the contents. Sediment core samples with a 4 in. diameter were obtained with a split spoon, drive core sampling tool. The sediment samples may have contained drilling water. Basalt samples or drill cuttings were a composite mixture of basalt cuttings, drilling water, sediments, and possibly caved material from higher levels within the well (Barraclough et al. 1976). Each of these exterior wells took four to five months of drilling time, with frequent movement of drilling tools in and out of the boreholes. Surface contamination and fallout particles were probably introduced to subsurface samples using this method.

Six boreholes inside the SDA (USGS-91 through USGS-96) were drilled with the dry air rotary drill, which did not require water to cool the bit and probably introduced less contamination than the cable tool method. Samples were collected using a variety of techniques (e.g., Shelby, sediment sampler, air blown) depending on the circumstances. The air-rotary method cuts the borehole by means of rotating a bit, which is pressed against the formation at the bottom of the hole. During drilling, the bit requires cooling and the cuttings must be removed from the hole. Both are accomplished by pumping compressed filtered air down the inside of the drill rod, out and around the bottom of the turning bit, and back up along the annular space between the rod and the borehole wall. Artificial contamination from this method was probably less than that from the cable-tool method; however, surface contamination could be introduced to subsurface samples by contaminating the drill, particles falling into the hole, or during air-blown sample collection at the wellhead.

Despite the possibilities of artificial contamination, Barraclough et al. (1976) indicated that these explanations were not adequate to account for the levels of contamination reported in the samples.

Barracough et al. (1976) state "...there simply is no credible source for those quantities of contamination to make contact and blend with the samples". Such statements point to the possibility of laboratory errors or uncertainties, but adequate quality assurance data (e.g., blanks and spikes) are not available to evaluate this vector. The radionuclide data from 1971 and 1972 provide evidence of contaminant transport to the interbeds, especially in the older parts of the SDA; however, the data from that time period remain questionable (see also DOE-ID 1983; Burgus and Maestas 1976).

As summarized by Barracough et al. (1976), data are questionable because of conflicting evidence. Data collected in the 30 years following the early 1970s do not support the concept of widespread contamination within and outside of the SDA in the vadose zone. Contamination could have been introduced to the subsurface prior to sampling by the water used in the cable-tool drilling process, by windblown or upper borehole sediments falling into the hole, with any of these possibilities exacerbated by the multiple trips up and down the hole to ream the hole and install casing. In addition, statistical (counting) error could account for some of the radionuclide concentrations.

The questionable data include the perched water and aquifer samples collected after the wells were completed. In particular, the aquifer samples from USGS-87 through -90 are questionable because these wells were drilled with the cable-tool method and sampled with a thief sampler. Barracough et al. (1976) state that there was opportunity for contaminated surficial sediments to enter the four exterior wells, and the concentration patterns in samples from these four wells suggest that artificial sample contamination occurred. Subsequent samples from these wells through 2000 have only sporadically contained radioactive contaminants above background.

Though some degree of uncertainty will always be associated with the issue of sample contamination during well drilling, improved techniques were applied to prevent sample contamination in each subsequent well drilling activity. In 1978, the sampling procedure was changed to include split samples that were analyzed independently of one another (Dames & Moore 1994). Protocol required that positive results had to be obtained in both samples (i.e., splits) to confirm the presence of radionuclides. In the 1970s, results were considered positive if they exceeded the  $2\sigma$  (95.4%) confidence interval (Dames & Moore 1994). In addition, the criteria for reporting positive detections have also tightened. In the 1980s, a  $3\sigma$  (99.7%) detection criterion replaced the  $2\sigma$  used previously; however, some data interpreters continued to report  $2\sigma$  results as positive detections. Thus, positive detections were defined with inconsistent protocol. In 1998, the radioanalytical data validation protocol officially adopted and implemented the  $3\sigma$  confidence interval to define a positive detection (see Section 4.5.2). This criterion was consistent with that applied by the USGS, IDEQ, and the INEEL Oversight Program.

Dames & Moore (1994) compiled and statistically reanalyzed most of the subsurface drilling and coring investigation data collected between 1971 and 1987. The core data presented in this report include data from sampling campaigns from 1971 to 2000. The 1993 investigation involved the sampling and analysis of previously unsampled, stored cores to obtain additional subsurface information.

#### **4.5.6 Lysimeter Data**

Lysimeters are used to obtain samples of soil moisture from unsaturated sediments or rock. The sample is drawn through a porous membrane or cup on the end of the lysimeter, which is usually imbedded in a silica flour backfill within the vadose zone material. Organic compounds generally are lost during the lysimeter sampling process (Wood et al. 1981). Early researchers noted that a ceramic membrane could interact and influence the chemistry of the material being sampled. Studies of soil water containing common anions, cations, and nutrients demonstrated that the porous membranes could modify the geochemistry of fluids by either sorbing or adding ions (Haines, Wade, and Topp 1982; Lord and

Shepherd 1993). Typically, the chemistry is affected by sorption of ions on the membrane, but several investigations have noted the addition of several trace constituents.

Few data relate to sampling for radionuclides with suction lysimeters. A laboratory partitioning study was conducted to evaluate the influence of the silica flour backfill and the porous cup in the suction lysimeters on sorption of selected radionuclides (Fjeld, Coates, and Elzerman 2000). The study suggests that Sr-85 and U-233 are not significantly attenuated; while Am-241 and Pu-239(IV) are attenuated by contact with the silica flour used to backfill the instruments. Tests were conducted on the sorption of radionuclides contained in a simulated groundwater while being passed through the ceramic porous membrane of a suction lysimeter. After 5 hours of contact with the porous cup, approximately 99.9% of the americium, 89% of the plutonium, 33% of the neptunium, and 3% of the uranium was retained in the ceramic. These data indicate the soil moisture collected in porous ceramic suction lysimeters will have lower concentrations of some radionuclides than the soil moisture in the surrounding undisturbed geologic media within the first five hours of sampling. Most of the lysimeters installed before 1999 had the porous ceramic cup.

Suction lysimeters with porous stainless steel were installed in the B-C and C-D interbeds in 1999 and 2000. The stainless steel should be less reactive than the ceramic membranes but may contribute trace metals to the samples.

#### **4.5.7 Aquifer Data**

The analysis of water samples collected from the deep wells outside the SDA in 1971 to 1974 showed trace quantities of waste radionuclides in some samples from all four wells. According to the authors of the report containing these data, "...the drilling and well construction techniques, the water-sample-collection methods, and the uniform distribution of positive results in all four wells suggest artificial contamination. Though these data could be the result of some waste migration to the aquifer, they are considered inconclusive evidence at this time" (Barracough et al. 1976). The data uncertainties introduced by drilling and well construction techniques are described in Section 4.5.6. For water sampling, the static thief sampler is implicated in Barracough et al. (1976) as causing some of the sample contamination, however, further explanation is not offered.

Samples from USGS-88 in the 1971 to 1972 contained anomalous concentrations of dissolved solids, magnesium, hydroxide, and high pH, suggesting cement contamination in the well. In addition, significant radionuclides were detected in samples from USGS-89 and USGS-90, which were not confirmed by later sampling, pointing to artificial contamination in these samples. Barracough et al. (1976) deemed that the data from the 1971 to 1974 sampling events were unreliable. Dedicated submersible pumps were installed in USGS-87, -88, -89, and -90 in October 1974, and sampling methods were developed that included purging three well volumes from the wells before collecting the sample. After implementation of these changes, radionuclides in the wells outside the SDA were not detected.

## **4.6 Radiological Results**

The radionuclide COPCs, tritium (H-3), and additional isotopes of plutonium are discussed in this section. Each radioisotope is evaluated for the waste zone, the surface, the vadose zone media (i.e., soil and rock in core collected during well drilling, soil moisture, and perched water), and the aquifer. Positive detections in the environment are evaluated against comparison concentrations such as RBC and MCLs. Details of the interpretation of radiological uncertainty associated with radiological results are provided in Section 4.5.2.

#### 4.6.1 Actinium-227

Actinium-227 exists in nature in very small concentrations from the decay of naturally-occurring U-235, and is an anthropic radioisotope that is a decay product of Pu-239. Actinium-227 decays by the emission of alpha and beta particles, has a 21.77-year half-life, and was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Though not typically analyzed for, the presence of Ac-227 can be inferred by the presence of its gamma-emitting progeny (i.e., Th-227) in routine gamma-spectrometric analysis. The results would be reported if it were present at concentrations above the gamma-spectrometric analysis detection limit, which is approximately 10 pCi/L. The comparison concentrations for Ac-227 are presented in Table 4-9.

Table 4-9. Comparison concentrations for actinium-227 in soil and groundwater.

Surface Soil Background Concentration (pCi/g)	Risk-Based Soil Concentration <sup>a</sup> (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>a</sup> (pCi/L)
Not established	6.8	Not established	15 (total alpha)	0.98

a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

**4.6.1.1 Waste Zone.** Approximately 5.12E-07 Ci of Ac-227 were originally disposed of in the SDA. The waste streams containing Ac-227 at the time of disposal are identified in Table 4-10.

Table 4-10. Actinium-227 waste streams and parent isotopes.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total (%)
CFA-690-1	Combustibles, animal carcasses, scrap metal, sources, sand, and gravel.	2.43E-07	47.5
TRA	Beryllium blocks.	1.76E-07	34.3
CFA-RWM-1	Central Facilities Area Sewage Treatment Plant unpainted concrete rubble, drying beds soils, clarifier piping, and trickle filter bricks.	7.20E-08	14.1
D&D-ARA-1	Low-level waste from the decontamination and demolition of the Auxiliary Reactor Area facilities. Waste stream consists primarily of contaminated metal and debris.	1.82E-08	3.6
Miscellaneous	Miscellaneous minor streams.	2.86E-09	0.6
<b>Total Disposals</b>		5.12E-07	100
U-235 ingrowth	Half-life equals 7.04E+08 years. See Section 4.6.19	1.79E+08	NA
Pu-239 ingrowth	Half-life equals 2.41E+04 years. See Section 4.6.13	7.17E+07	NA
Am-243 ingrowth	Half-life equals 7.38E+03 years. See Section 4.6.3	4.55E+04	NA

Additional quantities of Ac-227 are being generated over time through ingrowth (see Section 4.1.2). Table 4-6 also includes the amount of Ac-227 that would be produced if all of the parent decayed. Because of the long half-lives of the parent nuclides, substantial ingrowth requires many thousands of years. However, for completeness, the waste streams that contain parent nuclides also are listed in Table 4-6. Percentages of the total Ac-227 from parent isotopes are not given because the amount of Ac-227 present is dependant on the timeframe assessed.

Spectral gamma logging in the SDA provides no information about the distribution of Ac 227 in the waste zone. Distributions of parent nuclides are discussed in their respective subsections indicated in Table 4-6.

**4.6.1.2 Surface.** Actinium-227 has not been measured in routine surface sampling.

**4.6.1.3 Vadose Zone.** No data for Ac-227 are available from vadose zone core samples or from lysimeters. Though samples were not analyzed specifically for Ac-227, its presence can be inferred by concentrations of its Th-227 progeny. Routine gamma spectrometric analysis did not detect Th-227 above the minimum detectable activity.

**4.6.1.4 Aquifer.** Actinium-227 has not been detected in the aquifer. Though aquifer samples were not analyzed specifically for Ac-227, its presence can be inferred by concentrations of its Th-227 progeny. Routine gamma spectrometric analysis did not detect Th-227 above the minimum detectable activity.

#### 4.6.2 Americium-241

Americium-241 is an anthropic, transuranic radioisotope that is a decay product of Pu-241. It decays by the emission of alpha particles, has a 432.7-year half-life, and was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Because Am-241 is a surface pathway COPC, surface data are most significant to the Am-241 discussion. Americium-bearing waste in the SDA and the available Am-241 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-11.

Table 4-11. Comparison concentrations for americium-241 in soil and the aquifer.

Surface Soil Background Concentration <sup>a</sup> (pCi/g)	Risk-Based Soil Concentration <sup>b</sup> (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>a</sup> (pCi/L)
0.011	36.6	Not established	15 (total alpha)	4.6

a. Upper 95% tolerance limit with 95% confidence for composited surface soil (Rood, Harris, and White 1996).  
b. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

**4.6.2.1 Waste Zone.** Approximately 1.83E+05 Ci of Am-241 were disposed of in the SDA, with the majority being disposed of between the years of 1960 and 1972. The waste streams containing the majority of Am-241 activity are identified in Table 4-12.

Table 4-12. Waste streams containing americium-241.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
RFO-DOW-3H	Uncemented sludge.	1.46E+05	80.0
RFO-DOW-4H	Combustibles—paper, rags, plastic clothing, cardboard, wood and polyethylene bottles (Codes 330, 336, 337, 900, and 970).	2.52E+04	13.8
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot.	4.85E+03	2.6
INEEL	Idaho National Engineering and Environmental Laboratory reactor operations waste.	4.01E+03	2.2
Miscellaneous	Miscellaneous minor streams.	2.56E+03	1.4
<b>Total Disposals</b>		1.83E+05	100
Pu-241 ingrowth	Half-life equals 14.4 years. See Section 4.6.13	3.25E+04	NA

Additional quantities of Am-241 are being generated over time through ingrowth (see Section 4.1.2). Table 4-6 also includes the amount of Am-241 that would be produced by decay of the parent if all of the parent decayed. Because Pu-241 has a short half-life, the contribution to the Am-241 inventory occurs during the time period of evaluation. Percentages of Am-241 from the parent Pu-241 are not given because the amount of Am-241 present is dependent on the timeframe assessed. In addition, Am-241 will decay and produce substantial inventories of the daughter products Np-237, U-233, and Th-229.

The spectral gamma-logging tool detected Am-241 based on the 662 and 722 keV gamma rays. Of the 135 probeholes logged using this tool, 76 (56%) showed the presence of Am-241 above the noise level. Of the 4,863 total measurements (i.e., all probes and all depths), 1,068 (22%) showed the presence of Am-241 above the noise level. The Am-241 detection limit was approximately 35 nCi/g for the 662 keV gamma rays and 65 nCi/g for the 722 keV gamma rays. The maximum and average observed Am-241 levels were 30,449 and 841 nCi/g, respectively. The detection limit, maximum concentration, and average concentration are based on the assumption that Am-241 is uniformly distributed in the vicinity of the measurement points.

**4.6.2.2 Surface.** A total of 186 soil samples were collected between 1994 and 2000 from in and around the RWMC. Based on gamma spectrometric analytic results, 76 samples were evaluated for Am-241. There were 55 positive detections of Am-241, ranging from  $(1.02 \pm 0.34)E-02$  pCi/g at Pad A (LMITCO 1999) to  $1.6 \pm 0.2$  pCi/g at Pad A (LMITCO 1995c).

A total of 124 vegetation samples were collected between 1990 and 2000 from the RWMC and control locations. Of about 30 samples analyzed for Am-241, eight were positive detections ranging from  $(1.04 \pm 0.33)E-03$  pCi/g (LMITCO 1998) to  $(1.14 \pm 0.20)E-01$  pCi/g (LMITCO 1998).

A total of 210 surface run-off water samples were collected between 1991 and 2000 from the RWMC and control locations. Based on gamma spectrometric analytic results, about 93 samples were evaluated for Am-241, resulting in eight positive detections. The positive results ranged from  $(6.62 \pm 1.59)E-02$  pCi/L (LMITCO 1999) to  $3.8 \pm 0.7$  pCi/L (EG&G 1992). All run-off concentrations were less than the aquifer RBC of 4.6 pCi/L used for comparison.

**4.6.2.3 Vadose Zone.** The distributions of Am-241 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

**4.6.2.3.1 Vadose Zone Core Samples—**A total of 321 core samples were collected during well drilling and analyzed for Am-241 between 1971 and 2000 with 34 positive detections (see Table 4-13). The number of detections associated with each depth interval is shown in Table 4-14.

Table 4-13. Positive detections of americium-241 in vadose zone core samples.

Borehole Identification	Sample Depth (ft)	Concentration $\pm 1\sigma$ (pCi/g)	Date
D02	1.2 to 1.7	1.52 $\pm$ 0.06	1987
	15.5 to 16.0	0.050 $\pm$ 0.005	1987
4E	10.0 to 22.5	9.6 $\pm$ 0.7	1994
76-3	97.5 to 97.8	0.0084 $\pm$ 0.0014	1976
76-4A	23.5	0.021 $\pm$ 0.003	1976
	97.8	0.0064 $\pm$ 0.0017	1976
	226.0	0.023 $\pm$ 0.003	1976
78-2	235.7	0.033 $\pm$ 0.003	1978
79-2	99.1 to 99.9	0.031 $\pm$ 0.003	1979
	99.1 to 99.9	0.022 $\pm$ 0.002	1979
	99.9 to 101.7	0.013 $\pm$ 0.003	1979
	99.9 to 101.7	0.018 $\pm$ 0.002	1979
	101.7 to 103.0	0.024 $\pm$ 0.003	1979
	101.7 to 103.0	0.020 $\pm$ 0.003	1979
USGS-93	13.8 to 14.0	0.012 $\pm$ 0.003 <sup>a</sup>	1972
	101.0 to 103.0	0.063 $\pm$ 0.010 <sup>a</sup>	1972
	101.0 to 103.0	0.15 $\pm$ 0.02 <sup>a</sup>	1972
	103.0 to 105.0	0.045 $\pm$ 0.004 <sup>a</sup>	1972
USGS-96	110.0 to 112.9	0.030 $\pm$ 0.006 <sup>a</sup>	1972
TW1	101.0 to 101.2	0.44 $\pm$ 0.02	1987
	101.0 to 101.2	0.47 $\pm$ 0.02	1987
	101.2	0.103 $\pm$ 0.008	1987
	101.2	0.106 $\pm$ 0.009	1987
	101.2	0.137 $\pm$ 0.011	1987
	101.2	0.908 $\pm$ 0.008	1987
	101.2	0.107 $\pm$ 0.009	1987
	101.2	0.085 $\pm$ 0.009	1987
I-1S	105.5	0.022 $\pm$ 0.006	1999 to 2000
	110.6 to 111.0	0.021 $\pm$ 0.006	1999 to 2000
I-1D	237.6 to 238.0	0.016 $\pm$ 0.005	1999 to 2000
I-2S	99.0 to 100.0	0.021 $\pm$ 0.006	1999 to 2000
	111.0	0.019 $\pm$ 0.005	1999 to 2000
	112.5 to 113.0	0.031 $\pm$ 0.008	1999 to 2000
I-4D	237.5 to 238.0	0.021 $\pm$ 0.007	1999 to 2000

a. Data from 1972 through 1974 must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Table 4-14. Americium-241 detections in vadose zone core samples from each depth interval.

Depth Interval (ft)	Number of Detections/ Number of Samples (%)	Concentration Range (pCi/g)	Wells or Boreholes with Detections
0 to 35	5/30 (16.7)	0.012 to 9.6	4E, 76-4A, D02, USGS-93
35 to 140	25/139 (18.0)	0.006 to 0.908	76-3, 76-4A, 79-2, TW1, I-1S, I-2S
140 to 250	4/142 (2.8)	0.016 to 0.033	76-4A, 78-2, I-1D, I-4D
>250	0/10 (0)	Not applicable	Not applicable

Of the 34 positive detections, 32 exceeded the surface soil background concentration of 0.011 pCi/g (Rood, Harris, and White 1996). Detection rates were similar in the 0 to 35-ft and 35- to 140-ft depth intervals, 16.7 and 18.0%, respectively. The detection rate of 2.8% was considerably lower for samples collected at depths greater than 140 ft. Many of the Am-241 detections (i.e., 21 of 34) were corroborated by detections of other actinides such as Pu-238 and Pu-239. None of the four detections in the 140- to 250-ft depth interval were accompanied by detections of other actinides.

Six of the 13 cores with detectable Am-241 were located on the west end of the SDA, and three of the 13 occurred near Pad A and Pit 5. Eight analyses from TW1 at the 101-ft depth detected concentrations of Am-241, which provide confirmation that Am-241 is present at that location and depth. The results from Well 4E at 10 ft deep and from Well D02 at 1.5 ft deep, exceeded the surface soil background concentration but are lower than the calculated 1E-05 RBC for soil of 36.6 pCi/g.

**4.6.2.3.2 Lysimeter Samples at Depths of 0 to 35 ft**—A total of 106 shallow lysimeter samples were analyzed by INEEL for Am-241 between 1997 and May 2001, with five positive detections (see Table 4-15). The occurrence of the detections relative to other sampling events is shown in Figure 4-13.

Table 4-15. Positive detections of americium-241 in shallow lysimeters in the 0- to 35-ft depth interval.

Lysimeter	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
W23-L09	7.7	0.8 $\pm$ 0.2	A	November 1998
PA01-L15	14.3	<b>9 <math>\pm</math> 2<sup>a</sup></b>	B	April 1998
PA03-L33	10	4.2 $\pm$ 0.7	A	February 1998
98-5L39 (SDA-10)	10.5	0.8 $\pm$ 0.2	B	December 1998
		0.30 $\pm$ 0.09	B	March 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

Note: Concentration in **red bold** indicates that the value exceeds the 1E-05 aquifer risk-based concentration (4.6 pCi/L), which is not applicable to lysimeter samples but is presented as a basis of comparison.

		Lysimeter											
Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01- L15	PA02- L16	PA03- L33	W06- L27	W08- L13	W08- L14	W23- L08	W23- L09	W25- L28
1997	1												
	2												
	3												
	4												
1998	1						4.2						
	2				9								
	3												
	4			0.8								0.8	
1999	1												
	2												
	3												
	4												
2000	1			0.30									
	2												
	3												
	4												
2001	1												
	2												
	3												
	4												
Key		Analysis was performed for Am-241, but none was detected.											
		Am-241 was detected (pCi/L).											
		If more than one positive detection occurred in a well in a single quarter, only the highest concentration is listed.											

Figure 4-13. Shallow lysimeter monitoring results for americium-241.

The concentration of  $9 \pm 2$  pCi/L in Lysimeter PA01-L15 is relatively high compared to the positive detections in the other samples. The  $9 \pm 2$  pCi/L were yielded by one of two duplicate samples taken from Lysimeter PA01-L15 on the same day. The other sample did not contain detectable Am-241. In addition, seven other sampling events have been performed in Lysimeter PA01-L15 since April 1998, with no other detections. The detection of  $4.16 \pm 0.66$  pCi/L in Lysimeter PA03-L33 was not confirmed with a reanalysis, and the detection was not followed by any positive detections in subsequent sampling events. At least two subsequent samples have been collected following detections from the other wells through May 2001, with no positive detections. Lysimeters 98-5L39 and W23-L09 are located on the west end of the SDA, and Lysimeter PA03-L33 is located near Pad A.

The low concentrations of Am-241 in the lysimeter samples next to vadose zone core samples with detectable Am-241 may be interpreted as evidence of migration. The relatively high detections of Am-241 around Pad A in Lysimeters PA03-L33 and PA01-L15 are comparable to the  $1E-05$  RBC for the aquifer. The sample results may be biased low because of possible Am-241 retention in the porous ceramic cup in the lysimeters (see Section 4.5.6).

**4.6.2.3.3 Lysimeter Samples at Depths from 35 to 140 ft**—A total of 40 lysimeter samples from 13 locations were analyzed for Am-241 between 1997 and May 2001, with three positive detections as listed in Table 4-16. The occurrence of detections relative to nondetections is shown in Figure 4-14.

Table 4-16. Positive detections of Am-241 in lysimeter samples from 35 to 140 ft.

Lysimeter	Depth (ft)	Am-241 Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
D06-DL01	88.0	0.8 $\pm$ 0.2	A	December 1998
TW1-DL04	102.0	1.9 $\pm$ 0.5	A	March 2000
D15-DL06	98.0	2.4 $\pm$ 0.7	A	April 1998

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

Year	Quarter	Lysimeters												
		D06-DL01	D06-DL02	D15-DL06	I-1S	I-2S	I-3S	I-4S	I-5S	O-2S	O-3S	O-4S	O-5S	TW1-DL04
1997	1													
	2													
	3													
	4													
1998	1													
	2			2.4										
	3													
	4	0.8												
1999	1													
	2													
	3													
	4													
2000	1													1.9
	2													
	3													
	4													
2001	1													
	2													
	3													
	4													
Key		Analysis was performed for Am-241, but none was detected.												
		Am-241 was detected (pCi/L).												
		If more than one positive detection occurred in a well in a single quarter, only the highest concentration is listed.												

Figure 4-14. Intermediate-depth (35 to 140 ft) lysimeter monitoring results for americium-241.

The positive sample results could not be confirmed by reanalysis because of the limited water sample obtained from lysimeters. Subsequent samples collected from these three wells through May 2001 have not yielded positive detection of Am-241. Two of the three detections (i.e., Wells D06 and TW1) occurred in the vicinity of Pad A and Pit 5, and the third (Well D15) is located outside the SDA boundary on the southwest end of the site.

Developing trends in the intermediate-depth lysimeter data are not apparent. All three Am-241 detections over a 4-year period were less than the 1E-05 RBC for the aquifer of 4.6 pCi/L used as a basis of comparison. The porous ceramic cup on the lysimeter may be retaining a fraction of the Am-241 (see Section 4.5.6), thus introducing a low bias to the sample results. Therefore, Am-241 could be present in higher concentrations than measured.

**4.6.2.3.4 Lysimeter and Perched Water Samples at Depths Greater than 140 ft—**

Including USGS analyses, a total of 52 perched water samples, 10 filtered sediment samples, and five deep suction lysimeter samples were analyzed for Am-241 between 1974 and December 2000. Two positive detections of Am-241 occurred, both in Well USGS-92 as shown in Table 4-17. Neither sample exceeded the aquifer 1E-05 RBC of 4.6 pCi/L used for comparison. Well USGS-92 is not near locations where Am-241 was detected in vadose zone core samples or in the other lysimeter samples. The detection rate for the deep lysimeter and perched water samples was 3.8% (i.e., two out of 52 samples).

Table 4-17. Positive detections of americium-241 in deep perched water.

Well	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Date
USGS-92	214	0.041 $\pm$ 0.012	October 1976
		0.14 $\pm$ 0.04	October 1992

Subsequent water samples collected from Well USGS-92 through December 2000 have not shown Am-241 detections. Perched water samples are filtered because they typically contain sediments. The filtered sediments also were analyzed for Am-241 with no positive detections.

**4.6.2.4 Aquifer.** A total of 261 aquifer samples from INEEL wells were analyzed for Am-241 between 1992, when aquifer monitoring for Am-241 began, and April 2001 with five positive detections. None of the detections exceeded the calculated aquifer 1E-05 RBC of 4.6 pCi/L, as shown in Table 4-18. The distribution of Am-241 detections in the INEEL aquifer samples is shown in Figure 4-15. Only the October 1997 sample result was confirmed by reanalysis of the original sample. Subsequent samples collected from these wells through April 2001 have not shown positive detections.

Table 4-18. Positive detections of americium-241 in the aquifer.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
M11S	0.026 $\pm$ 0.008	B	April 1999
M1S	1.13 $\pm$ 0.13	D	October 1997
	1.03 $\pm$ 0.08	D	October 1997
	1.97 $\pm$ 0.13	B	May 1998
M3S	0.027 $\pm$ 0.008	B	September 2000

a. Confirmation flag:

B = Reanalysis performed, no confirmation.

D = Detection confirmed by reanalysis.

Note: Highlighted values are the original and the confirmatory analyses. Positive detection was confirmed.

In addition to the RWMC monitoring aquifer wells managed and routinely sampled by the INEEL, the USGS manages, controls, and routinely samples eight other aquifer wells in the vicinity of the RWMC (see Section 4.4), and also collects samples from some of the INEEL wells. A total of 489 USGS aquifer well samples in the vicinity of the RWMC were analyzed for Am-241 between 1972 and

October 2000, with 23 detections (see Table 4-19). Results from the USGS and INEEL aquifer sampling from 1992 through 2001 are shown in Figure 4-15. Samples collected by the USGS in Wells M1S and M3S from 1997 through 2000 did not verify the positive detections yielded in the INEEL samples. The USGS does not collect samples from Well M11S.

All but two of the USGS detections occurred between 1972 and 1974, shortly after the wells were drilled and installed (see Figure 4-16). The 1972 and 1974 detections are suspect because of possible contamination problems associated with early well drilling and well construction techniques and the types of sampling methodology employed at that time (Barraclough et al. 1976) (see Section 4.5.5). Subsequent samples collected from the USGS wells from 1975 through 2000 have shown only two positive Am-241 detections, one in 1981 and one in 1982. Numerous sampling events since these detections have not identified Am-241. The concentrations of Am-241 detected are well below the aquifer 1E-05 RBC of 4.6 pCi/L.

**Summary of Americium-241.** Americium-241 is a COPC because it poses a risk in the 1,000-year simulation period from soil ingestion, inhalation, external exposure, and crop ingestion pathways (Becker et al. 1998). Approximately 1.83E+05 Ci of Am-241 were disposed of in the SDA, with about 80% of that being in the form of uncemented sludge from RFP. Americium-241 has been detected in about 56% of the waste zone probeholes examined with the spectral gamma logging tool, and has been detected in surface soil, vegetation, and run-off samples (see Table 4-20).

Approximately 17 to 18% of the vadose zone core samples collected in the 0- to 35-ft and 35- to 140-ft depth intervals contain detectable amounts of Am-241, compared with approximately 3% in the depth interval from 140 to 250 ft. The Am-241 detection rate in soil moisture samples is less than 8% in all depth intervals, and the Am-241 concentrations in the lysimeter samples may be biased low by Am-241 retention on the ceramic cups in the lysimeters (see Section 4.5.6).

Spatially, there appears to be a cluster of Am-241 detections in both vadose zone core samples and soil moisture samples in the 0- to 35-ft and 35- to 140-ft depth intervals in the region below Pad A and Pit 5 and at the western end of SDA near Pits 1 and 2. However, the detections in soil moisture samples are sporadic and do not exhibit temporal trends. Americium-241 was detected in aquifer samples from Well M1S south of Pits 1 and 2 in 1997 and 1998, and from Wells M3S and M11S, which are both upgradient of the SDA. The distribution of Am-241 detections in the various depth intervals is depicted in Figure 4-17.

The aquifer detection rate is very low at 2%. All detections are less than the aquifer RBC of 4.6 pCi/L with the exception of one USGS sample from the questionable 1972 data set.

Table 4-19. Positive detections of americium-241 in aquifer wells monitored by the U.S. Geological Survey.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Date
USGS-87	$0.040 \pm 0.010^a$	October 1972
	$0.30 \pm 0.02^a$	May 1973
	$0.11 \pm 0.02^a$	August 1973
	$0.13 \pm 0.02^a$	September 1973
USGS-88	$0.045 \pm 0.008^a$	April 1973
	$0.13 \pm 0.02^a$	May 1973
	$0.07 \pm 0.02^a$	June 1973
	$0.08 \pm 0.02^a$	August 1973
	$0.07 \pm 0.02^a$	September 1973
	$0.020 \pm 0.006$	July 1982
USGS-89	<b><math>5 \pm 1^a</math></b>	October 1972
	$0.011 \pm 0.002^a$	June 1973
	$0.07 \pm 0.02^a$	July 1973
	$0.14 \pm 0.03^a$	August 1973
	$0.09 \pm 0.02^a$	September 1973
	$0.11 \pm 0.02^a$	September 1973
	$0.027 \pm 0.002^a$	January 1974
	$0.09 \pm 0.02^a$	December 1974
USGS-90	$1.5 \pm 0.4^a$	September 1972
	$0.17 \pm 0.02^a$	April 1973
	$0.07 \pm 0.02^a$	July 1973
	$0.13 \pm 0.03^a$	September 1973
	$0.14 \pm 0.04$	October 1981

a. The 1972 to 1974 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Note: Concentration in **red bold** indicates that the value exceeds the 1E-05 aquifer risk-based concentration of 4.6 pCi/L.

Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11A31	OW-2	
1992	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
1993	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
1994	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
1995	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
1996	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
1997	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
1998	1	Green	Green	Green	Green		Green	Green	Green	1.13															
	2	Green	Green	Green	Green		Green	Green	Green	1.97															
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
1999	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
2000	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green	0.027															
2001	1	Green	Green	Green	Green		Green	Green	Green																
	2	Green	Green	Green	Green		Green	Green	Green																
	3	Green	Green	Green	Green		Green	Green	Green																
	4	Green	Green	Green	Green		Green	Green	Green																
Key		Analysis was performed for Am-241, but none was detected.																							
		Am-241 was detected (pCi/L).																							
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.																							

Figure 4-15. Aquifer monitoring results of americium-241 in Idaho National Engineering and Environmental Laboratory and U.S. Geological Survey wells from 1992 through 2001.

Figure 4-16. Aquifer americium-241 monitoring results from the U.S. Geological Survey, 1972 through 1991.

Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120
1972	1								
1972	2								
1972	3								
1972	4	0.040 <sup>a</sup>	5			1.5 <sup>b</sup>			
1973	1								
1973	2	0.3	0.13	0.011	0.17	0.13			
1973	3	0.13	0.08	0.14	0.13				
1973	4								
1974	1								
1974	2			0.027					
1974	3								
1974	4				0.09				
1975	1								
1975	2								
1975	3								
1975	4								
1976	1								
1976	2								
1976	3								
1976	4								
1977	1								
1977	2								
1977	3								
1977	4								
1978	1								
1978	2								
1978	3								
1978	4								
1979	1								
1979	2								
1979	3								
1979	4								
1980	1								
1980	2								
1980	3								
1980	4								
1981	1								
1981	2								
1981	3								
1981	4					0.14			
1982	1								
1982	2								
1982	3							0.020	
1982	4								
1983	1								
1983	2								
1983	3								
1983	4								
1984	1								
1984	2								
1984	3								
1984	4								
1985	1								
1985	2								
1985	3								
1985	4								
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1988	1								
1988	2								
1988	3								
1988	4								
1989	1								
1989	2								
1989	3								
1989	4								
1990	1								
1990	2								
1990	3								
1990	4								
1991	1								
1991	2								
1991	3								
1991	4								

Note: If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.  
a. Value reported in Barracough et al. (1976) is 15±0.04 pCi/L in Table IV and 0.15±0.40 pCi/L in Table A-IX. The laboratory data stored on microfiche at the HDR are illegible, thus the value cannot be confirmed.  
b. Table A-IX in Barracough et al. (1976) report this value as 0.05±0.01 pCi/L. Laboratory data on microfiche at the HDR indicate that 0.04 pCi/L is correct.  
Analysis was performed for Am-241, but none was detected.

Table 4-20. Frequencies of americium-241 detection in sampled media.

Media	Detection Rate (%)	Range of Detected Concentrations	Total Number of Detections Higher than the Risk-Based Concentration <sup>a</sup>	Wells with Detections Higher than the Risk-Based Concentration <sup>a</sup>
Waste zone	Boreholes: 56 Measurements: 22	0.035 to 30.4 pCi/g	0	None
Surface soil	72.4	0.01 to 1.6 pCi/g	0	None
Surface runoff	8.6	0.067 to 3.8 pCi/L	0	None
Vadose zone (0 to 35 ft):				
Cores	16.7	0.012 to 9.6 pCi/g	0	None
Soil moisture	4.8	0.30 to 9	1	PA01
Vadose zone (35 to 140 ft):				
Cores				
Soil moisture	18.0	0.006 to 0.908 pCi/g	0	None
	7.5	0.8 to 2.4 pCi/L	0	None
Vadose zone (140 to 250 ft):				
Cores				
Soil moisture	2.8	0.016 to 0.033 pCi/g	0	None
	3.5	0.041 to 0.14 pCi/L	0	None
Vadose zone (>250 ft):				
Cores	0	Not analyzed	0	None
Aquifer-Idaho National Engineering and Environmental Laboratory	1.9	0.011 to 1.97 pCi/L	0	None
Aquifer-U.S. Geological Survey	4.7	0.01 to 5 pCi/L	1	USGS-89

a. The calculated 1E-05 risk-based concentration (RBC) for soil is 36.6 pCi/g. For lysimeter, perched water, and aquifer samples, the calculated 1E-05 aquifer RBC is 4.6 pCi/L, which does not apply to perched water and lysimeter samples but is presented as a basis for comparison.

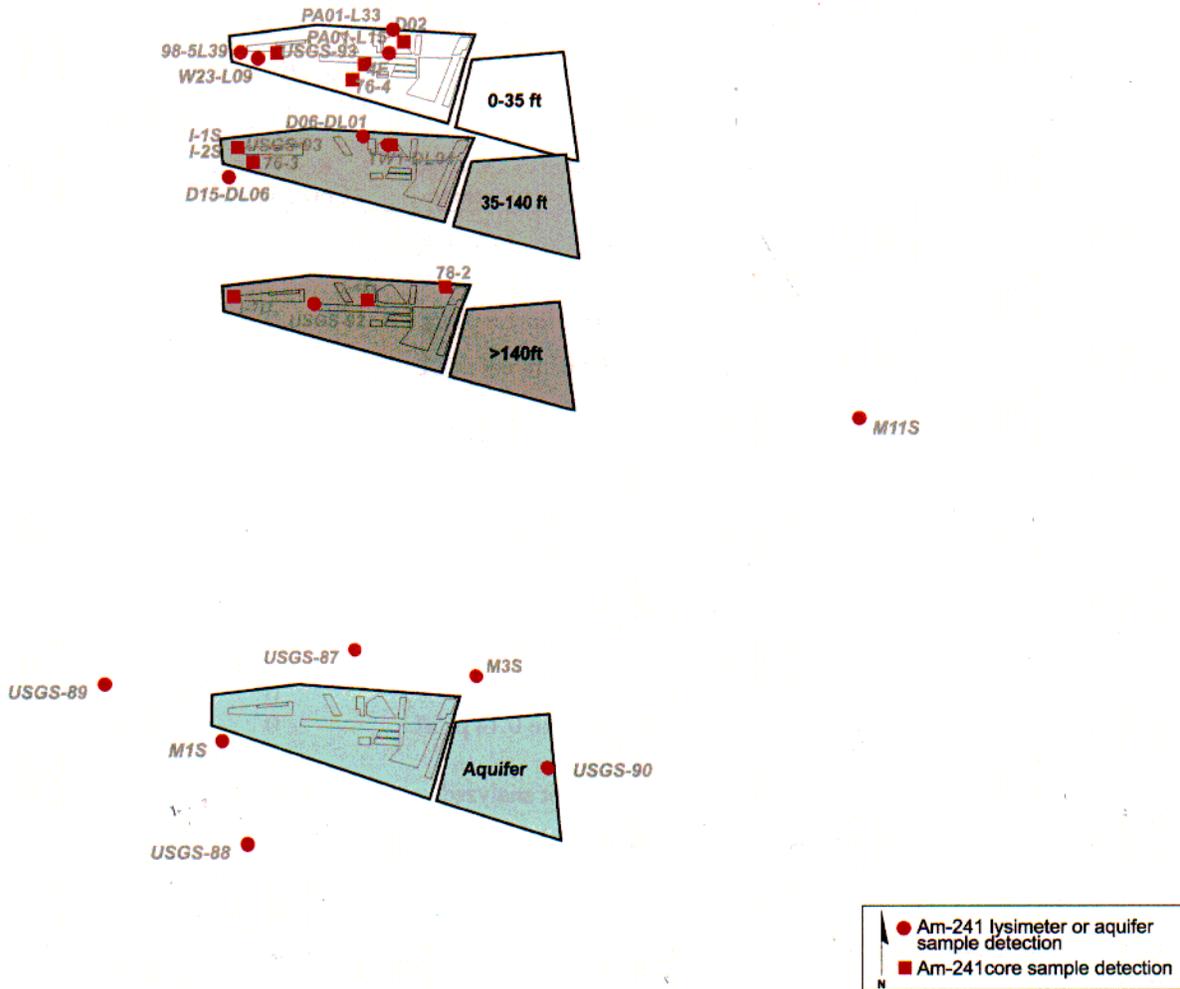


Figure 4-17. Locations of americium-241 detections in vadose zone core, lysimeters, and the aquifer.

### 4.6.3 Americium-243

Americium-243 is an anthropic, transuranic radioisotope that is produced from nuclear reactor operations and weapons manufacturing and testing. It decays by the emission of alpha particles, has a 7,370-year half-life. Americium-243 was identified as a COPC in the IRA, primarily from the external exposure pathway (Becker et al. 1998), and because it is the long-lived parent of another COPC, Pu-239. It was explicitly modeled to assess the affects of progeny ingrowth on fate and transport and on cumulative risk from Pu-239. Americium-bearing waste in the SDA are summarized below.

Americium-243 has not been included on the ER Program radionuclide target list provided to the analytical laboratories subcontracted to the INEEL. It is not essential to routinely sample and analyze for Am-243 because (a) the presence of Am-243 can be inferred from detection of its gamma-emitting progeny (Np-239) above the detection limit (about 10 pCi/L) by routine gamma spectrometric analysis, (b) to analyze specifically for Am-243, a nonroutine radiometric tracer would be required, and the sample would have to be prepared and analyzed separately from customary americium analysis, (c) concentrations would likely be below the method detection limit, and (d) Am-243 was not retained for further risk analysis in the IRA (Becker et al. 1998).

**4.6.3.1 Waste Zone.** Approximately 1.34E+02 Ci of Am-243 were disposed of in the SDA. The waste streams containing the majority of Am-243 activity are identified in Table 4-21. Americium-243 decays to produce Pu-239, U-235, Pa-231, and Ac-227 (see Section 4.1.2). However, because of the small initial inventory, the relative contribution to the total inventory of the daughter products is small.

Table 4-21. Waste streams containing americium-243.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste	1.34E+02	99.6
Miscellaneous	Miscellaneous minor streams	~0	0.4
<b>Total Disposals</b>		<b>1.34E+02</b>	<b>100</b>

**4.6.3.2 Summary of Americium-243.** No analytical data are available for Am-243.

### 4.6.4 Carbon-14

Carbon-14 is a radioisotope generated by nuclear operations as an activation product. It decays by the emission of beta particles and has a 5,715-year half-life. It also occurs naturally with low abundance in the environment. Carbon-14 was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Carbon-14-bearing waste in the SDA and the available C-14 monitoring data for all media are summarized below. Monitoring for C-14 began after the PSRA (Burns et al. 1994; Loehr et al. 1994) and the LLW Radiological Performance Assessment (Maheras et al. 1994) identified C-14 as a possible contributor to unacceptable risk or dose. The sampling data in this section are evaluated against the comparison concentrations in Table 4-22.

Table 4-22. Comparison concentrations for carbon-14 in groundwater and soil.

Surface Soil Background Concentration (pCi/g)	Risk-Based Soil Concentration <sup>a</sup> (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>a</sup> (pCi/L)
Not established	2,845	Not established	2,000	307

a. Calculated risk-based concentration, equivalent to an increased cancer risk of 1E-05.

**4.6.4.1 Waste Zone.** Approximately 500 Ci of C-14 were disposed of in the SDA. Waste streams containing the majority of C-14 activity are identified in Table 4-23. Gamma spectral logging in the waste zone provides no information about C-14.

Table 4-23. Waste streams containing C-14.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Test Reactor Area (TRA)	Activation products.	2.08E+02	41.7
NRF-616-3H, 4H, 8H	Core structural pieces.	1.07E+02	21.3
TRA	Beryllium waste.	9.26E+01	18.5
CPP-603-1H	Fuel end pieces.	4.58E+01	9.2
Argonne National Laboratory-West	Subassembly hardware.	1.66E+01	3.3
Miscellaneous	Miscellaneous minor streams.	1.45E+01	2.9
TRA-603-1H	TRA resins.	7.81E+00	1.6
ANL-785-1	Subassembly low-level waste from the Hot Fuel Examination Facility experiments.	7.51E+00	1.5
<b>Total Disposals</b>		<b>5.00E+02</b>	<b>100</b>

**4.6.4.2 Surface.** No data are available because C-14 has not been a target analyte for surface sampling.

**4.6.4.3 Vadose Zone.** The distributions of C-14 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

**4.6.4.3.1 Vadose Zone Core Samples—**A total of 52 core samples were analyzed for C-14 between 1994 and 2000 and no positive detections. Previous core sampling investigations from 1971 to 1993 did not analyze for C-14 because it was not identified as a radionuclide of concern until 1994 (Burns et al. 1994; Loehr et al. 1994; Maheras et al. 1994). The distribution of samples over the depth intervals is shown in Table 4-24.

Table 4-24. Distribution of C-14 in vadose zone core samples in the various depth intervals.

Depth Interval (ft)	Number of Detections/ Number of Samples (%)	Range (pCi/g)	Cores with Detections
0 to 35	0/11 (0)	Not detected	None
35 to 140	0/25 (0)	Not detected	None
140 to 250	0/16 (0)	Not detected	None
Greater than 250	0/0 (0)	Not detected	None

**4.6.4.3.2 Lysimeter Samples at Depths from 0 to 35 ft**—A total of 59 shallow lysimeter samples were analyzed for C-14 between 1997 and September 2000, with seven positive detections as shown in Table 4-25. Five of the seven positive detections were from one lysimeter (i.e., PA02-L16). The occurrence of C-14 detections in the shallow lysimeter samples is shown in Figure 4-18.

Only the August 1997 C-14 results for Lysimeter PA02-L16 was a confirmed positive detection by reanalysis of the original sample. The other samples that contained detectable C-14 were of insufficient volume to perform the confirmation analyses. Concentrations in Lysimeter PA02-L16 appear to be increasing over time, though the concentrations are still one order of magnitude below the aquifer RBC of 307 pCi/L used for comparison. The most recent sample collected from Lysimeter PA02-L16 did not contain detectable concentrations of C-14. In fact, none of the recent lysimeter samples have shown positive detections of C-14.

Table 4-25. Positive detections of carbon-14 in shallow lysimeters.

Lysimeter	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
PA02-L16	8.7	16 $\pm$ 3	A	April 1997
		18 $\pm$ 4	D	August 1997
		19 $\pm$ 4	D	August 1997
		21.8 $\pm$ 1.9	A	April 1998
		26 $\pm$ 5	A	May 1999
W06-L27	11.8	11 $\pm$ 3	A	April 1997
98-4L38 (SDA-08)	17	24 $\pm$ 5	A	May 1999

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

D = Detection confirmed by reanalysis.

Note: Highlighted values are the original and confirmation analyses. Positive detection was confirmed.

**4.6.4.3.3 Lysimeter Samples at Depths of 35 to 140 ft**—A total of eight lysimeter samples from the three wells were analyzed for C-14 between 1997, when C-14 monitoring began, and November 1998, with no positive detections. Only samples from Lysimeters D06-DL02, TW1-DL04, and D15-DL06 were analyzed for C-14; the other lysimeter samples did not yield sufficient water volume during sampling to perform the C-14 analysis.

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01- L15	PA02- L16	PA03- L33	W06-L27	W08-L13	W08-L14	W23-L08	W25-L28
1997	1											
	2					16		11				
	3					19						
	4											
1998	1											
	2					21.8						
	3											
	4											
1999	1											
	2		24			26						
	3											
	4											
2000	1											
	2											
	3											
	4											
2001	1											
	2											
	3											
	4											
Key		Analysis was performed for C-14 , but none was detected.										
		C-14 was detected (pCi/L).										
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.										

Figure 4-18. Occurrence of carbon-14 in shallow lysimeters (in pink).

**4.6.4.3.4 Perched Water Samples at Depths Greater than 140 ft**—A total of 10 water samples and nine filtered sediment samples from the perched water wells were analyzed for C-14 between 1997 and November 1999. There were five positive detections of C-14 in the water samples and four positive detections in the filtered sediments. None of the perched water samples exceeded the aquifer RBC of 307 pCi/L used for comparison. Results for filtered sediments from the samples were all less than 2,845 pCi/g, the 1E-05 RBC for surface soil (see Table 4-26). The RBCs do not apply to lysimeters and are provided here only as a basis of comparison.

Well USGS-92 filtrate and filtered fractions yielded repeated detections of C-14, though three more recent sampling events have not indicated C-14 presence in that well. The USGS does not analyze the perched water from Well USGS-92 for C-14.

No data are available for the deep lysimeter samples because the volumes of water collected were insufficient to perform the C-14 analysis.

The vadose zone soil moisture sample results are well below the aquifer RBC for C-14, and the filtered sediments are below the 1E-05 RBC for surface soil. The aquifer and soil RBC are not applicable to lysimeter results and are used only for comparison.

Table 4-26. Positive detections of carbon-14 in perched water.

Well	Depth (ft)	Concentration $\pm (1\sigma)$ (pCi/L) Water	Confirmation Flag <sup>a</sup>	Concentration $\pm (1\sigma)$ (pCi/g) Filtered Sediments	Confirmation Flag <sup>a</sup>	Date
8802D	220	20 $\pm$ 4	A	Analyzed for, but not detected (ND)	None	February 1998
USGS-92	214	12 $\pm$ 3	A	0.63 $\pm$ 0.09	A	April 1997
		13 $\pm$ 2	B	ND	None	August 1997
		20 $\pm$ 4	D	ND	None	February 1998
		14 $\pm$ 4	D	0.51 $\pm$ 0.12	B	February 1998
		ND	None	0.54 $\pm$ 0.15	A	April 1998
		ND	None	3.2 $\pm$ 0.5	A	March 1999

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

D = Detection confirmed by reanalysis.

Note: Highlighted values are the original and confirmation analyses. Positive detection was confirmed.

**4.6.4.4 Aquifer.** Aquifer monitoring for C-14 began in 1994. A total of 239 samples were analyzed for C-14 between 1994 and April 2001, returning 19 positive detections as summarized in Table 4-27. The distribution of detected concentrations of C-14 over the entire span of C-14 aquifer monitoring is shown in Figure 4-19.

Aquifer Wells M12S and M13S, with three or more detections, are located approximately 1 to 2 miles upgradient from the SDA. Carbon-14 may be migrating from the SDA in a vapor phase or originate from INTEC or TRA.

The concentrations of C-14 are one to two orders of magnitude below the 1E-05 aquifer RBC for C-14, which is 307 pCi/L.

Data collected in September 1996 suggested seven other positive C-14 results that are not included in this analysis because of unacceptable data quality. These seven results were reevaluated and classified as either false positive or estimated results because C-14 also was detected in the corresponding field blank at a concentration equivalent to those in the sample results. The September 1996 data were revalidated and a revised limitations and validations report was issued<sup>a</sup>.

The USGS does not analyze for C-14 in the eight wells that they manage, control, and routinely sample.

a. John Schaffer, Bechtel BWXT Idaho, LLC, Letter to Kathleen Hain, U.S. Department of Energy Idaho Operations Office, January 31, 2002, CCN 29543, Idaho National Engineering and Environmental Laboratory, Bechtel BWXT Idaho, LLC, Idaho Falls, Idaho.

Table 4-27. Positive detections of carbon-14 in aquifer wells.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
M1S	4.9 $\pm$ 0.6	A	January 1999
	2.8 $\pm$ 0.7	A	July 2000
M3S	3.3 $\pm$ 0.7	A	July 2000
M4D	5.7 $\pm$ 1.7	B	June 1994
	28 $\pm$ 5	B	January 1995
M6S	5.3 $\pm$ 0.5	A	October 1999
M7S	1.8 $\pm$ 0.5	B	October 1999
	2.2 $\pm$ 0.7	D	July 2000
	2.2 $\pm$ 0.7	D	July 2000
M11S	2.8 $\pm$ 0.8	B	April 2001
M12S	3.0 $\pm$ 0.9	A	July 1998
	4.4 $\pm$ 0.5	A	January 1999
	2.1 $\pm$ 0.7	A	July 2000
	2.9 $\pm$ 0.8	A	April 2001
M13S	6.7 $\pm$ 0.9	A	July 1998
	3.2 $\pm$ 0.7	A	July 2000
	3.3 $\pm$ 0.8	A	April 2001
M14S	10.9 $\pm$ 0.7	A	July 1999
	4.0 $\pm$ 0.9	A	September 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

D = Detection confirmed by reanalysis.

Note: Highlighted values are the original and confirmation analyses. Positive detection was confirmed.

**4.6.4.5 Summary of Carbon-14.** Carbon-14 was identified as a COPC for the groundwater ingestion exposure pathway (Becker et al. 1998). Carbon-14 is not included in routine surface monitoring, but has been monitored in the vadose zone since 1997 and in the aquifer since 1994. Carbon-14 has been detected in lysimeter, perched water, and aquifer well samples, but not in any of the vadose zone core samples (see Table 4-28). The distribution of the C-14 detections in the various depth intervals at the SDA is shown in Figure 4-20.

Detected concentrations of C-14 are sporadic and are two to three orders of magnitude below the MCL of 2,000 pCi/L. Five of the seven shallow lysimeter detections were from Well PA01 near Pad A.

It appears that C-14 is present in the aquifer. The most frequent aquifer detections occur in aquifer Wells M12S and M13S, which are hydrologically upgradient from the SDA. The upgradient detections of C-14 are not yet understood, but may be caused by vapor transport from the SDA or from unidentified upgradient sources.

Table 4-28. Carbon-14 detection rates for the sampled media.

Media	Detection Rate (%)	Range of Detected Concentrations	Total Number of Detections Greater than Risk-Based Concentration <sup>a</sup>	Wells with Detections Greater than Risk-Based Concentration
<b>Vadose zone (0 to 35 ft):</b>				
Cores	0	Not applicable (NA)	0	None
Soil moisture	11.9	11 to 26 pCi/L	0	None
<b>Vadose zone (35 to 140 ft):</b>				
Cores	0	NA	0	None
Soil moisture	0	NA	0	None
<b>Vadose zone (&gt;140 ft):</b>				
Cores	0	NA	0	None
Soil moisture	50	12 to 20 pCi/L	0	None
<b>Aquifer</b>	7.9	1.8 to 28 pCi/L	0	None

a. For core samples, the 1E-05 risk-based concentration (RBC) is 2,845 pCi/g. For soil moisture and aquifer samples, the RBC applied was 307 pCi/L. The RBC does not apply to soil moisture and perched water samples, but is used here as a basis of comparison.

Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11A31	OW-2
1994	1															
	2			5.7												
	3															
	4															
1995	1			28												
	2															
	3															
	4															
1996	1															
	2															
	3															
	4															
1997	1															
	2															
	3															
	4															
1998	1															
	2															
	3								3.0	6.7						
	4								4.4							
1999	1	4.9														
	2															
	3										10.9					
	4															
2000	1															
	2															
	3	2.8	3.3						2.1	3.2	4.0					
	4															
2001	1															
	2							2.8	2.9	3.3						
	3															
	4															
Key		Analysis was conducted for C-14, but none was detected.														
		C-14 was detected (pCi/L).														
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.														

Figure 4-19. Occurrence of carbon-14 detections in the aquifer monitoring wells, 1994 through April 2001.

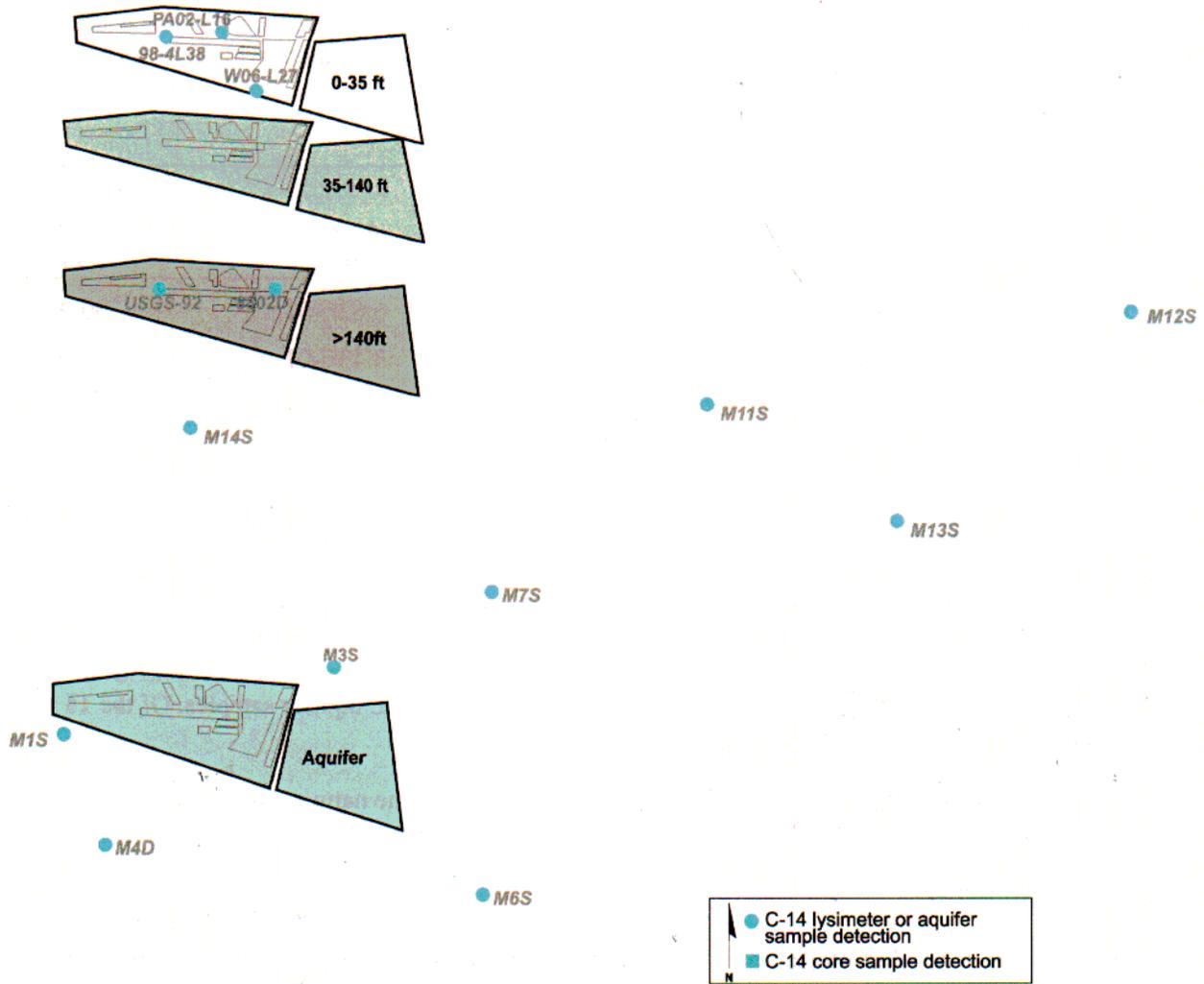


Figure 4-20. Locations of wells and lysimeters with detected concentrations of carbon-14.

#### 4.6.5 Chlorine-36

Chlorine-36 is a radioisotope that is generated by nuclear reactor operations and weapons testing. It also is produced in extremely low concentrations in the environment by cosmic-ray interactions with argon. It decays by the emission of beta particles, has a 30,100-year half-life, and was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathways (Becker et al. 1998). The comparison concentrations for Cl-36 are shown in Table 4-29.

Table 4-29. Comparison concentrations for chlorine-36 in groundwater and soils.

Surface Soil Background Concentration (pCi/g)	Risk-Based Soil Concentration <sup>a</sup> (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>a</sup> (pCi/L)
Not established	10.4	Not established	700	144

a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

Approximately 1.11 Ci of Cl-36 were disposed of in the SDA. Table 4-30 identifies the waste streams containing the majority of Cl-36 activity. Gamma spectral logging data provide no information about Cl-36.

Table 4-30. Waste streams containing chlorine-36.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Test Reactor Area	Beryllium blocks	6.62E-01	59.9
OFF-UBM-1H	Ore processing waste	3.43E-01	31.0
NRF-618-8R	Structural components removed from Navy nuclear fuel modules (e.g., end boxes) 1989 to 1993	1.01E-01	9.1
<b>Total Disposals</b>		<b>1.11E+00</b>	<b>100</b>

No analytical data are available for Cl-36. In the evaluation of vadose zone core samples collected during well drilling from 1971 to 2000, Cl-36 was not analyzed. Historically, Cl-36 has not been included on the radionuclide target list provided to the analytical laboratories subcontracted to the INEEL. In September and December 2001, Cl-36 analysis was performed on INEEL aquifer samples. Of the 15 wells sampled, none had detectable concentrations of Cl-36.

**4.6.5.1 Summary of Chlorine-36.** Analytical data to evaluate the nature and extent of Cl-36 are not available because Cl-36 has not been a target analyte for environmental monitoring.

#### 4.6.6 Cesium-137

Cesium-137 is a radioisotope that is produced from nuclear reactor operations and weapons testing. It decays by the emission of beta particles and gamma rays, has a 30-year half-life, and is ubiquitous in the environment at low levels as a consequence of atmospheric bomb testing. The IRA identified Cs-137 as a COPC primarily for the external exposure pathways (Becker et al. 1998).

Cesium-137-bearing waste in the SDA and the available Cs-137 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-31.

Table 4-31. Comparison concentrations for cesium-137 in groundwater and soil.

Surface Soil Background Concentration <sup>a</sup> (pCi/g)	Risk-Based Soil Concentration <sup>b</sup> (pCi/g)	Aquifer Background Concentration (pCi/L) <sup>c</sup>	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>b</sup> (pCi/L)
0.82	183	0	200	15.7

a. Upper 95% tolerance limit with 95% confidence for composited surface soil (Rood, Harris, and White 1996).

b. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

c. Knobel, Orr, and Cecil (1992).

**4.6.6.1 Waste Zone.** Approximately 6.17E+05 Ci of Cs-137 were disposed of in the SDA. Table 4-32 identifies the waste streams containing the majority of Cs-137 activity.

Table 4-32. Waste streams containing cesium-137.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations	1.32E+05	21.4
TRA-603-15H	Metal	1.04E+05	16.9
ANL-765-2H	Subassembly hardware	8.94E+04	14.5
TRA-642-6H	Scrap metal	6.02E+04	9.8
Miscellaneous	Miscellaneous minor streams	4.75E+04	7.7
TRA-603-1H	Resins	4.86E+04	7.9
ANL-785-1H	Subassembly hardware	4.23E+04	6.9
TRA-603-4H	Core and loop components	2.64E+04	4.3
OFF-ATI-1H	Fuel	2.56E+04	4.2
TRA-603-9H	Fuel	2.20E+04	3.5
ANL-765-1H	Dry active waste	1.10E+04	1.8
CPP-633-1H	High-efficiency particulate air filters	7.76E+03	1.3
<b>Total Disposals</b>		6.17E+05	100

The gamma spectral logging tool detected Cs-137 based on the 662 keV gamma rays. Of the 135 probeholes logged using this tool, 43 (32%) showed the presence of Cs-137 above the noise level. Of the 4,863 total measurements collected from all probes at all depths, 359 (7%) showed the presence of Cs-137 above the noise level. The Cs-137 detection limit was approximately 0.3 pCi/g. The maximum and average observed Cs-137 levels were 141 and 5.3 pCi/g, respectively. The detection limit, maximum concentration, and average concentration are based on the assumption that Cs-137 is uniformly distributed in the vicinity of the measurement points.

**4.6.6.2 Surface.** A total of 186 soil samples collected between 1994 and 2000 from in and around the RWMC were analyzed for Cs-137, yielding 80 positive detections. The positive results ranged from  $0.07 \pm 0.02$  to  $1.19 \pm 0.10$  pCi/g (INEEL 2001).

A total of 124 vegetation samples collected between 1990 and 2000 from the RWMC were analyzed for Cs-137 resulting in one positive detection of  $0.22 \pm 0.06$  pCi/g (LMITCO 1998).

A total of 210 surface run-off water samples collected from the RWMC between 1991 and 2000 were evaluated for Cs-137, yielding 13 positive detections. The positive results ranged from  $0.7 \pm 0.2$  pCi/L (EG&G 1994) to  $37 \pm 3$  pCi/L (LMITCO 1997).

**4.6.6.3 Vadose Zone.** The distributions of Cs-137 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

**4.6.6.3.1 Vadose Zone Core Samples**—A total of 290 vadose zone core samples from well drilling were analyzed for Cs-137 between 1971 and 2000, resulting in 13 positive detections (see Table 4-33). None of the positive detections were greater than the 1E-05 RBC for soil or above the surface soil background concentration for the INEEL (Rood, Harris, and White 1996). Seven of the 13 detections are associated with data from the early 1970s, which are known to be questionable (Barraclough et al. 1976; DOE-ID 1983). The detection rates for the various depth intervals are shown in Table 4-34.

Table 4-33. Positive detections of cesium-137 from vadose zone core samples.

Borehole Identification	Sample Depth (ft)	Concentration $\pm 1\sigma$ (pCi/g)	Date
D10	0	0.37 $\pm$ 0.04	1994
3E	3 to 5.5	0.09 $\pm$ 0.02	1994
6V	2 to 10	0.106 $\pm$ 0.019	1994
USGS-93	98.0 to 101.0	0.10 $\pm$ 0.02 <sup>a</sup>	1972
78-3	226.9	0.07 $\pm$ 0.02	1978
79-1	114.8 to 121.2	0.08 $\pm$ 0.02	1979
	121.6 to 223.4	0.08 $\pm$ 0.02	1979
USGS-89	241.6 to 243.2	0.040 $\pm$ 0.010 <sup>a</sup>	1971
USGS-92	223.0 to 225.5	0.13 $\pm$ 0.03 <sup>a</sup>	1972
USGS-94	262.3 to 264.6	0.18 $\pm$ 0.03 <sup>a</sup>	1972
USGS-95	112.0 to 113.3	0.220 $\pm$ 0.010 <sup>a</sup>	1972
	226.8 to 229.3	0.23 $\pm$ 0.03 <sup>a</sup>	1972
USGS-96	122.8 to 124.8	0.55 $\pm$ 0.04 <sup>a</sup>	1972

a. The 1971 to 1972 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Table 4-34. Summary of Cs-137 occurrences in vadose zone core samples.

Depth Interval (ft)	Number of Cs-137 Detections/Number of Samples (%)	Concentration Range (pCi/g)	Cores with Detections
0 to 35	3/33 (9.1)	0.09 to 0.37	3E, 6V, D10
35 to 140	5/120 (4.2)	0.08 to 0.55	93, 95, 96, 79-1
140 to 250	4/129 (3.1)	0.040 to 0.23	78-3, 89, 92, 95
Greater than 250	1/8 (12.5)	0.18	94

Because Cs-137 is known to be present in surface soils from nuclear fallout at concentrations approximating 0.82 pCi/g (Rood, Harris, and White 1996), the potential exists for introducing surface contamination into samples during coring and collection. Cesium-137 was detected in the background Well 79-1.

**4.6.6.3.2 Lysimeter Samples at Depths from 0 to 35 ft**—A total of 101 shallow lysimeter samples were analyzed for Cs-137 between 1997, when Cs-137 monitoring began, and May 2001, with two positive detections (see Table 4-35). Sample volumes were not sufficient to reanalyze and confirm the positive detections. The high Cs-137 result obtained in September 2000 from Well 98-1L35 (SDA-01) of  $1,760 \pm 136$  pCi/L was a single event and subsequent samples collected from this lysimeter through May 2001 have shown no positive Cs-137 detections. The detections of Cs-137 in the shallow lysimeters are depicted in Figure 4-21.

Table 4-35. Positive detections of cesium-137 in shallow lysimeters.

Lysimeter	Depth (ft)	Number of Analyses and Sampling Events	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
PA01-L15	14.3	11 analyses 8 events	<b>324 <math>\pm</math> 24</b>	A	April 1996
98-1L35 (SDA01)	16.5	6 analyses 6 events	<b>1760 <math>\pm</math> 136</b>	A	September 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

Note: Values in **red bold** indicate that the concentration exceeds the MCL of 200 pCi/L. The MCL does not apply to lysimeter samples, but is used here as a basis of comparison.

**4.6.6.3.3 Lysimeter Samples at Depths from 35 to 140 ft**—A total of 38 samples from 12 lysimeters were analyzed for Cs-137 between 1997, when Cs-137 monitoring began, and May 2001, with no positive detections. Only the Lysimeters D06-DL02, TW1-DL04, and D15-DL06 yielded enough sample to run analyses for Cs-137. The other lysimeters did not yield enough volume of water to perform the analysis.

**4.6.6.3.4 Perched Water Samples at Depths Greater than 140 ft**—A total of 53 perched water samples and five filtered sediment samples were analyzed for Cs-137 by the USGS and INEEL between 1972 and September 2000. No positive detections of Cs-137 were identified in samples collected from perched water Wells USGS-92 and 8802D. No data are available for the deep lysimeter samples because the volume of water collected was insufficient to perform the analyses.

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01- L15	PA02- L16	PA03- L33	W06- L27	W08- L13	W08- L14	W23- L08	W23- L09	W25- L28
1996	1												
	2				324								
	3												
	4												
1997	1												
	2												
	3												
	4												
1998	1												
	2												
	3												
	4												
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3	1760											
	4												
2001	1												
	2												
	3												
	4												
Key			Analysis was performed for Cs-137, but none was detected.										
			Cs-137 was detected (pCi/L).										
			If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.										

Figure 4-21. Occurrences of cesium-137 detections in the shallow lysimeters.

**4.6.6.4 Aquifer.** A total of 197 samples from 16 aquifer wells around the RWMC were analyzed for Cs-137 between 1996 and April 2001, with three positive detections of Cs-137 (see Table 4-36). Only the sample from Well M4D was reanalyzed, and the detection was not confirmed. Subsequent samples collected from these wells through April 2001 have not shown positive detections. Figure 4-22 shows the occurrence of positive detections and nondetections of Cs-137 in INEEL and USGS wells.

Table 4-36. Positive detections of cesium-137 in aquifer well samples collected between the years 1996 and 2001.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
M4D	<b>20 <math>\pm</math> 6</b>	B	April 1996
M12S	7.8 $\pm$ 1.1	A	September 2000
M13S	7.6 $\pm$ 1.2	A	September 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed

B = Reanalysis performed, no confirmation

Note: Values in **red bold** indicate that the concentration exceeds the 1E-05 risk-based concentration of 15.7 pCi/L.

Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11A31	OW-2					
1992	1																												
	2																												
	3																												
	4																												
1993	1																												
	2																												
	3																												
	4																												
1994	1																												
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	3																												
	4																												
1995	1	1020																											
	2																												
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1996	1																												
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	4																												
2001	1																												
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	3																												
	4																												
Key																													
		Analysis was performed for Cs-137, but none was detected.																											
		Cs-137 was detected (pCi/L).																											
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.																											

Figure 4-22. Occurrences of cesium-137 detections in the aquifer monitoring wells from 1992 through 2001.

In addition to the 16 RWMC monitoring aquifer wells managed and routinely sampled by INEEL, the USGS manages, controls, and routinely samples eight other wells in the vicinity of the RWMC. A total of 496 USGS aquifer well samples in the vicinity of the RWMC were analyzed for Cs-137 between 1972 and October 2000, with 10 detections (see Table 4-37). The occurrence of detection and nondetections is shown in Figure 4-23.

Table 4-37. Positive detections of cesium-137 in aquifer well samples collected by the U.S. Geological Survey between 1972 and 2000.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Date
USGS-87	<b>90 <math>\pm</math> 20<sup>a</sup></b>	October 1973
	<b>1020 <math>\pm</math> 30</b>	January 1995
USGS-88	<b>24 <math>\pm</math> 5<sup>a</sup></b>	November 1972
	<b>30 <math>\pm</math> 9</b>	September 1987
USGS-89	<b>90 <math>\pm</math> 10<sup>a</sup></b>	September 1972
	<b>27 <math>\pm</math> 6<sup>a</sup></b>	October 1972
	<b>24 <math>\pm</math> 7</b>	October 1976
	<b>25 <math>\pm</math> 6</b>	September 1987
USGS-90	<b>30 <math>\pm</math> 6<sup>a</sup></b>	February 1972
	<b>90 <math>\pm</math> 10<sup>a</sup></b>	October 1972

a. The data from 1972 to 1974 must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Note: Values in **red bold** indicate that the concentration exceeds the 1E-05 aquifer risk-based concentration of 15.7 pCi/L.

Figure 4-23. Occurrences of cesium-137 detections in the aquifer monitoring wells from 1972 through 1991.

Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120
1972	1				30				
	2								
	3								
	4		24	90					
1973	1								
	2								
	3								
	4								
1974	1								
	2								
	3								
	4								
1975	1								
	2								
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1990	1								
	2								
	3								
	4								
1991	1								
	2								
	3								
	4								

Analysis was performed for Cs-137, but none was detected.  
 Cs-137 was detected (pCi/L).  
 If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.

Six of the 10 detections in the USGS wells occurred between 1972 and 1974, shortly after the wells were drilled and installed. The 1972 to 1974 detections are suspect because of cross-contamination problems associated with early well drilling and well construction techniques, and the types of sampling methodology employed at that time (Barraclough, et al. 1976, Section 4.4). After 1974, only four USGS samples have contained detectable amounts of Cs-137. The high Cs-137 result obtained from Well USGS-87 in January 1995 ( $1,020 \pm 30$  pCi/L) was a single event and subsequent samples collected from this well have not shown positive detections. Furthermore, Well USGS-087 is hydrologically upgradient from the SDA.

**4.6.6.5 Summary of Cesium-137.** In the IRA (Becker et al. 1998), Cs-137 was identified as a COPC for external exposure. Approximately  $6.17E+05$  Ci of Cs-137 were disposed of in the SDA. Spectral gamma logging data indicate that 32% of the probeholes contained detectable Cs-137, while Cs-137 was detected in about 5% of the vadose zone core samples (see Table 4-38) at background levels.

Two high concentrations were detected in lysimeter samples at an approximate depth of 15 ft but the samples were not in close proximity and subsequent detections from the same lysimeters did not occur. Overall, Cs-137 was detectable in only 2% of the shallow (i.e., 0 to 35 ft) lysimeters and none of the intermediate depth (i.e., 35 to 140 ft) to deep vadose zone samples (depths greater than 140 ft) (see Table 4-38). Detectable levels of Cs-137 were present in approximately 2% of the aquifer well samples, but detections in the aquifer were sporadic.

The distribution of Cs-137 in the sampled media is shown in Figure 4-24. In general, Cs-137 occurs sporadically throughout the vadose zone and aquifer in and around the SDA, but there are no evident spatial or temporal trends. Vadose zone samples suggest that Cs-137 has not leached deeper than 35 ft. No obvious trends are associated with Cs-137; however, occasionally Cs-137 has been detected in samples at relatively high levels. There does not seem to be any pattern to its occurrence.

Table 4-38. Detection rates of cesium-137 in the sampled media.

Media	Detection Rate (%)	Range of Detected Concentrations	Total Number of Detections Greater than the Risk-Based Concentration	Wells with Concentrations Greater Than the Maximum Contaminant Level
Source	Probeholes: 32 Measurements: 7	0.3 to 141 pCi/g	0	None
Surface soil	43.0	0.07 to 1.19 pCi/g	0	None
Run-off water	6.2	0.7 to 37 pCi/L	0	None
Vadose zone 0 to 35 ft:				
Cores	9.1	0.09 to 0.37 pCi/g	0	None
Soil moisture	2.0	324 to 1760 pCi/L	2	PA01, 98-1
Vadose zone 35 to 140 ft:				
Cores	4.2	0.08 to 0.55 pCi/g	0	None
Soil moisture	0	Not applicable (NA)	0	None
Vadose zone >140 ft:				
Cores	3.6	0.04 to 0.23 pCi/g	0	None
Soil moisture	0	NA	0	None

Table 4-34. (continued).

Media	Detection Rate (%)	Range of Detected Concentrations	Total Number of Detections Greater than the Risk-Based Concentration	Wells with Concentrations Greater Than the Maximum Contaminant Level
Aquifer-Idaho National Engineering and Environmental Laboratory	1.5	7.6 to 20 pCi/L	1	M4D
Aquifer-U.S. Geological Survey	2.0	24 to 1020 pCi/L	10	USGS-87, -88, -89, -90

a. For surface soil and cores, the 1E-05 risk-based concentration (RBC) for soil is 183 pCi/g. For soil moisture and aquifer, the values are compared to the 1E-05 aquifer RBC, which is 15.7 pCi/L. The 1E-05 aquifer RBC does not apply to soil moisture, but is used here only as a basis of comparison.

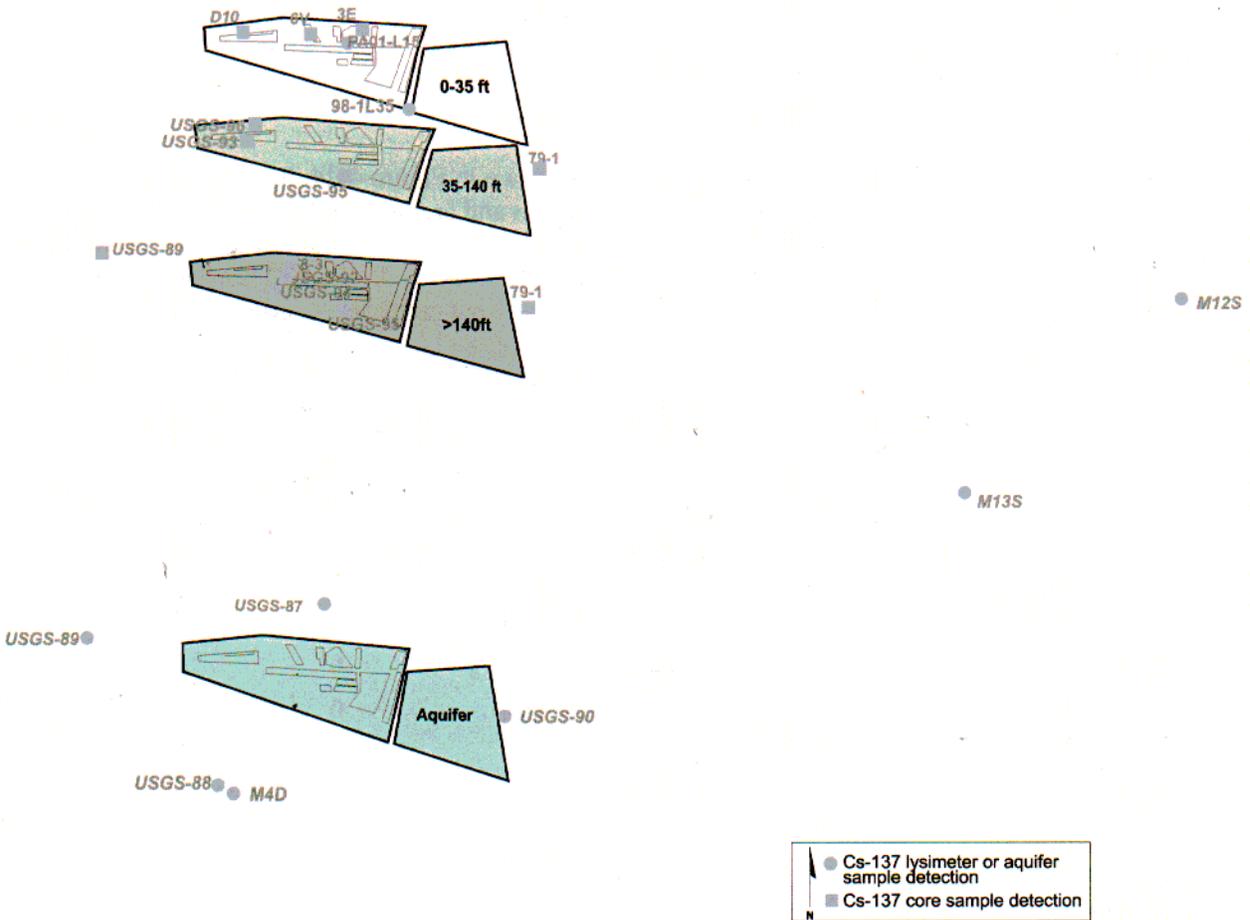


Figure 4-24. Distribution of cesium-137 in the various sampled depths in the vadose zone and aquifer.

## 4.6.7 Tritium

Tritium (H-3) is a radioisotope of hydrogen that is produced from nuclear reactor operations and weapons manufacturing and testing. It also is produced in the environment by interactions of cosmic rays with gases in the atmosphere. It decays by the emission of beta particles with a half-life of 12.3 years.

Though tritium was not identified in the IRA as a COPC, its nature and extent is described here because of its potential use as a vapor-phase model calibration target for future modeling planned for OU 7-08, the OCVZ Project. In addition, a significant H-3 trend has been observed in lysimeter Well W06, and elevated H-3 concentrations in lysimeter Well TW1 at 102 ft. These may be connected to a small isolated H-3 plume in the aquifer beneath the SDA. The H-3 data associated with all lysimeters may ultimately provide valuable ancillary information about contaminant migration in the vadose zone and the source of the isolated H-3 plume beneath the SDA. The H-3 background concentration range in the aquifer is 0 to 40 pCi/L (Knobel, Orr, and Cecil 1992), and the MCL is 20,000 pCi/L.

**4.6.7.1 Waste Zone.** Gamma spectral logging data provide no information about tritium.

**4.6.7.2 Surface.** No surface data are available for H-3.

**4.6.7.3 Vadose Zone.** Tritium has not been detected in vadose zone core samples. The distributions of H-3 in soil moisture and perched water in the various depth intervals are discussed below.

**4.6.7.3.1 Lysimeter Samples at Depths from 0 to 35 ft—**A total of 56 shallow lysimeter samples were analyzed by INEEL for H-3 between 1997 and September 2000, with 22 detections in eight lysimeters. The positive results varied from a minimum of  $129 \pm 34$  pCi/L (Well W08-L14) to a maximum of  $9,100 \pm 1,180$  pCi/L (Well W06-L27). All of the detected concentrations are less than the aquifer MCL, and all except some samples from Well W06-L27 (11.8-ft deep) are less than 2,000 pCi/L.

Most of the detections occurred sporadically and infrequently, with the exception of samples collected from lysimeter Wells W06 and PA02. Lysimeter Well W06 is located in the southeast corner of the SDA, and Well PA02 is near Pad A. The H-3 in lysimeter Well W06-L27 is most likely from the TRA beryllium blocks that are disposed of nearby. Well PA02-L16, which is located in the southern end of Pad A at an 8.5-ft depth, also has frequent positive detections that appear to be trending upwards; however, when combined with the nondetects, the trend is obscured. Subsequent samples collected from the lysimeters, other than lysimeter Wells W06-L27 and PA02-L16, have not shown detectable H-3.

**4.6.7.3.2 Lysimeter Samples at Depths of 35 to 140 ft—**A total of eight lysimeter samples from the three wells were analyzed for H-3 between 1997 and November 1998, with three positive detections, all in TW1-DL04. Results ranged from 1,680 to 2,950 pCi/L, and all detections were in 1998. Samples were only obtained from Lysimeters D06-DL02, TW1-DL04, and D15-DL06. The other lysimeters did not yield sufficient water volume to perform analyses.

**4.6.7.3.3 Perched Water Samples from Depths Greater than 140 ft—**A total of 45 perched water samples and eight filtered sediment samples were analyzed for H-3 by the USGS and INEEL between 1972 and November 1999. Eight positive detections were measured, which ranged from 169 to 1,570 pCi/L. All detected concentrations were from samples taken from Well USGS-92. None of the results exceed the MCL of 20,000 pCi/L.

Subsequent samples collected from Well USGS-92 in the two later sampling events (March and November 1999) did not contain detectable H-3. The deep lysimeter well samples were not analyzed for H-3 because the volume of water collected was insufficient to perform the analysis.

**4.6.7.4 Aquifer.** A total of 284 RWMC aquifer well samples were analyzed by INEEL for H-3 between 1992 and April 2001, with 107 detections. The positive results varied from  $398 \pm 87$  pCi/L to  $2,600 \pm 400$  pCi/L (107 measurements), with the majority of values between 1,100 to 1,800 pCi/L. Six of the INEEL wells in the vicinity of the RWMC contain H-3 concentrations above SRPA background levels but much below the MCL of 20,000 pCi/L. Those wells are M3S, M7S, M12S, M14S, M16S, and M17S and have been monitored since 1992. Wells M3S and M7S are close to the SDA but the rest of the wells are 805 m (0.5 mi) or more upgradient. Tritium concentrations in Wells M3S and M7S are trending slightly down over time, which may be related to the decay of H-3 over time and dispersion in the aquifer.

In addition to the 16 RWMC monitoring wells routinely sampled by INEEL, the USGS manages, controls, and routinely samples eight other wells in the vicinity of the RWMC. These eight wells have been monitored by the USGS for H-3 since 1972. A total of 700 USGS aquifer well samples in the vicinity of the RWMC were analyzed for H-3 between 1972 and October 2000, with 236 detections. The most frequent detections come from the RWMC Production Well, where 90 out of 93 analyses contained concentrations of detectable H-3; Well USGS-87, with 62 detections out of 118 samples; and Well USGS-90, yielding 82 detections out of 111 samples. The H-3 concentrations are about an order of magnitude below the MCL, but above background. The concentration ranges measured by the USGS correspond with that of the INEEL well data.

The Site-wide environmental monitoring program has been sampling the RWMC Production Well since 1995 to comply with State of Idaho drinking water monitoring requirements. A total of 23 RWMC Production Well samples were analyzed for H-3 between 1995 and May 2001. The well routinely shows H-3 levels above background but significantly below the MCL of 20,000 pCi/L. The positive results varied from  $1,090 \pm 135$  to  $2,800 \pm 225$  pCi/L, with the majority of positive values between 1,200 and 1,800 pCi/L. These concentration ranges correspond with that of the USGS and INEEL well data.

An H-3 plume is known to extend many miles south of the TRA and INTEC facilities, though the plume appears to have little or no impact on the aquifer directly beneath the RWMC. A small isolated H-3 plume beneath the RWMC extends to the northwest and does not appear to have any association with the current TRA and INTEC H-3 plumes, as evidenced by the lack of H-3 detections from Wells M11S and M13S.

**4.6.7.4.1 Special Tritium Studies in Area of Activated Beryllium**—The following excerpts and figures are from monitoring studies<sup>b</sup> conducted by Paul D. Ritter near the activated beryllium buried at the RWMC.

Six activated beryllium reflector blocks from the ATR were buried in the southeast corner of the SDA in 1993. These blocks contained a total of 293,300 Ci of tritiated hydrogen gas. The tritiated hydrogen gas is oxidized to tritiated water in the soil surrounding the beryllium. Soil moisture monitoring in the shallow vadose zone started in 1994 to characterize the migration of H-3 from the beryllium blocks.

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b. P. D. Ritter Interdepartmental Memorandum to R. R. Seitz, October 2, 2001, "Transmittal of FY-2001 Summary Report of Results of Monitoring Near Activated Beryllium at SVR-20," PDR-07-01, Idaho National Engineering and Environmental Laboratory, Bechtel BWXT Idaho, LLC, Idaho Falls, Idaho.

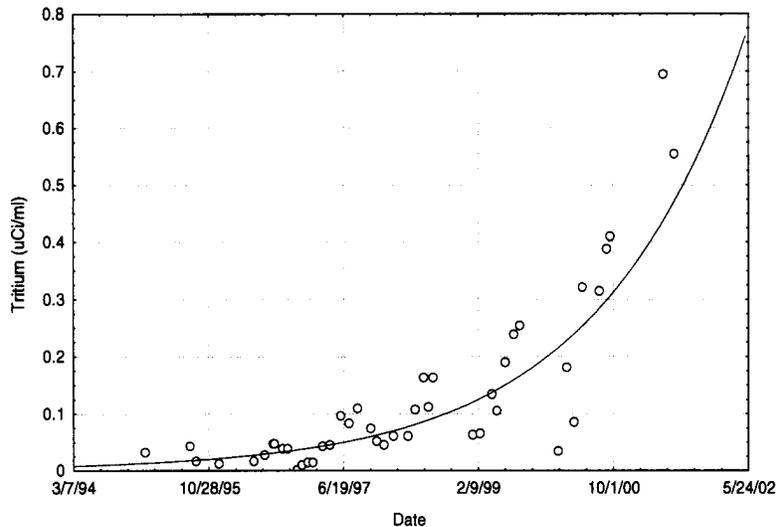


Figure 4-25. Tritium concentration in soil moisture at 20.3-ft depth.

The soil moisture samples were collected approximately 2 to 3 ft from the buried beryllium at depths of 8.9, 14.7, and 20.3 ft. The H-3 concentrations in soil moisture near the beryllium blocks showed significant trends that reached maximum concentrations of 3.4 µCi/ml (3.4E+09 pCi/L) at 8.9 ft, 0.28 µCi/ml (2.8E+08 pCi/L) at 14.7 ft, and 0.70 µCi/ml (7.0E+08 pCi/L) at 20.3 ft (see Figure 4-25 for 20.3-ft depth example).

The concentration of H-3 observed in soil moisture over long periods of time has a nonlinear trend. This trend cannot continue indefinitely, but there is no indication that the concentrations will peak or plateau over the next few years. The H-3 trend associated with lysimeter Well W06 (i.e., 197 ft) west of borehole SVR-20) suggests a large area near the buried beryllium has been impacted by the radial distribution (migration) of H-3 from the beryllium blocks.

Air samples also are collected a few feet above ground over the buried beryllium blocks (near borehole SVR-20). Environmental monitoring samples are routinely collected throughout each year. Additional intensive sampling is conducted by Waste Management Projects during summer and early fall of each year. The H-3 concentrations measured in ambient air vary considerably during the year, with peak concentrations occurring during the late summer months. Tritium concentrations in ambient air have reached peak concentrations around 1E+05 to 1E+06 pCi/m<sup>3</sup>. The estimated amounts of H-3 released to the atmosphere each year vary from less than 1 Ci to more than 100 Ci.

**4.6.7.5 Summary of Tritium.** Tritium is regularly detected above background in several lysimeters and wells near the SDA (see Table 4-39). The past 4 years of H-3 data from the shallow lysimeters (i.e., 56 analyses) do not contain sufficient evidence to conclude that H-3 in the vadose zone is contributing to the isolated H-3 plume in the aquifer beneath the SDA. Wells upgradient from the SDA contain detectable H-3 and it is possible that these detections are associated with a plume from upgradient rather than from the SDA. More data are needed to define whether the aquifer occurrences are attributable to SDA, TRA, or INTEC.

Table 4-39. Detection rates of tritium in the sampled media.

Media	Detection Rate (%)	Range of Detected Values (pCi/L)	Total Number of Detections Greater than the Maximum Contaminant Level (20,000 pCi/L)
Soil moisture: 0 to 35 ft	39.2	129 to 9,100	22
Soil moisture: 35 to 140 ft	37.5	1,680 to 2,950	0
Soil moisture: greater than 140 ft	13.3	169 to 1570	0
Aquifer-Idaho National Engineering and Environmental Laboratory	37.6	398 to 2600	0
Aquifer-U.S. Geological Survey	33.7	700 to 5400	0

#### 4.6.8 Iodine-129

Iodine-129 is a radioisotope that is produced from nuclear reactor operations and weapons testing. It also is produced in the environment in extremely low concentrations by interactions of cosmic rays with gases in the atmosphere, and from the spontaneous fission of naturally occurring U-238 (Mann and Beasley 1994). It decays by the emission of beta particles, has a 1.57E+07 year half-life, and was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Iodine-129-bearing waste in the SDA and the available I-129 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-40.

Table 4-40. Comparison concentrations for iodine-129 in groundwater and soils.

Surface Soil Background Concentration (pCi/g)	Risk-Based Soil Concentration <sup>a</sup> (pCi/g)	Aquifer Background Concentration (pCi/L) <sup>b</sup>	Maximum Contaminant Levels (pCi/L)	Risk-Based Aquifer Concentration <sup>b</sup> (pCi/L)
Not established	29.3	0	1	3.2

a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05 (Knobel, Orr, and Cecil 1992).

**4.6.8.1 Waste Zone.** Approximately 0.15 Ci of I-129 were disposed of in the SDA. Table 4-41 identifies the waste streams containing the majority of I-129 activity. Gamma spectral logging data provide no information regarding I-129.

**4.6.8.2 Surface.** No surface data are available for I-129 because it has not been a target analyte for surface monitoring.

**4.6.8.3 Vadose Zone.** The distributions of I-129 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

Table 4-41. Waste streams containing iodine-129.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste	1.49E-01	94.5
Naval Reactors Facility	Test specimens	2.67E-03	1.7
PBF-620-1	Miscellaneous scrap	1.90E-03	1.2
<b>Total Disposals</b>		1.58E-01	100

**4.6.8.3.1 Vadose Zone Core Samples**—A total of 52 core samples were analyzed for I-129 between 1994 and 2000, with no positive detections. Samples were collected between 1994 and 2000 from the following SDA boreholes: I-1S, I-1D, I-2S, I-2D, I3S, I4D, I5S, O-1S, O-1D, O-2S, O-2D, O-3S, O-3D, 2E, 3E, 4E, 5E, 3V, 4V, 5V, 6V, 7V, 8V, 9V, and 10V. Previous core sampling investigations (1971 to 1993) did not analyze for I-129, as it was not a radionuclide of principal concern at that time. The distribution of samples in the various depth intervals is summarized in Table 4-42.

Table 4-42. Distribution of vadose zone core samples for iodine-129 analyses.

Depth Interval (ft)	Number of I-129 Detections/ Number of Cores Sampled	Detection Rate (%)	Cores with Detections
0 to 35	0/11	0	None
35 to 140	0/25	0	None
140 to 250	0/16	0	None
Greater than 250	0/0	Not applicable	None

**4.6.8.3.2 Lysimeter Samples at Depths of 0 to 35 ft**—A total of 59 shallow lysimeter samples were analyzed by INEEL for I-129 between 1997 and September 2000, with three positive detections (see Table 4-43).

Table 4-43. Detected concentrations of iodine-129 in the shallow vadose zone lysimeters.

Lysimeter	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
98-1L35 (SDA-01)	16.5	<b>53 <math>\pm</math> 18</b>	A	November 1998
98-5L39 (SDA-10)	17.0	<b>29 <math>\pm</math> 6</b>	A	December 1998
W25-L28	15.5	<b>22 <math>\pm</math> 7</b>	A	June 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

Note: Values in **red bold** indicate that the concentration exceeds the maximum contaminant level (MCL) of 1 pCi/L. The maximum contaminant level for the aquifer does not apply to soil moisture samples, but are used here as a basis of comparison.

Despite the relatively high concentrations of I-129 in the lysimeter samples, the I-129 detections occur only sporadically. Figure 4-26 shows the occurrences of the I-129 detections. None of the positive sample results could be supported by reanalysis of the original sample. Subsequent samples collected from these lysimeter wells through September 2000 have not shown detectable I-129. There are no spatial trends to the I-129 detections. The lysimeter wells are located some distance from each other, not clustered.

**4.6.8.3.3 Lysimeter Samples at Depths of 35 to 140 ft**—A total of seven samples from three lysimeters were analyzed by INEEL for I-129 between 1997 and November 1998, with no positive detections. The other lysimeter wells in this depth interval were not analyzed for I-129 because the volume of water collected from them was insufficient to perform the analysis.

**4.6.8.3.4 Perched Water Samples at Depths Greater than 140 ft**—A total of nine water samples and 10 filtered sediment samples from the perched water wells (USGS-92 and 8802D) were analyzed by INEEL for I-129 between 1997 and November 1999. No positive detections of I-129 were identified. Because of the limited sample volumes, the detection sensitivity is not adequate for comparison to the drinking water MCL of 1 pCi/L. No data are available for the deep lysimeter well samples because the volume of water collected was insufficient to perform the analysis. The USGS does not analyze samples from Well USGS-92 for I-129.

**4.6.8.4 Aquifer.** A total of 242 RWMC aquifer well samples were analyzed by INEEL for I-129 between 1994 and April 2001. Five positive detections were identified in more than 20 sampling campaigns (see Table 4-44). Aquifer Well M1S was the only well with more than one I-129 detection and one of the detections was unusually high. Samples collected in aquifer Well M1S during the 11 sampling events since the last detection have contained undetectable levels of I-129.

The July 1998 sample from M1S was reanalyzed but the result was a nondetect. The other samples with positive detections were not reanalyzed. Three of the sample results exceeded the MCL of 1 pCi/L (i.e., aquifer Wells M1S, M7S, and M10S). These exceedances were one-time detections.

Following routine sample collection in September 1996, seven I-129 results were reported as positive. On closer evaluation of the data package, it was discovered that I-129 also was detected in the corresponding field blank at a concentration equivalent to the sample results ( $3.7 \pm 0.3$  pCi/L). Results from the aquifer wells sampled in this campaign (i.e., M1S, M3S, M4D, M6S, and M10S) were declared false positives. The September 1996 data were revalidated and the revised limitations and validation report reissued to DOE-ID (see footnote a, p. 4-52). No USGS I-129 data are available for comparison because the USGS does not analyze for I-129 in their eight RWMC wells.

The radioanalytical detection sensitivity for I-129 is about the same as its MCL (1 pCi/L), so trends cannot be identified before the concentration actually exceeds the MCLs. A radioanalytical laboratory that can achieve lower I-129 detection sensitivities (e.g., 10 times lower than the MCL [0.1 pCi/L]) is being identified through the INEEL monitoring program. Future INEEL aquifer well samples will be sent to this radioanalytical laboratory for low-level I-129 analyses.

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01- L15	PA02- L16	PA03- L33	W06- L27	W08- L13	W08- L14	W23- L08	W23- L09	W25- L28
1997	1												
	2												
	3												
	4												
1998	1												
	2												
	3												
	4	53		29									
1999	1												
	2												
	3												
	4												
2000	1												
	2												22
	3												
	4												
2001	1												
	2												
	3												
	4												
Key		Analysis was performed for I-129, but none was detected.											
		I-129 was detected (pCi/L).											
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.											

Figure 4-26. Occurrences of iodine-129 detections in shallow lysimeter wells.

Table 4-44. Positive detections of iodine-129 in aquifer.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
M1S	<b>17.0 <math>\pm</math> 1.5</b>	A	April 1996
	1.0 $\pm$ 0.2	B	July 1998
M6S	0.59 $\pm$ 0.17	A	October 1997
M7S	<b>1.5 <math>\pm</math> 0.4</b>	A	October 1998
M10S	<b>1.7 <math>\pm</math> 0.4</b>	A	April 1997

a. Confirmation flag:

A = No second sample collected, no reanalysis performed

B = Reanalysis performed, no confirmation

Note: Values in **red bold** indicate that the concentration exceeds the aquifer maximum contaminant level of 1 pCi/L.

**4.6.8.5 Summary of Iodine-129.** Because of its high mobility and toxicity, I-129 is a risk driver; however, the monitoring data to date do not present a clear picture of I-129 occurrence in the vadose zone or the aquifer well near the SDA. Only 0.16 Ci of I-129 have been buried in the SDA and no additional I-129 is generated from radioactive decay of other nuclides.

There is no obvious pattern or trend to the I-129 vadose zone or aquifer well monitoring data to suggest that I-129 is widespread in the SDA. Detection rates are low with no detections of I-129 in the core samples or in soil moisture samples from intermediate and deep samples (see Table 4-45). Monitoring results in the soil moisture show that I-129 has been detected infrequently in the shallow (0 to 35 ft) lysimeters and in the aquifer wells but not in the deeper vadose zone. Figure 4-27 shows the distribution of I-129 in the sampled media. The pattern of detections in only the shallow vadose zone and in the aquifer suggests that I-129 may be moving around in the waste zone, but has not yet migrated beneath the waste zone into the interbeds or perched water. Aquifer well detections are considerably (i.e., 2 miles) upgradient, suggesting a possible upgradient source of I-129 (e.g., INTEC).

Table 4-45. Detection rates of iodine-129 in the sampled media.

Media	Detection Rate (%)	Concentration Range	Total Number of Detections Higher than Maximum Contaminant Level <sup>a</sup> or Risk-Based Concentration <sup>a</sup>	Wells Higher than Maximum Contaminant Level
Vadose zone 0 to 35 ft:				
Cores	0	NA	0	None
Soil moisture	5.1	22 to 53 pCi/L	3	None
Vadose zone 35 to 140 ft:				
Cores	0	NA	0	None
Soil moisture	0	NA	0	None
Vadose zone >140 ft:				
Cores	0	NA	0	None
Soil moisture	0	NA	0	None
Aquifer	2.1	0.59 to 17.0 pCi/L	3	M1S, M7S, M10S

a. The concentrations for cores are compared to the risk-based concentration of 29.9 pCi/g. The soil moisture and aquifer results are compared to the maximum contaminant level of 1 pCi/L. The maximum contaminant level does not apply to soil moisture data but is used here as a basis of comparison.

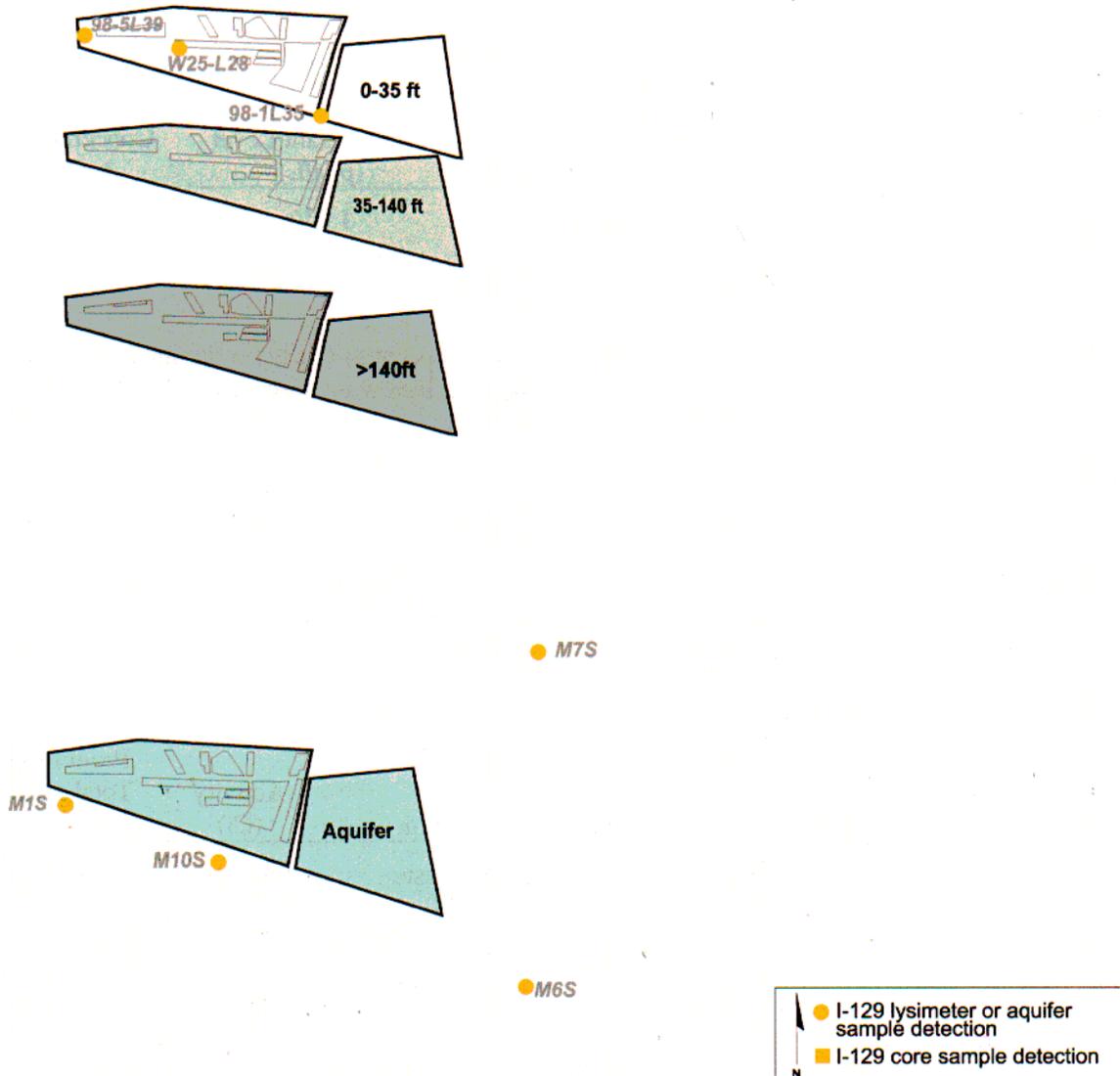


Figure 4-27. Locations where iodine-129 was detected in lysimeter and well samples.

#### 4.6.9 Niobium-94

Niobium-94 is a radioisotope that is an activation product produced by nuclear reactor operations. It decays by the emission of beta particles and gamma rays, has a half-life of  $2.0E+06$  years and was identified in the IRA as a COPC, primarily for the external exposure and groundwater ingestion pathway (Becker et al. 1998).

Niobium-94-bearing waste in the SDA and the available Nb-94 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-46.

Table 4-46. Comparison concentrations for niobium-94 in groundwater and soils.

Surface Soil Background Concentration	Risk-Based Soil Concentration <sup>a</sup> (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>a</sup> (pCi/L)
Not established	387	Not established	1,070	61.3

a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

No aquifer or lysimeter well data for Nb-94 are identified because it is not a routine target analyte. However, it would have been detected and reported if concentrations were observed above the gamma-analysis detection limit.

The calculated MCL for Nb-94 is 1,070 pCi/L based on a dose of 4 mrem/year (40 CFR 141.16). Therefore, the gamma detection sensitivity would be more than adequate for detecting Nb-94.

**4.6.9.1 Waste Zone.** Approximately 1,000 Ci of Nb-94 were disposed of in the SDA. Table 4-47 identifies the waste streams containing the majority of Nb-94 activity. Gamma spectral logging data provide no information about Nb-94.

Table 4-47. Waste streams containing niobium-94.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste	8.80E+02	87.6
CPP-603-1H	Fuel end pieces	4.74E+01	4.7
Test Reactor Area	Activation products	4.06E+01	4.0
Miscellaneous	Miscellaneous minor streams	2.31E+01	2.3
NRF-618-12H	Core structural components	1.31E+01	1.3
<b>Total Disposals</b>		<b>1.00E+03</b>	<b>100</b>

**4.6.9.2 Surface.** No surface sample data are available because Nb-94 has not been a target analyte for monitoring.

**4.6.9.3 Vadose Zone.** No gamma spectrometric analytic results are available for Nb-94 in vadose zone core samples because Nb-94 was not a target analyte. Though not a target analyte, Nb-94 would have been detected and reported if concentrations were observed above the gamma spectrometric analysis detection limit (<0.1 pCi/g) in routine gamma analysis. No detections were reported from vadose zone core analyses, suggesting that the gamma analysis did not detect Nb-94 higher than 0.1 pCi/g.

Niobium-94 was not a target analyte in the lysimeter samples but would have been reported had it been detected above the contract-required detection limit for gamma-emitting radionuclides (<200 pCi/L). No reportable quantities of Nb-94 were detected in the lysimeter samples.

**4.6.9.4 Aquifer.** No aquifer well gamma spectrometric analytic results are available for Nb-94 because no analyses were performed. If concentrations of Nb-94 above the gamma-analysis detection limit had been observed, Nb-94 would have been included in the laboratory report. The contract-required detection limit for gamma-emitting radionuclides in aquifer samples using gamma spectrometric analysis is 30 pCi/L. The analytical laboratories routinely achieve the minimum detectable activities between 3 and 10 pCi/L in aquifer samples. No detection levels of gamma-emitting radionuclides were reported.

**4.6.9.5 Summary of Niobium-94.** The data are inadequate to assess the distribution and occurrence of Nb-94 in the vadose zone. Indirect measurements by gamma spectrometric analytic results obtained on groundwater samples suggest that Nb-94 is not present in the aquifer.

**4.6.10 Neptunium-237**

Neptunium-237 is an anthropic, transuranic radioisotope that is a decay product of Am-241. It is produced by nuclear reactor operations, decays by the emission of alpha particles, and has a half-life of 2.14E+06 years. Neptunium-237 was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Neptunium-237-bearing waste in the SDA and the available Np-237 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-48.

Table 4-48. Comparison concentrations for neptunium-237.

Surface Soil Background	Risk-Based soil Concentration <sup>a</sup> (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>a</sup> Aquifer 1E-05 (pCi/L)
Not established	49.0	Not established	15 (total alpha)	7.1

a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

**4.6.10.1 Waste Zone.** Approximately 2.6 Ci of Np-237 were disposed of in the SDA. Table 4-49 identifies the waste streams containing the majority of Np-237 activity.

Additional quantities of Np-237 are also produced over time through ingrowth (see Section 4.1.2). Table 4-49 includes the amount of Np-237 that would be produced if all of the parent decays. Percentages of the total Np-237 from the parent isotopes are not given because the amount of Np-237 present is dependant on the timeframe assessed. The decay of Np-237 will produce U-233 and Th-229.

The spectral gamma moisture logging tool detected Np-237 based on the 312 keV gamma rays from the daughter product, Pa-233. Of the 135 probeholes logged using this tool, 57 (42%) showed the presence of Pa-233 above the noise level. Of the 4863 total measurements (i.e., all probes and all depths), 511 (11%) showed the presence of Pa-233 above the noise level. The Pa-233 detection limit was approximately 1.7 pCi/g. The maximum and average observed Pa-233 levels were 141 and 5.3 pCi/g, respectively. The detection limit, maximum and average concentrations are based on the assumption that Pa-233 is uniformly distributed in the vicinity of the measurement points.

Table 4-49. Waste streams containing neptunium-237.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste	7.54E-01	28.5
TRA-603-15H	Metal	6.85E-01	25.9
TRA-603-1H	Resins	4.13E-01	15.6
TRA-642-6H	Core, vessel and loop components	3.96E-01	15.0
TRA-603-4H	Core and loop components	1.74E-01	6.6
TRA-603-9H	Expended fuel and ceramic fuel	1.22E-01	4.6
Miscellaneous	Miscellaneous minor streams	6.61E-02	2.5
TRA-632-1H	Core structural pieces	3.42E-02	1.3
<b>Total Disposals</b>		2.64E+00	100
Am-241 ingrowth	Half-life equals 432 years. See Section 4.6.2	3.69E+01	NA
Pu-241 ingrowth	Half-life equals 14.4 years See Section 4.6.13	6.56E+00	NA

**4.6.10.2 Surface.** No surface data are available because Np-237 has not been a target analyte for surface monitoring.

**4.6.10.3 Vadose Zone.** The distributions of Np-237 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

**4.6.10.3.1 Vadose Zone Core Samples—**No vadose zone core sample gamma spectrometric analytic results are available for Np-237. In previous subsurface sample evaluations (1971 to 2000), Np-237 was not considered a radionuclide of concern. However, in the 1998 IRA, it was identified as a COPC though it has not been included on the radionuclide target list provided to the analytical laboratories subcontracted to the INEEL. Neptunium-237 is now identified as a COPC and has been included on the radionuclide target list provided to the analytic laboratories.

**4.6.10.3.2 Lysimeter Samples at Depths of 0 to 35 ft—**A total of 28 shallow lysimeter samples were analyzed by INEEL for Np-237 between June 2000 (when Np-237 monitoring began) and May 2001, with no positive detections in any of the 12 INEEL shallow lysimeter wells.

**4.6.10.3.3 Lysimeter Samples at Depths of 35 to 140 ft—**No positive detections of Np-237 were identified in the 15 samples analyzed from the 35 to 140-ft interval of the vadose zone between June 2000 and May 2001.

**4.6.10.3.4 Lysimeter and Perched Water Samples at Depths Greater than 140 ft—**A total of five Np-237 analyses were performed on perched water and deep suction lysimeter well samples, with no positive detections. No data are available for perched water samples from Well 8802D because the volume of water collected was insufficient to perform Np-237 analysis. Also, the laboratory was unable to obtain sediment samples from the USGS-92 perched water well sample. The USGS does not analyze perched water from Well USGS-92 for Np-237.

**4.6.10.4 Aquifer.** A total of 150 samples from 15 INEEL wells were analyzed by INEEL for Np-237 between 1998 and April 2001, with no positive detections. The USGS does not analyze for Np-237 in the eight RWMC wells they manage, control, and routinely sample.

**4.6.10.5 Summary of Neptunium-237.** Only 2.6 Ci of Np-237 were disposed of in the SDA, but substantially more are expected to be generated in the waste from the decay of Pu-241 and Am-241. Given the increased inventory associated with ingrowth and the relatively high mobility of Np-237, Np-237 is a risk driver. Neptunium-237 has been detected in the waste zone with the spectral gamma moisture logging tool but has not been detected in any of the nearly 200 samples collected in the vadose zone or aquifer wells (see Table 4-50). No evidence indicates that Np-237 has migrated outside of the SDA.

Table 4-50. Detection rate for neptunium-237 in various media.

Media	Detection Rate (%)	Range of Detected Concentrations	Total Number of Detections Higher than the Maximum Contaminant Level <sup>a</sup>	Wells Higher than Maximum Contaminant Level <sup>a</sup>
Source	Cores: 42% Measurements: 11%		0	None
Cores	0	0	0	None
Soil moisture: 0 to 35 ft	0	0	0	None
Soil moisture: 35 to 140 ft	0	0	0	None
Soil moisture: >140 ft	0	0	0	None
Aquifer	0	0	0	None

**4.6.11 Protactinium-231**

Protactinium-231 is an anthropic radioisotope that is a decay product of U-235. It is produced by nuclear reactor operations, decays by the emission of alpha particles, and has a half-life of 3.28E+04 years. It was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Protactinium-231 is not a target analyte for monitoring but its presence can be inferred if its parent radionuclide (i.e., U-235) is detected.

**4.6.11.1 Waste Zone.** Negligible amounts (i.e., 8.64E-04 Ci) of Pa-231 were disposed of in the SDA as identified in Table 4-51. Additional quantities of Pa-231 are being generated over time through ingrowth (see Section 4.1.2). Table 4-51 also includes the amount of Pa-231 that would be produced if all of the parent decayed. Because of the long half-lives of the parent nuclides, it will be many thousands of years before substantial ingrowth occurs. However, for completeness, the waste streams that contain parent nuclides are listed in Table 4-51. Percentages of the total Pa-231 from parent isotopes are not given because the amount of Pa-231 present is dependant on the timeframe assessed.

Gamma spectral logging data were not analyzed for Pa-231.

Table 4-51. Waste streams containing protactinium-231.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
D&D-ARA-1	Low-level waste from the decontamination and demolition of the Advanced Reactor Area facilities. Waste stream consists primarily of contaminated metal and debris.	8.56E-04	99
Miscellaneous	Miscellaneous minor streams.	8.44E-06	1
<b>Total Disposals</b>		8.64E-04	100
U-235 ingrowth	Half-life equals 7.04E+08 years. See Section 4.6.19	1.05E+05	NA
Pu-239 ingrowth	Half-life equals 2.41E+04 years. See Section 4.6.13	4.19E+04	NA
Am-243 ingrowth	Half-life equals 7.38E+03 years. See Section 4.6.3	2.66E+01	NA

**4.6.11.2 Summary of Protactinium-231.** There are no analytical data for Pa-231 because it is not a target analyte for environmental monitoring. However, its presence can be inferred by positive detections of U-235.

#### 4.6.12 Lead-210

Though Pb-210 is the terminating radioisotope in the naturally occurring U-238 decay chain, its natural abundance is so small it is assumed to be zero. Therefore, Pb-210 in the environment should be considered anthropic. Lead-210 decays by the emission of beta particles with a half-life of 22.6 years. Lead-210 was identified in the IRA as a COPC, primarily for the soil and crop ingestion pathway (Becker et al. 1998).

Lead-210-bearing waste streams in the SDA are summarized below. Lead-210 is not a target analyte for monitoring but its presence can be inferred if its parent radionuclide (i.e., U-238) is detected.

**4.6.12.1 Waste Zone.** Approximately 5.1E-07 Ci of Pb-210 were disposed of in the SDA. Table 4-52 identifies the waste streams containing the majority of Pb-210 activity.

Additional quantities of Pb-210 are being generated over time through ingrowth (see Section 4.1.2) Table 4-52 also includes the amount of Pb-210 that would be produced if all of the parent decayed. Because of the long half-lives of the parent nuclides, it will be many thousands of years before substantial ingrowth occurs. However, for completeness, the waste streams that contain parent nuclides are also listed in Table 4-52. Percentages of the total Pb-210 from parent isotopes are not given because the amount of Pb-210 present is dependant on the timeframe assessed.

**4.6.12.2 Summary of Lead-210.** No analytical data are available for Pb-210 because it is not a target analyte for environmental monitoring. The presence of Pb-210 can be inferred by positive detections of U-238.

Table 4-52. Waste streams containing lead-210.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
ALE-ALE-1H	Building rubble, electric wires, piping, machinery, tracers and sources, glass, gloves, paper, filters, and vermiculite.	4.83E-07	94.7
WER-CMP-1	Compacted waste—combination of glass, plastic, absorbents, cloth, paper, and wood.	2.70E-08	5.3
<b>Total Disposals</b>		5.10E-07	100
U-238 ingrowth	Half-life equals 4.47E+09 years. See Section 4.6.19	2.35E+10	NA
U-234 ingrowth	Half-life equals 2.45E+05 years. See Section 4.6.19	7.41E+05	NA
Pu-238 ingrowth	Half-life equals 8.78E+01 years. See Section 4.6.13	6.74E+04	NA
Ra-226 ingrowth	Half-life equals 1.60E+03 years. See Section 4.6.16	4.30E+03	NA
Th-230 ingrowth	Half-life equals 7.70E+04 years.	1.08E+02	NA

#### 4.6.13 Plutonium

All plutonium isotopes are anthropic and transuranic products of nuclear reactor operations or nuclear weapons production, deployment, and testing. Plutonium-238, Pu-239, and Pu-240 decay by the emission of alpha particles, have half-lives of 87.7, 2.41E+04, and 6.56E+03 years, respectively. Plutonium-241 decays by the emission of beta particles and has a 14.4-year half-life. Plutonium-239 and Pu-240 were identified in the IRA as COPCs primarily for the soil and crop ingestion pathway (Becker et al. 1998). Plutonium-238 was not identified as a COPC in the IRA (Becker et al. 1998) but was retained for analysis of isotopic ratios. The results for Pu-238, Pu-239, and Pu-240 are discussed in this section, along with plutonium isotopic ratios that are indicative of waste derived from weapons- or fuel-related disposals.

Plutonium-239 is often reported as Pu-239, Pu-239/240, or Pu-239+240. Any of the three reporting conventions is acceptable, but technically, it is most correct to report Pu-239 as either Pu-239/240 or Pu-239+240 because the individual isotopes cannot be chemically separated and they have alpha particle energies that are nearly identical. Therefore, it is nearly impossible to differentiate the isotopes in environmental samples using routine alpha spectroscopy. Nonradiochemical methods such as mass spectrometry must be applied to obtain results for each separate radionuclide.

Data analysis for WAG 7 includes evaluating the Pu-238:Pu-239/240 ratio when both plutonium isotopes are detected to determine if detected concentrations emanate from weapons-grade or reactor-grade plutonium. Concentrations of Pu-238 without Pu-239/240 or with a Pu-238:Pu-239/240 ratio of about 11 imply reactor-grade plutonium. Weapons-grade plutonium contains much more Pu-239/240 than Pu-238, with a Pu-238:Pu-239/240 ratio of approximately 0.02 to 0.03.

Comparison concentrations for the plutonium isotopes are presented in Table 4-53.

Table 4-53. Comparison concentrations for plutonium in groundwater and soils.

Contaminant	Surface Soil Background Concentration <sup>a</sup> (pCi/g)	Risk-Based Soil Concentration (pCi/g)	Aquifer Background Concentration (pCi/L)	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>b</sup> (pCi/L)
Plutonium-238	0.0049	29.2	0	15 (total alpha)	3.6
Plutonium-239	0.10 <sup>c</sup>	28.8	0	15 (total alpha)	3.5
Plutonium-240	0.10 <sup>c</sup>	28.8	0	15 (total alpha)	3.5

a. Soil background represents the 95% tolerance limit with 95% confidence for a composite soil sample (Rood, Harris, and White 1996).

b. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05d (Knobel, Orr, and Cecil 1992).

c. Result is for Pu-239/240 combined.

**4.6.13.1 Waste Zone.** Approximately 1.71E+04 Ci of Pu-238 were disposed of in the SDA. Table 4-54 identifies the waste streams containing the majority of Pu-238 activity. Approximately 6.48E+04 Ci of Pu-239 and 1.71E+04 Ci of Pu-240 were disposed of in the SDA. Tables 4-55 and 4-56 identify the waste streams containing the majority of Pu-239 and Pu-240 activity. All of the plutonium isotopes generate daughter products: Pu-238 decays to U-234, Th-230, Ra-226 and Pb-210; Pu-239 decays to U-235, Pa-231, and Ac-227; and Pu-240 decays to U-236, Th-232, and Ra-228. See the respective sections for individual daughter products to determine the relative contribution of plutonium decay to the daughter inventory.

Table 4-54. Waste streams containing plutonium-238.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste.	1.46E+04	85.3
Miscellaneous	Miscellaneous minor streams.	6.50E+02	3.8
RFO-DOW-9H	Noncombustibles—gloveboxes, equipment, pumps, motors, control panels, and office equipment.	5.00E+02	2.9
TRA-603-9H	Expended fuel and ceramic fuel.	4.95E+02	2.9
RFO-DOW-3H	Uncemented sludge.	2.75E+02	1.6
RFO-DOW-6H	Filters.	2.32E+02	1.4
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot.	1.99E+02	1.2
RFO-DOW-4H	Combustibles—paper, rags, plastic clothing, cardboard, wood, and polyethylene bottles (Codes 330, 336, 337, 900, and 970).	1.74E+02	1.0
<b>Total Disposals</b>		<b>1.71E+04</b>	<b>100</b>

Table 4-55. Waste streams containing plutonium-239.

Waste Stream	Waste Stream Description	Activity (Ci)	Proportion of Activity (%)
RFO-DOW-9H	Noncombustibles—gloveboxes, equipment, pumps, motors, control panels, and office equipment.	1.70E+04	26.3
RFO-DOW-3H	Uncemented sludge.	9.40E+03	14.5
RFO-DOW-6H	Filters.	7.90E+03	12.2
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot.	6.79E+03	10.5
RFO-DOW-4H	Combustibles—paper, rags, plastic clothing cardboard, wood, and polyethylene bottles.	5.96E+03	9.2
RFO-DOW-7H	Glass—including raschig rings.	5.37E+03	8.3
RFO-DOW-8H	Lead from glovebox gloves and sheeting.	4.53E+03	7.0
RFO-DOW-11H	Graphite molds.	3.37E+03	5.2
INEEL	Idaho National Engineering and Environmental Laboratory reactor operations waste.	1.29E+03	2.0
RFO-DOW-5H	Concrete and brick.	1.25E+03	1.9
Miscellaneous	Miscellaneous minor streams.	1.23E+03	1.9
RFO-DOW-13H	Resins.	7.31E+02	1.1
<b>Total Disposals</b>		<b>6.48E+04</b>	<b>100</b>

Table 4-56. Waste streams containing plutonium-240.

Waste Stream	Waste Stream Description	Activity (Ci)	Proportion of Activity (%)
RFO-DOW-9H	Noncombustibles—gloveboxes, equipment, pumps, motors, control panels, and office equipment.	3.85E+03	22.5
INEEL	Idaho National Engineering and Environmental Laboratory reactor operations waste.	2.36E+03	13.8
RFO-DOW-3H	Uncemented sludge.	2.12E+03	12.4
RFO-DOW-6H	Filters.	1.78E+03	10.4
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot.	1.53E+03	9.0
RFO-DOW-4H	Combustibles—paper, rags, plastic clothing, cardboard, wood, and polyethylene bottles (Codes 330, 336, 337, 900, and 970).	1.35E+03	7.9
RFO-DOW-7H	Glass—including raschig rings.	1.21E+03	7.1
RFO-DOW-8H	Lead from glovebox gloves and sheeting.	1.02E+03	6.0
RFO-DOW-11H	Graphite molds.	7.62E+02	4.5
OFF-LRL-2H	Concrete, bricks, and asphalt.	4.53E+02	2.7
Miscellaneous	Miscellaneous.	3.42E+02	2.0
RFO-DOW-5H	Concrete and brick.	2.82E+02	1.7
<b>Total Disposals</b>		<b>1.71E+04</b>	<b>100</b>

Spectral gamma logging provided no data about Pu-238 or Pu-240, but detected Pu-239 based on the 414 keV gamma rays. Of the 135 probeholes logged using the spectral gamma logging tool, 100 (74%) showed the presence of Pu-239 above the noise level. Of the 4,863 total measurements collected from all probes at all depths, 1,261 (26%) showed the presence of Pu-239 above the noise level. The Pu-239 detection limit was approximately 29 nCi/g. The maximum and average observed Pu-239 levels were 194,171 nCi/g, and 2,246 nCi/g, respectively. The detection limit, maximum concentration, and average concentration are based on the assumption that Pu-239 is uniformly distributed in the vicinity of the measurement points.

**4.6.13.2 Surface.** A total of 186 soil samples were collected between 1994 and 2000 from around the RWMC. Based on gamma spectrometric analytic results, 76 samples were selected for Pu-238 and Pu-239/240 analysis. Five positive detections of Pu-238 were identified ranging from  $(5.1 \pm 1.4)E-03$  pCi/g at TSA (LMITCO 1995c) to  $(3.19 \pm 0.53)E-02$  pCi/g in the Pad A area (INEEL 2001). Fifty-nine positive detections of Pu-239/240 were identified, which ranged from  $(9.0 \pm 2.0)E-03$  pCi/g at SWEPP 5 (LMITCO 1996) to  $1.22 \pm 0.12$  pCi/g at the active area (INEEL 2001).

A total of 124 vegetation samples were collected between 1990 and 2000 from the RWMC and control locations. Based on gamma spectrometric analytic results, about 30 samples were evaluated for Pu-238 and Pu-239/240. No positive detections of Pu-238 were identified; however seven positive detections of Pu-239/240 were identified. The positive detections of Pu-239/240 in vegetation samples ranged from  $(4.58 \pm 0.15)E-04$  pCi/g (INEEL 2000) to  $(1.0 \pm 0.2)E-02$  pCi/g (EG&G 1991).

A total of 210 surface run-off water samples were collected between 1991 and 2000 from the RWMC and control locations. Based on gamma spectrometric results, about 90 samples were evaluated for Pu-238 and Pu-239/240. No positive detections of Pu-238 were identified; however, eight positive detections of Pu-239/240 were identified. The positive detections of Pu-239/240 ranged from  $(2.04 \pm 0.75)E-02$  pCi/L (INEEL 2000) to  $(1.1 \pm 0.3)E-01$  pCi/L (LMITCO 1995c).

**4.6.13.3 Vadose Zone Core Samples.** The distributions of plutonium in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

**4.6.13.3.1 Plutonium-238 in Vadose Zone Core Samples—**A total of 341 vadose zone core samples collected during well drilling were analyzed for Pu-238 between 1971 and 2000. Eighteen positive detections were identified with 13 above the INEEL surface soil background of 0.0049 pCi/g. Four of the 13 samples above background were analyzed in 1972 and the data are of questionable quality because of cross-contamination concerns. All positive detections are listed in Table 4-57.

A summary of the occurrence of Pu-238 detections by depth interval is shown in Table 4-58. The majority of valid Pu-238 detections (i.e., those not taken between 1971 and 1974) are located in the Pad A and Pit 5 areas (i.e., Wells D02 and TW1).

Table 4-57. Positive detections of plutonium-238 in vadose zone core samples.

Borehole Identification	Sample Depth (ft)	Concentration $\pm 1\sigma$ (pCi/g)	Date
78-5	101.7	0.0031 $\pm$ 0.0010	1978
USGS-93	101.0 to 103.0	0.0076 $\pm$ 0.0015 <sup>a</sup>	1972
	103.0 to 105.0	0.014 $\pm$ 0.003 <sup>a</sup>	1972
USGS-96	100.5 to 101.0	0.0059 $\pm$ 0.0015 <sup>a</sup>	1972
	110.0 to 112.9	0.009 $\pm$ 0.002 <sup>a</sup>	1972
D02	1.2 to 1.7	0.26 $\pm$ 0.02	1987
	15.5 to 16.0	0.0149 $\pm$ 0.0018	1987
	229.7 to 230.0	0.0024 $\pm$ 0.0007	1987
	230.0 to 230.3	0.0065 $\pm$ 0.0019	1987
	230.0 to 230.3	0.0322 $\pm$ 0.0017	1987
	230.0 to 230.3	0.0015 $\pm$ 0.0004	1987
	230.0 to 230.3	0.0033 $\pm$ 0.0006	1987
TW1	101.0 to 101.2	0.017 $\pm$ 0.002	1987
	101.0 to 101.2	0.0118 $\pm$ 0.0017	1987
	101.2	0.0046 $\pm$ 0.0014	1987
	101.2	0.0063 $\pm$ 0.0017	1987
	101.2	0.0065 $\pm$ 0.0016	1987
	101.2	0.010 $\pm$ 0.003	1987

a. The 1971 and 1972 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Table 4-58. Summary of plutonium-238 occurrences in the vadose zone core samples.

Depth Interval (ft)	Number of Pu-238 Detections/Total Number of Samples (%)		Range (pCi/g)	Cores with Detections
0 to 35	2/33 (6.1)		0.0149 to 0.26	D02
35 to 140	11/140 (7.8)		0.0031 to 0.017	78-5, TW-1, USGS-93, USGS-96
140 to 250	5/157 (3.2)		0.0015 to 0.033	D02
Greater than 250	0/11 (0)		Not applicable	None

**4.6.13.3.2 Plutonium-239/240 in Vadose Zone Core Samples**—A total of 352 vadose zone core samples collected during well drilling were analyzed for Pu-239/240 between 1971 and 2000. Twenty-nine positive detections were identified; however, nine of those were suspect because of well drilling and sampling methods used in the early 1970s (see Section 4.5.5). The samples with detected concentrations of Pu-239/240 are listed in Table 4-59.

Table 4-59. Positive detections of plutonium-239/240 in vadose zone core samples.

Borehole Identification	Sample Depth (ft)	Concentration $\pm 1\sigma$ (pCi/g)	Date
76-3	97.5 to 97.8	0.017 $\pm$ 0.005	1976
78-5	240.3	0.013 $\pm$ 0.002	1978
79-2	99.1 to 99.9	0.061 $\pm$ 0.004	1979
	99.1 to 99.9	0.056 $\pm$ 0.004	1979
	99.9 to 101.7	0.034 $\pm$ 0.003	1979
	99.9 to 101.7	0.037 $\pm$ 0.003	1979
	101.7 to 103.0	0.038 $\pm$ 0.003	1979
	101.7 to 103.0	0.036 $\pm$ 0.003	1979
I-3S	100.0	0.009 $\pm$ 0.003	1999
USGS-87	231.2 to 233.0	0.029 $\pm$ 0.004 <sup>a</sup>	1971
USGS-88	521.0 to 522.0	0.022 $\pm$ 0.003 <sup>a</sup>	1971
USGS-91	7.83 to 8.92	0.026 $\pm$ 0.005 <sup>a</sup>	1972
	236.5 to 237.0	0.140 $\pm$ 0.007 <sup>a</sup>	1972
USGS-93	98.0 to 101.0	0.110 $\pm$ 0.007 <sup>a</sup>	1972
	101.0 to 103.0	0.230 $\pm$ 0.011 <sup>a</sup>	1972
	101.0 to 103.0	0.540 $\pm$ 0.012 <sup>a</sup>	1972
	103.0 to 105.0	0.081 $\pm$ 0.011 <sup>a</sup>	1972
USGS-96	100.5 to 101.0	0.045 $\pm$ 0.002 <sup>a</sup>	1972
D02	1.2 to 1.7	1.13 $\pm$ 0.05	1987
	15.5 to 16.0	0.255 $\pm$ 0.009	1987
	230.0 to 230.3	0.058 $\pm$ 0.002	1987
TW1	101.0 to 101.2	0.74 $\pm$ 0.04	1987
	101.0 to 101.2	0.61 $\pm$ 0.03	1987
	101.2	0.197 $\pm$ 0.013	1987
	101.2	0.190 $\pm$ 0.013	1987
	101.2	0.200 $\pm$ 0.013	1987
	101.2	0.168 $\pm$ 0.009	1987
	101.2	0.170 $\pm$ 0.009	1987
	101.2	0.178 $\pm$ 0.013	1987

a. The 1971 and 1972 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Table 4-60 shows the number of cores sampled and the number of cores in which Pu-239/240 was detected by depth interval. The occurrence of Pu-239/240 in depth intervals is consistent with the pattern of Pu-238 detections in Wells USGS-93, USGS-96, D02, and TW1.

Most (i.e., 21) detections were observed in close proximity to the B-C interbed, though many of those analyses were duplicate samples. Detections at the B-C interbed depth are concentrated primarily in two areas in the SDA; near Pit 5 (Boreholes 79-2, D02 and TW1) and the west end of the SDA (i.e., Well 76-3, USGS-93, and USGS-96).

Two detections were identified in the shallow surficial sediments (one near Pit 5 and the other near Pit 14), and four near the C-D interbed (also near Pit 5 and Pit 14 plus two outside the SDA). Well USGS-88 (south of the SDA) had detectable concentrations of Pu-239/240 at 520 ft. Plutonium-239/240 detections in Boreholes TW1 and D02 are corroborated by detections of Pu-238 and Am-241.

Table 4-60. Summary of plutonium-239/240 occurrences in vadose zone core samples.

Depth Interval (ft)	Number of Pu-239/240 Detections/Total Number of Core Samples (%)	Range (pCi/g)	Cores with Detections
0 to 35	3/37 (8.1)	0.026 to 1.13	D02, USGS-91
35 to 140	21/147 (14.3)	0.009 to 0.74	76-3, 79-2, I-3S, USGS-93, USGS-96, TW1
140 to 250	4/157 (2.5)	0.013 to 0.14	78-5, D02, USGS-87, USGS-91
>250	1/11 (9.0)	0.022	USGS-88

**4.6.13.3 Plutonium Ratios in Vadose Zone Core Samples**—When a sample contains both Pu-238 and Pu-239/240, the ratio of Pu-238:Pu-239/240 can be an indicator of whether the waste source was originally reactor operations or weapons manufacturing. In general, activity ratios around 0.02 to 0.03 are indicative that the plutonium in the sample originated from weapons manufacturing waste, and activity ratios around 11 are indicative that the waste source was reactor operations. A sample with Pu-238 but no detectable Pu-239/240 is usually indicative of waste from reactor operations. A sample with Pu-239/240 but no Pu-238 is indicative of weapons-related waste.

For the RWMC core samples, most plutonium detections and ratios suggest that the plutonium detections are predominantly from weapons manufacturing waste (see Table 4-61). However, some detections and ratios also indicate the presence of plutonium from reactor operations such as samples from Well D02 at the 230-ft depth. Nearby core samples from Wells TW1 and 79-2 at approximately 100-ft depth show evidence of weapons manufacturing waste.

Table 4-61. Detections of plutonium-238, plutonium-239/240, and plutonium-238:plutonium-239/240 activity ratios for vadose zone core samples.

Borehole Identification	Pu-238 (pCi/g)	Pu-239/240 (pCi/g)	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process	Sample Depth (ft)	Date
76-3	Analyzed for but not detected (ND)	0.017	Not applicable (NA)	Weapons <sup>a</sup>	97.5 to 97.8	1976
78-5	0.0031	ND	NA	Reactors <sup>b</sup>	101.7	1978
78-5	ND	0.013	NA	Weapons <sup>a</sup>	240.3	1978
79-2	ND	0.061	NA	Weapons <sup>a</sup>	99.1 to 99.9	1979
79-2	ND	0.056	NA	Weapons <sup>a</sup>	99.1 to 99.9	1979
79-2	ND	0.034	NA	Weapons <sup>a</sup>	99.9 to 101.7	1979
79-2	ND	0.037	NA	Weapons <sup>a</sup>	99.9 to 101.7	1979
79-2	ND	0.038	NA	Weapons <sup>a</sup>	101.7 to 103.0	1979
79-2	ND	0.036	NA	Weapons <sup>a</sup>	101.7 to 103.0	1979
USGS-87	ND	0.029 <sup>c</sup>	NA	Weapons <sup>a,c</sup>	231.2 to 233.0	1971
USGS-88	ND	0.022 <sup>c</sup>	NA	Weapons <sup>a,c</sup>	521.0 to 522.0	1971

Table 4-61. (continued).

Borehole Identification	Pu-238 (pCi/g)	Pu-239/240 (pCi/g)	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process	Sample Depth (ft)	Date
USGS-91	ND	0.026 <sup>c</sup>	NA	Weapons <sup>a,c</sup>	7.83 to 8.92	1972
USGS-91	ND	0.140 <sup>c</sup>	NA	Weapons <sup>a,c</sup>	236.5 to 237.0	1972
USGS-93	0.0076 <sup>c</sup>	0.110 <sup>c</sup>	0.069	Weapons <sup>a,c</sup>	98 to 101	1972
USGS-93	ND	0.230 <sup>c</sup>	NA	Weapons <sup>a,c</sup>	101 to 103	1972
USGS-93	0.014 <sup>c</sup>	0.540 <sup>c</sup>	0.026	Weapons <sup>a,c</sup>	101 to 103	1972
USGS-93	ND	0.081 <sup>c</sup>	NA	Weapons <sup>a,c</sup>	103 to 105	1972
USGS-96	0.0059 <sup>c</sup>	0.045 <sup>c</sup>	0.131	Indeterminate <sup>c</sup>	100.5 to 101.0	1972
USGS-96	0.009 <sup>c</sup>	ND	NA	Reactors <sup>b,c</sup>	110.0 to 112.9	1972
D02	0.26	1.13	0.230	Indeterminate	1.2 to 1.7	1987
D02	0.0149	0.255	0.058	Weapons <sup>a</sup>	15.5 to 16.0	1987
D02	0.0024	ND	NA	Reactors <sup>b</sup>	229.7 to 230.0	1987
D02	0.0065	ND	NA	Reactors <sup>b</sup>	230.0 to 230.3	1987
D02	0.0322	0.058	0.555	Indeterminate	230.0 to 230.3	1987
D02	0.0015	ND	NA	Reactors <sup>b</sup>	230.0 to 230.3	1987
D02	0.0033	ND	NA	Reactors <sup>b</sup>	230.0 to 230.3	1987
TW1	0.017	0.74	0.023	Weapons <sup>a</sup>	101 to 101.2	1987
TW1	0.0118	0.61	0.019	Weapons <sup>a</sup>	101 to 101.2	1987
TW1	0.0046	0.197	0.023	Weapons <sup>a</sup>	101.2	1987
TW1	0.0063	0.190	0.033	Weapons <sup>a</sup>	101.2	1987
TW1	0.0065	0.200	0.033	Weapons <sup>a</sup>	101.2	1987
TW1	ND	0.168	NA	Weapons <sup>a</sup>	101.2	1987
TW1	ND	0.170	NA	Weapons <sup>a</sup>	101.2	1987
TW1	0.010	0.178	0.056	Weapons <sup>a</sup>	101.2	1987

a. Positive Pu-239/240 detections, without detections of Pu-238, are indicative of weapons (i.e., manufacturing waste or fallout). The Pu-238: Pu-239/240 ratio for weapons manufacturing waste is 0.02 to 0.03.

b. Positive Pu-238 detections without detections of Pu-239/240 are indicative of high burnup reactor fuel and fuel processing waste. The Pu-238 activity in high burnup reactor fuel and fuel processing waste is approximately 11 times higher than the Pu-239/240 activity. Thus, the Pu-238:Pu-239/240 ratio for fuel is approximately 11. In many cases presented in this table, the concentration of expected Pu-239/240 would be too low to detect.

c. The 1971 and 1972 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

**4.6.13.3.4 Summary of Plutonium in Vadose Zone Core Samples**—Plutonium was detected infrequently in core samples, with detection rates of 5.3% for Pu-238 and 8.2% for Pu-239/240. The detections are very low level, ranging from two to four orders of magnitude below the soil 1E-05 RBC. Generally, detections do not occur contiguously throughout the depth of a core, but occur sporadically or are concentrated at one depth interval.

A cluster of Pu-238 and Pu-239/240 detections exists in the Pad A and Pit 5 area, especially around the B-C interbed. These detections include the following:

- Numerous detections of Pu-238 and Pu-239/240 in Well TW1 near Pit 5 around the 100-ft depth, with no detections in the numerous samples from the 225 to 227-ft depth.
- Detectable Pu-239/240 with no Pu-238 at three different depth intervals, concentrated between 99.1 and 103 ft, with no detections in the 28-, 70- or 230-ft depths.
- Detectable Pu-238 and Pu-239/240 in shallow (less than 15 ft) and deep (230 ft) samples from Well D02 near Pit 5. No samples were collected from the 100-ft depth interval of Well D02.

Plutonium activity ratios calculated on the core samples most often suggest that the waste source originated from weapons manufacturing rather than reactor operations, though some samples are suggestive of reactor fuel. Where ratios were interpreted as reactor-related waste, the interpretation was founded on no detectable Pu-239/240, rather than because the ratio was greater than the indicator value of 11.

**4.6.13.3.5 Plutonium-238 in Shallow Lysimeter Samples**—A total of 105 shallow lysimeter samples were analyzed for Pu-238 between 1997 and May 2001, with seven positive detections (see Table 4-62). Four of the detections were greater than the 1E-05 aquifer RBC of 3.6 pCi/L. The aquifer RBC does not apply to lysimeter samples, but is used only for a basis of comparison. Five of the seven samples that exceeded the aquifer RBC occurred near Pad A and Pit 5. The PA prefix on the lysimeter name indicates a Pad A lysimeter. Of the five detections near Pad A, the three samples from Lysimeters PA01 and PA02 were reanalyzed and detections were not confirmed. The two samples containing detectable amounts of Pu-238 in Lysimeter PA03 were not reanalyzed because of insufficient sample volume. The occurrence of the Pu-238 detections in shallow lysimeter samples is shown in Figure 4-28.

Table 4-62. Detected concentrations of plutonium-238 in shallow lysimeters.

Lysimeter	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
PA01-L15	14.3	<b>9 <math>\pm</math> 2</b> 2.3 $\pm$ 0.7	B	April 1998
PA02-L16	8.7	<b>3.7 <math>\pm</math> 0.4</b>	B	September 2000
PA03-L33	10	<b>24 <math>\pm</math> 2</b> 2.2 $\pm$ 0.5	A	August 1997
98-4L38 (SDA-08)	17	0.9 $\pm$ 0.3	A	February 1998
98-5L39 (SDA-10)	10.5	<b>5.6 <math>\pm</math> 1.6</b>	B	September 2000
			B	April 1998

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

Note: Values in **red bold** indicate that the concentration exceeds the 1E-05 aquifer risk-based concentration (RBC) of 3.6 pCi/L for Pu-238. The RBCs for the aquifer do not apply to soil moisture samples, but are used here as a basis of comparison.

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01-L15	PA02-L16	PA03-L33	W06-L27	W08-L13	W08-L14	W23-L08	W23-L09	W25-L28
1997	1												
	2												
	3						24						
	4												
1998	1						2.2						
	2			5.6	9								
	3												
	4												
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3		0.9		2.3								
	4					3.7							
2001	1												
	2												
	3												
	4												
Key		Analysis was performed for Pu-238, but none was detected.											
		Pu-238 was detected (pCi/L).											
		If more than one detection occurred in a Well in a single quarter, only the highest concentration is listed.											

Figure 4-28. Occurrence of plutonium-238 in shallow lysimeter samples (detected concentrations in pink).

Four of the seven positive Pu-238 detections were greater than the aquifer RBC. The ceramic cup of the lysimeter may filter plutonium and bias the measurement low (see Section 4.5.6); therefore, the Pu-238 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

A Pu-238 trend might be developing in Lysimeter PA02-L16. All but one of the Pu-238 values in this lysimeter are nondetections, but an observable increase has been observed in their concentrations over time. There was a statistical detection result greater than  $2\sigma$  but less than  $3\sigma$  in September 2000 and a positive detection in December 2000.

The August 1997 sample from Lysimeter PA03-L33 exceeded the aquifer RBC of 3.6 pCi/L. The next sample taken from Lysimeter PA03-L33 (February 1998) contained detectable amounts of Pu-238, but five subsequent samples pulled from that lysimeter well (April and December, 1998; May and November 1999; and March 2000) did not contain detectable Pu-238 (see Figure 4-29). Ultra low-level thermal ionization mass spectrometry (TIMS) analysis did not confirm the presence of Pu-238 above 0.002 pCi/L in PA03-L33 or any other shallow lysimeter well (see Section 4.6.14).

**4.6.13.3.6 Plutonium-239/240 in Shallow Lysimeter Samples**—A total of 107 shallow lysimeter well samples were analyzed for Pu-239/240 between 1997 and May 2001, resulting in one positive detection. The positive sample came from Lysimeter PA02-L16 in December 2000 and had a

concentration of  $0.70 \pm 0.17$  pCi/L. The positive result was not confirmed by reanalysis of the original sample. The occurrence of the positive Pu-239/240 detection relative to the other shallow lysimeter sampling events is shown in Figure 4-29.

The plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01-L15	PA02-L16	PA03-L33	W06-L27	W08-L13	W08-L14	W23-L08	W23-L09	W25-L28
1997	1												
	2												
	3												
	4												
1998	1												
	2												
	3												
	4												
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3												
	4					0.7							
2001	1												
	2												
	3												
	4												
Key		Analysis was performed for Pu-239/240, but none was detected.											
		Pu-239/240 was detected (pCi/L).											
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.											

Figure 4-29. Occurrence of plutonium-239/240 detections in shallow lysimeters.

**4.6.13.3.7 Plutonium Ratios in Shallow Lysimeter Samples**—When a sample contains both Pu-238 and Pu-239/240, the ratio of Pu-238:Pu-239/240 can be an indicator of whether the waste source was originally reactor operations or weapons manufacture. In general, activity ratios around 0.02 to 0.03 are indicative that the plutonium in the sample originated from weapons manufacturing waste, and activity ratios around 11 are indicative that the waste source was reactor operations. A sample with Pu-238 but no detectable Pu-239/240 is usually indicative of waste from reactor operations. A sample with Pu-239/240 but no Pu-238 is indicative of weapons-related waste.

All plutonium detections and ratios associated with shallow soil moisture sample analysis indicate the plutonium detections are from high burnup reactor-related waste and not weapons manufacturing waste (see Table 4-63). The lysimeter wells showing reactor-generated plutonium (Wells PA01, PA02,

and PA03) are located near Pad A and Pit 5. Soil moisture samples from these same lysimeters also show elevated levels of uranium. A single, low-level Pu-238 detection was identified that is associated with Well 98-4. Well 98-5 at the west end of the SDA also yielded a single detection; however, it contained a supporting Pu-239/240 detection with a ratio that suggests plutonium in this soil moisture sample is likely from reactor operations.

Table 4-63. Detections of plutonium and plutonium-238:plutonium-239/240 activity ratios associated with positive detections from the same shallow lysimeter samples.

Lysimeter	Pu-238 (pCi/L)	Pu-239/240 (pCi/L)	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process	Date
98-4L38	0.9	Analyzed for but not detected (ND)	Not applicable (NA)	Reactors <sup>a</sup>	September 2000
98-5L39	5.6	ND	NA	Reactors <sup>a</sup>	April 1998
PA01-L15	9	ND	NA	Reactors <sup>a</sup>	April 1998
PA01-L15	2.3	ND	NA	Reactors <sup>a</sup>	September 2000
PA02-L16	3.7	0.7	5.3	Reactors <sup>a</sup>	December 2000
PA03-L33	24	ND	NA	Reactors <sup>a</sup>	August 1997
PA03-L33	2.2	ND	NA	Reactors <sup>a</sup>	February 1998

a. Positive Pu-238 detections without accompanying detections of Pu-239/240 are indicative of high burnup reactor fuel and fuel processing waste. The Pu-238 activity in high burnup reactor fuel and fuel processing waste is approximately 11 times higher than the Pu-239/240 activity. Thus, the Pu-238:Pu-239/240 ratio for reactor operations is approximately 11.

**4.6.13.3.8 Summary of Plutonium in Shallow Lysimeter Samples**—Plutonium detections are sporadic in shallow lysimeter samples. The detection rate was 6.7% for Pu-238 and 0.9% for Pu-239/240. Five of the seven Pu-238 detections occurred around Pad A and Pit 5. The only Pu-239/240 detection also occurred near Pad A. The ratios associated with shallow soil moisture sample analysis suggest that the plutonium detections are from high burnup reactor-related waste and not weapons manufacturing waste.

#### 4.6.13.4 Lysimeter Samples at Depths of 35 to 140 ft

**4.6.13.4.1 Plutonium-238 in Intermediate-Depth Lysimeter Samples**—A total of 40 samples from 13 lysimeters in the 35 to 140-ft depth interval were analyzed for Pu-238 between 1997 and May 2001, with three positive detections (see Table 4-64). One of these was greater than the 1E-05 aquifer RBC of 3.6 pCi/L. The detections are shown in Figure 4-30.

All positive detections occurred in the August 1997 sampling round. The positive sample results could not be confirmed by reanalysis because available sample volumes were limited. Subsequent samples collected from these three wells (through May 2001) have not contained detectable levels of Pu-238.

Yr	Quarter	D06-DL01	D06-DL02	D15-DL06	I-1S	I-2S	I-3S	I-4S	I-5S	O-2S	O-3S	O-4S	O-5S	TW1-DL04
1997	1													
	2													
	3	11.6	3.3	3.1										
	4													
1998	1													
	2													
	3													
	4													
1999	1													
	2													
	3													
	4													
2000	1													
	2													
	3													
	4													
2001	1													
	2													
	3													
	4													
Key		Analysis was performed for Pu-238, but none was detected.												
		Pu-238 was detected (pCi/L).												
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.												

Figure 4-30. Occurrence of detectable plutonium-238 (in pink) in lysimeter samples from the 35 to 140-ft depth interval.

Table 4-64. Positive detections of plutonium-238 in the vadose zone samples from 35 to 140-ft depth interval.

Lysimeter	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
D06-DL01	88	<b>11.6 <math>\pm</math> 1.8</b>	A	August 1997
D06-DL02	44	3.3 $\pm$ 0.6	A	August 1997
D15-DL06	98	3.1 $\pm$ 0.7	A	August 1997

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

Note: Values in red bold indicate that the concentration exceeds the 1E-05 aquifer risk-based concentration (RBC) of 3.6 pCi/L. The RBCs for the aquifer do not apply to soil moisture samples, but are used here as a basis of comparison.

The detection in Lysimeter D06-DL01 exceeded the aquifer 1E-05 RBC, but no detectable concentrations have been measured in this lysimeter since 1998. However, the plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-238 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

**4.6.13.4.2 Plutonium-239/240 in Intermediate-Depth Lysimeter Samples**—A total of 39 lysimeter samples from the 35 to 140-ft depth interval were analyzed by the INEEL for Pu-239/240 between 1997 and May 2001, with three positive detections (see Table 4-65). The occurrence of these detections is shown graphically in Figure 4-31.

Table 4-65. Plutonium-239/240 detections in lysimeters from the 35 to 140-ft depth interval of the vadose zone.

Lysimeter	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
TW1-DL04	101.7	0.34 $\pm$ 0.09	A	November 1998
D15-DL06	98	1.1 $\pm$ 0.3	A	August 1997
O4S-DL24	98	3.3 $\pm$ 1.0	B	December 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

Yr	Quarter	D06-DL01	D06-DL02	D15-DL06	I-1S	I-3S	I-4S	I-5S	O-2S	O-3S	O-4S	O-5S	TW1-DL04
1997	1												
	2												
	3			1.1									
	4												
1998	1												
	2												
	3												
	4												0.34
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3												
	4										3.3		
2001	1												
	2												
	3												
	4												
Key		Analysis was performed for Pu-239/240, but none was detected.											
		Pu-239/240 was detected (pCi/L).											
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.											

Figure 4-31. Occurrence of plutonium-239/240 detections in lysimeter samples from 35 to 140-ft deep. Pink indicates a detected concentration.

The positive sample results were all less than the aquifer RBC and were not confirmed by reanalysis. Subsequent samples collected from these three wells (through May 2001) have not contained detectable Pu-239/240.

Some of the lysimeter samples analyzed using TIMS indicated that samples from Lysimeter TW1-DL04 may contain Pu-239. This is discussed more in Section 4.6.14.

The detected concentrations of Pu-239/240 in lysimeter samples are less than the aquifer RBC of 3.5 pCi/L. However, the plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

**4.6.13.4.3 Plutonium Ratios in Intermediate-Depth Lysimeter Samples**—Most plutonium detections and ratios associated with the intermediate-depth soil moisture sample analyses indicate the plutonium detections are from both weapons manufacturing waste and reactor fuel (see Table 4-66). Wells D06 and TW1 are located near each other, yet their ratios indicate different waste sources. This inconclusive information may be associated with variability in sample concentrations near the detection limit.

Table 4-66. Detections of plutonium-238 and plutonium-239/240, and the plutonium-238: 239/240 activity ratios for intermediate-depth lysimeter samples.

Lysimeter	Pu-238 (pCi/L)	Pu-239/240 (pCi/L)	Pu-238: Pu-239/240 Activity Ratio	Possible Waste Source	Sample Depth (ft)	Date
D06-DL01	11.6	Analyzed for but not detected (ND)	Not applicable (NA)	Reactors <sup>a</sup>	36 to 140	08/1997
D06-DL02	3.3	ND	NA	Reactors <sup>a</sup>	36 to 140	08/1997
D15-DL06	3.1	1.1	2.8	Indeterminate	36 to 140	08/1997
O4S-DL24	ND	3.31	NA	Weapons <sup>b</sup>	36 to 140	12/2000
TW1-DL04	ND	0.34	NA	Weapons <sup>b</sup>	36 to 140	11/1998

a. Positive Pu-239/240 detections, without detections of Pu-238, are indicative of weapons (i.e., manufacturing waste or fallout). The Pu-239/240 activity in weapons manufacturing waste is approximately 40 times higher than the Pu-238 activity. Therefore, the Pu-238:Pu-239/240 ratio for weapons manufacturing waste is 0.02 to 0.03, whereas the Pu-238:Pu-239/240 ratio for fallout is approximately 0.03 to 0.06.

b. Positive Pu-238 detections without detections of Pu-239/240 are indicative of high burnup reactor fuel and fuel processing waste. The Pu-238 activity in high burnup reactor fuel and fuel processing waste is approximately 11 times higher than the Pu-239/240 activity. Therefore, the Pu-238:Pu-239/240 ratio for fuel is approximately 11. In many cases presented in this table, the concentration of expected Pu-239/240 would be too low to detect.

**4.6.13.4.4 Summary of Plutonium in Intermediate-Depth Lysimeter Samples**—Plutonium occurs sporadically in the intermediate-depth lysimeters. Detection rates in the routine monitoring samples were 7.5% for Pu-238 and 7.7% for Pu-239/240. However, the plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

Two noteworthy trends were identified in the plutonium data, as follows:

- Detectable concentrations of Pu-238 occurred in lysimeters at the 44- and 88-ft depths in Well D06 in the August 1997 sampling
- Plutonium-239/240 was detected in core TW1 (i.e., 101 to 101.2 ft), and later in Lysimeter TW1-DL04 (i.e., 101.7 ft).

Otherwise, no other trends are notable. In Well D06 lysimeters, positive detections have not occurred in the three sampling events subsequent to the August 1997 detections. Plutonium ratios in the intermediate-depth lysimeters are indicative of both weapons- and reactor-related waste.

#### 4.6.13.5 Deep Lysimeter and Perched Water Samples at Depths Greater than 140 ft

**4.6.13.5.1 Plutonium-238 in Deep Lysimeter and Perched Water Samples**—The USGS and INEEL jointly sample perched Well USGS-92. A total of 56 water samples and nine filtered sediment samples from the deep suction lysimeters and perched water wells were analyzed for Pu-238 by the USGS and INEEL between 1972 and December 2000. Three positive detections were identified (see Table 4-67). One of the samples exceeded the 1E-05 RBC for the aquifer.

Table 4-67. Positive detections of plutonium-238 from lysimeters and perched water wells.

Lysimeter or Well	Depth (ft)	Concentration $\pm$ 1 $\sigma$	Confirmation Flag <sup>a</sup>	Concentration $\pm$ 1 $\sigma$	Confirmation Flag <sup>a</sup>	Date
		(pCi/L) Water		(pCi/g) Filtered Sediments		
USGS-92	214	0.025 $\pm$ 0.008 <sup>b</sup>	None	Not analyzed (NA)	None	May 1974
		0.39 $\pm$ 0.05	None	NA	None	November 1994
		NA	None	1.4 $\pm$ 0.3	A	April 1997
		<b>4.8 <math>\pm</math> 1.0</b>	B	NA	None	December 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

b. The 1972 to 1974 data must be used with discretion. They are questionable because of cross-contamination concerns.

Note: Values in **red bold** indicate that the concentration exceeds the 1E-05 aquifer risk-based concentration (RBC) of 3.6 pCi/L for Pu-238.

Subsequent water samples collected from Well USGS-92 (through December 2000) have not contained detectable Pu-238. The reanalysis result of the December 2000 water sample was a nondetect. A questionable Pu-238 detection was identified in May 1974. Detections associated with USGS wells between 1972 and 1974 are known to be suspect and questionable because of cross-contamination problems associated with early well drilling and well construction techniques and the types of sampling methodology employed at that time (Barraclough et al. 1976) (see Section 4.5.7).

Perched water samples are filtered because they typically contain sediments. Some filtered fractions also were analyzed for Pu-238. The filtered fraction from one sample had a detection of Pu-238 but could not be confirmed by reanalysis because of limited sample volume.

Plutonium in the perched water samples collected with the bailer (e.g., Well USGS-92 or 8802D) is not subject to sorption by the ceramic filter because there is no porous cup involved.

**4.6.13.5.2 Plutonium-239/240 in Deep Lysimeter and Perched Water Samples**—A total of 56 water samples and nine filtered sediment samples from the deep suction lysimeters and perched water wells were analyzed for Pu-239/240 by the USGS and WAG 7 between 1972 and December 2000. Two positive detections were identified, neither of which exceeded the aquifer RBC of 3.5 pCi/L (see Table 4-68).

Table 4-68. Positive detections of plutonium-239/240 from lysimeters and perched water wells.

Lysimeter or Well	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L) Water	Confirmation Flag <sup>a</sup>	Concentration $\pm 1\sigma$ (pCi/g) Filtered Sediments	Confirmation Flag <sup>a</sup>	Date
USGS-92	214	Not analyzed (NA)	None	0.32 $\pm$ 0.06	B	February 1998
O6D-DL26	225	2.7 $\pm$ 0.6	None	NA	A	June 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

Perched water samples are filtered because they typically contain sediments. The filtered fractions also are analyzed for Pu-239/240. Two separate samples were collected from Well USGS-92 in February 1998 and filtered, and the positive sediment sample result was not confirmed by reanalysis of the duplicate sample. The USGS and INEEL jointly sample perched water from Well USGS-92; however, the other RWMC perched wells and lysimeters are the responsibility of the INEEL.

Subsequent water samples collected from perched Well USGS-92 and lysimeter Well O6D (through December 2000) have not contained detectable amounts of Pu-239/240. The positive water sample result from Well O6D could not be confirmed by reanalysis of the original sample because the volume of water collected was insufficient to perform the analysis.

Plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations. However, perched water samples collected with the bailer (e.g., Well USGS-92 or 8802D) are not subject to ceramic filtering because no porous cup is involved. Ultra low-level Pu-239 and Pu-240 analyses using TIMS were conducted on some perched water samples to verify the presence of plutonium. The results are presented in Section 4.6.14. The TIMS results for perched Well 8802D justify continued observation, but no conclusions can be drawn based on the limited data set.

**4.6.13.5.3 Plutonium Ratios in Deep Lysimeter and Perched Water Samples**—The plutonium detections and ratios associated with the deep lysimeter and perched water sample analyses indicate the plutonium originates from both weapons manufacturing waste and reactor operations (see Table 4-69). A single, low-level Pu-239/240 detection associated with lysimeter Well O6D was identified; however, it is premature to conclude that the Pu-239/240 detected in this well is from weapons without additional radioanalytical data. It is interesting to note that the two perched water sample results from Well USGS-92 are indicative of reactor operations, whereas a filtered sediment sample, from a different Well-USGS-92 sample indicates weapons waste. Most likely, the conflicting indications are associated with analytical error near the detection limit.

Table 4-69. Detections of Pu-238, Pu-239/240, and the Pu-238:Pu-239/240 activity ratios for deep lysimeter or perched water well samples.

Lysimeter or Well	Pu-238 (pCi/L)	Pu-239/240	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process Source	Sample Type	Sample Depth (ft)	Date
O6D-DL26	Analyzed for but not detected (ND)	2.7 pCi/L <sup>a</sup>	Not applicable (NA)	Weapons	Soil moisture	220	June 2000
USGS-92	0.39 <sup>b</sup>	ND	NA	Reactors <sup>b</sup>	Perched water	214	November 1994
USGS-92	ND	0.32 pCi/g	NA	Weapons <sup>a</sup>	Filtered sediment	214	February 1998
USGS-92	4.8	ND	NA	Reactors <sup>b</sup>	Perched water	214	December 2000

a. Positive Pu-239/240 detections, without detections of Pu-238, are indicative of weapons manufacturing waste or fallout. The Pu-239/240 activity in weapons manufacturing waste is approximately 40 times higher than the Pu-238 activity. Therefore, the Pu-238:Pu-239/240 ratio for weapons manufacturing waste is 0.02 to 0.03, whereas the Pu-238:Pu-239/240 ratio for fallout is approximately 0.03 to 0.06.

b. Positive Pu-238 detections without detections of Pu-239/240 are indicative of high burnup reactor fuel and fuel processing waste. The Pu-238 activity in high burnup reactor fuel and fuel processing waste is approximately 11 times higher than the Pu-239/240 activity. Therefore, the Pu-238:Pu-239/240 ratio for fuel is approximately 11. In many cases presented in the table above, the concentration of expected Pu-239/240 would be too low to detect.

#### 4.6.13.5.4 Summary of Plutonium in Deep Lysimeter and Perched Water

**Samples**—Plutonium occurs sporadically in samples collected from the deep lysimeters and perched water wells. When detected, the Pu-238 or Pu-239/240 in Well USGS-92 occurred in either the sediment or the water sample, but never occurred in both media from the same sampling event. The detections in perched Well USGS-92 are most likely because of sample contamination or random error equivalent to that seen in true background locations. The positive detection in the liquid sample was not confirmed by reanalysis and it is unlikely that Pu-238 would be detected in the liquid but not the solid form. The plutonium detections and ratios associated with the deep lysimeter and perched water sample analyses are indicative of both weapons manufacturing waste and reactor operations.

#### 4.6.13.6 Aquifer

**4.6.13.6.1 Plutonium-238 in Aquifer Samples**—Of the total 264 RWMC aquifer well samples analyzed by INEEL for Pu-238 between 1992 and April 2001, 10 were positive detections (see Table 4-70). The occurrences of the detections from both the INEEL and USGS wells monitored between 1992 and 2001 are shown in Figure 4-32.

Only the October 2000 Pu-238 results for aquifer Wells M7S and M11S had supporting reanalysis confirmation of the original sample. Subsequent samples collected from the seven wells (through April 2001) have not contained detectable Pu-238 with the exception of a Pu-238 detection in aquifer Well M6S from the January 2001 sample collection period.

In addition to the detections shown in Table 4-70, eight results were identified from the September 2000 INEEL sampling campaign that had been reported as positive detections, but were reevaluated and classified as false positive because Pu-238 also was detected in the corresponding field blank at a concentration equivalent to the sample results. The September 2000 data were revalidated and

the revised limitations and validations report was issued to DOE-ID on January 31, 2002 (see footnote a, p. 4-52).

Table 4-70. Detected concentrations of Pu-238 from aquifer monitoring around the Radioactive Waste Management Complex.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
M1S	0.019 $\pm$ 0.006	B	October 2000
M3S	0.37 $\pm$ 0.07	B	September 2000
M4D	0.028 $\pm$ 0.008	B	October 2000
M6S	0.044 $\pm$ 0.010	B	April 1999
	0.17 $\pm$ 0.03	B	January 2001
M7S	0.071 $\pm$ 0.013	D	October 2000
	0.047 $\pm$ 0.010	D	October 2000
M10S	0.018 $\pm$ 0.006	A	October 2000
M11S	0.026 $\pm$ 0.007	D	October 2000
	0.030 $\pm$ 0.007	D	October 2000

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

D = Detection confirmed by reanalysis.

Note: Highlighted values indicate that the sample was reanalyzed and the reanalysis confirmed the presence of Pu-238.

Seven of the 10 Pu-238 detections in Table 4-70 occurred in October 2000. The large number of positive Pu-238 detections from the October 2000 sampling event is unusual. These positive, low-level Pu-238 detections were highly scrutinized by INEEL and the USGS scientists and no analytical anomalies were found that would discredit the results. However, there are several reasons why the October 2000 results from the INEEL are still questionable. These are listed below:

- Samples from Wells M1S and M3S are routinely cosampled by the INEEL, the USGS, and state oversight program. The radioanalytical results are used for comparative purposes to help confirm the presence or absence of measured radionuclides. The samples collected by the state oversight program in October 2000 show one detection from Well M1S and one nondetection from Well M3S (see Table 4-71). None of the USGS samples between 1993 and April 2001 showed positive detections for Pu-238, including the sample from October 2000 (see Table 4-72). The comparative results provide conflicting evidence about the presence of Pu-238 in samples collected from Wells M1S and M3S.
- Other actinides (e.g., Pu-239/240 and Am-241) were not detected with the Pu-238, which is unusual for contamination emanating from waste generated by weapons manufacturing.
- Because of the inconsistent results, the potential for cross-contamination at the analytical laboratory was examined. No issues were identified; however, additional quality control samples were specified for subsequent sampling efforts to increase confidence in the analytical results for low-level detections at concentrations very close to the method detection limit.

Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	AI/A31	OW-2	
1992	1																								
1992	2																								
1992	3																								
1992	4																								
1993	1																								
1993	2																								
1993	3																								
1993	4																								
1994	1																								
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2000	2																								
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2000	4																								
2001	1																								
2001	2																								
2001	3																								
2001	4																								
Key		Analysis was performed for Pu-238, but none was detected.																							
		Pu-238 was detected (pCi/L).																							

Figure 4-32. Occurrence of plutonium-238 in aquifer samples collected by the Idaho National Engineering and Environmental Laboratory and U.S. Geological Survey from 1992 through 2001.

Table 4-71. Plutonium-238 detections in cosampled Wells M1S and M3S during September and October 2000.

Sampler	September 2000		October 2000	
	M1S	M3S	M1S	M3S
Idaho National Engineering and Environmental Laboratory	Analyzed for but not detected (ND)	Detected	Detected	ND
U.S. Geological Survey	Not sampled (NS)	NS	ND	NS
State oversight	ND	ND	Detect	ND

Table 4-72. Plutonium-238 detections from U.S. Geological Survey aquifer monitoring around the Radioactive Waste Management Complex.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Date
USGS-87	$0.040 \pm 0.009^a$	April 1973
	$0.029 \pm 0.008^a$	May 1973
	$0.080 \pm 0.006^a$	November 1973
USGS-88	$0.028 \pm 0.007^a$	April 1973
	$0.27 \pm 0.03^a$	May 1973
	$0.040 \pm 0.010^a$	December 1973
	$0.033 \pm 0.009^a$	April 1974
USGS-89	$0.81 \pm 0.08$	April 1983
	$0.040 \pm 0.010^a$	September 1973
	$0.021 \pm 0.006^a$	November 1973
	$0.040 \pm 0.010^a$	April 1974
USGS-90	$0.040 \pm 0.010^a$	May 1974
	$0.96 \pm 0.09^a$	February 1972
	<b><math>9.00 \pm 0.03^a</math></b>	September 1972
	$0.13 \pm 0.02^a$	July 1973
	$0.035 \pm 0.009^a$	February 1974

a. The 1972 to 1974 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Note: Values in **red bold** indicate that the concentration exceeded the 1E-05 aquifer risk-based concentration for Pu-238 of 3.6 pCi/L.

- A statistical analysis of the data indicated that the cluster of detections was statistically anomalous, and that the detected Pu-238 was most likely from a source other than the aquifer (Leecaster 2002).

Numerous improvements were made to the sampling and analytical protocols to increase confidence in the analytical results for low-level detections at concentrations very close to the method detection limit (see Section 4.5.1). The INEEL sampling, analytical, and data reporting protocols now require an equipment rinsate, a certified sealed quality control blank that is not opened until it arrives at the analytical laboratory, and statistical hypothesis testing of all plutonium and americium data. Also,

because of the cluster of Pu-238 detections, the laboratory created a cleanroom for processing and preparing very low-level samples.

Only the October 2000 Pu-238 results for aquifer Wells M7S and M11S had supporting reanalysis confirmation of the original sample. Subsequent samples collected from the seven wells in Table 4-72 (through April 2001) have not contained detectable Pu-238 from the January 2001 sample collection period, with the exception of a Pu-238 detection in aquifer Well M6S (see Figure 4-32).

In addition to the aquifer monitoring routinely conducted by the INEEL, the USGS manages, controls, and routinely samples eight other aquifer wells in the vicinity of the RWMC. These eight wells have been monitored by the USGS for Pu-238 since 1972. A total of 489 USGS aquifer well samples in the vicinity of the RWMC were analyzed for Pu-238 between 1972 and October 2000. There were 16 detections (3.3%), with 15 of them occurring between 1972 and 1974, shortly after the wells were drilled and installed (see Table 4-72). The 1972 to 1974 detections are known to be suspect and questionable because of cross-contamination problems (Barraclough et al. 1976). Samples collected by the USGS between 1975 and 2000 have shown only one detectable Pu-238 concentration. The detection occurred in a sample collected from Well USGS-88 in April 1983. The relatively high concentration was not confirmed by reanalysis and no detections have occurred in the 51 subsequent sampling events from April 1983 through October 2000. The concentrations of detectable Pu-238 are below the MCL for total alpha-emitting radionuclides (i.e., 15 pCi/L). The 1972 through 1991 USGS Pu-238 occurrences are shown in Figure 4-33.

Figure 4-33. Occurrences of plutonium-238 in aquifer samples collected by the U.S. Geological Survey from 1972 through 1991.

Year	Quarter	USGS-7	USGS-8	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120
1972	1								
	2								
	3								9.00
	4								
1973	1								
	2	0.40	0.27	0.40	0.13				
	3								
	4								
1974	1								
	2			0.033	0.40				
	3								
	4								
1975	1								
	2								
	3								
	4								
1976	1								
	2								
	3								
	4								
1977	1								
	2								
	3								
	4								
1978	1								
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1980	1								
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	3								
	4								
1981	1								
	2								
	3								
	4								
1982	1								
	2								
	3								
	4								
1983	1								
	2								0.81
	3								
	4								
1984	1								
	2								
	3								
	4								
1985	1								
	2								
	3								
	4								
1986	1								
	2								
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1988	1								
	2								
	3								
	4								
1989	1								
	2								
	3								
	4								
1990	1								
	2								
	3								
	4								
1991	1								
	2								
	3								
	4								

Analysis was conducted for Pu-238, but none was detected.  
 Pu-238 was detected (pCi/L).  
 If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.

**4.6.13.6.2 Plutonium-239/240 in Aquifer Samples**—A total of 264 RWMC aquifer well samples were analyzed by the INEEL for Pu-239/240 between 1992 and April 2001, with three positive detections (see Table 4-73).

Table 4-73. Plutonium-239/240 detections in wells monitored by the Idaho National Engineering and Environmental Laboratory.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
M3S	0.09 $\pm$ 0.02	B	September 2000
M4D	1.3 $\pm$ 0.3 <b>4.3 <math>\pm</math> 0.5</b>	A A	May 1993 November 1993

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

Note: Values in **red bold** indicate that the concentration exceeds the 1E-05 aquifer risk-based concentration of 3.5 pCi/L for Pu-239/240.

The sample from Well M3S (with the positive result) was reanalyzed and the reanalysis failed to confirm that the contaminant was present. The samples from Well M4D (with positive detections) were not reanalyzed. Subsequent samples collected from the two wells (through April 2001) have not contained detectable Pu-239/240. The occurrence of the detections relative to other samples collected by the INEEL between 1992 and 2001 is shown in Figure 4-34.

Samples from the INEEL aquifer Wells M1S, M3S, and M7S are routinely split with the USGS and the radioanalytical results are used for comparative purposes to help confirm detections and nondetections. None of the samples split with the USGS between 1993 and April 2001 showed positive detections for Pu-239/240.

Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120	MIS	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	A11A31	OW-2	
1992	1	Yellow																							
1992	2	Yellow																							
1992	3	Yellow																							
1992	4	Yellow																							
1993	1	Yellow																							
1993	2	Yellow																							
1993	3	Yellow																							
1993	4	Yellow																							
1994	1	Yellow																							
1994	2	Yellow																							
1994	3	Yellow																							
1994	4	Yellow																							
1995	1	Yellow																							
1995	2	Yellow																							
1995	3	Yellow																							
1995	4	Yellow																							
1996	1	Green																							
1996	2	Green																							
1996	3	Green																							
1996	4	Green																							
1997	1	Green																							
1997	2	Green																							
1997	3	Green																							
1997	4	Green																							
1998	1	Green																							
1998	2	Green																							
1998	3	Green																							
1998	4	Green																							
1999	1	Green																							
1999	2	Green																							
1999	3	Green																							
1999	4	Green																							
2000	1	Green																							
2000	2	Green																							
2000	3	Green																							
2000	4	Green																							
2001	1	Green																							
2001	2	Green																							
2001	3	Green																							
2001	4	Green																							
Key		Green	Analysis was conducted for Pu-239/240, but none was detected.																						
		Yellow	Pu-239/240 was detected (pCi/L).																						
		Pink	If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.																						

Figure 4-34. Occurrence of detectable Pu-239/240 in aquifer samples collected by the Idaho National Engineering and Environmental Laboratory and U.S. Geological Survey from 1992 through 2001.

Besides the 15 RWMC monitoring wells routinely sampled by the INEEL, the USGS manages, controls, and routinely samples eight other wells in the vicinity of the RWMC. These eight wells have been monitored by the USGS for Pu-239/240 since 1972. Out of 485 analyses, six detections of Pu-239/240 were identified (see Table 4-74).

Table 4-74. Plutonium-239/240 detections in U.S. Geological Survey monitoring wells.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Date
USGS-87	0.030 $\pm$ 0.004 <sup>a</sup>	November 1973
	0.030 $\pm$ 0.008 <sup>a</sup>	April 1974
USGS-88	0.040 $\pm$ 0.009 <sup>a</sup>	April 1974
	0.040 $\pm$ 0.010	October 1976
USGS-89	0.29 $\pm$ 0.02 <sup>a</sup>	May 1973
	0.036 $\pm$ 0.008 <sup>a</sup>	May 1974

a. The 1972 to 1974 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Five of the six detections occurred between 1972 and 1974, shortly after the wells were drilled and installed. The 1972 to 1974 detections are known to be suspect because of cross-contamination problems (Barraclough et al. 1976). Only one subsequent sample collected from the USGS wells (from 1975 through 2000) has contained detectable Pu-239/240. The occurrences of all the positive Pu-239/240 detections in the USGS wells between 1972 and 1991 are shown in Figure 4-35.

The concentrations of detectable Pu-239/240 are below the aquifer 1E-05 RBC of 3.5 pCi/L.

Low-level TIMS analyses of aquifer samples do not confirm the presence of Pu-239 in the aquifer (see Section 4.6.14)

**4.6.13.6.3 Plutonium Ratios in Aquifer Samples**—The activity ratios for the aquifer samples with detectable plutonium are shown in Table 4-75. Plutonium-238 has been detected in aquifer samples using radiochemical analysis, without detecting Pu-239 (e.g., several wells in the October 2000 sampling and Well USGS-88 in April 1983). Such occurrences are suggestive of reactor-related waste because reactor waste contains more Pu-238 activity than Pu-239/240 activity.

Some of the 1970s plutonium data from the aquifer samples are questionable because of cross-contamination concerns. Excluding the 1970s data 15 plutonium detections remain (i.e., 11 Pu-238 and four Pu-239/240) out of 29 analyses (see Table 4-75). Of those 15 detections, eight are associated with the September and October 2000 sampling events. The September and October plutonium data are highly questionable because (a) such a cluster of detections is highly irregular, (b) no plutonium detections have been identified in subsequent sampling events, (c) the field blank for the September 2000 samples contained a positive detection of Pu-238, (d) the results were not corroborated by samples collected in the same time frame by the oversight committee or USGS, and (e) the two sample sets did not contain a sealed quality control blank sample to assess potential laboratory-introduced contamination (see Section 4.6.1.3).

Figure 4-35. Occurrence of Pu-239/240 in wells monitored by the U.S. Geological Survey from 1972 through 1991.

Year	Quarter	USGS-87	USGS-88	USGS-89	USGS-90	RWMC Prod	USGS-117	USGS-119	USGS-120
1972	1								
	2								
	3								
	4								
1973	1								
	2			0.29					
	3								
	4								
1974	1								
	2		0.030	0.040	0.036				
	3								
	4		0.030						
1975	1								
	2								
	3								
	4								
1976	1								
	2								
	3								
	4								
1977	1								
	2								
	3								
	4								
1978	1								
	2								
	3								
	4								
1979	1								
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1989	1								
	2								
	3								
	4								
1990	1								
	2								
	3								
	4								
1991	1								
	2								
	3								
	4								

Analysis was performed for Pu-239/240, but none was detected.  
 Pu-239/240 was detected (pCi/L).  
 If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.

Table 4-75. Plutonium detections and Pu-238:Pu-239/240 activity ratios for aquifer samples.

Aquifer Well	Pu-238 pCi/L	Pu-239/240 pCi/L	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process <sup>a,b</sup>	Sample Depth Screened Interval (ft)	Date
M1S	0.019	Analyzed for but not detected (ND)	Not applicable (NA)	Reactors <sup>b</sup>	608 to 638	Oct 2000
M3S	0.37	0.09	4.1	Indeterminate	603 to 633	Sept 2000
M4D	0.0276	ND	NA	Reactors <sup>b</sup>	798 to 828	Oct 2000
M4D	ND	1.3	NA	Weapons <sup>a</sup>	798 to 828	May 1993
M4D	ND	4.3	NA	Weapons <sup>a</sup>	798 to 828	Nov 1993
M6S	0.044	ND	NA	Reactors <sup>b</sup>	642 to 668	April 1999
M6S	0.17	ND	NA	Reactors <sup>b</sup>	642 to 668	Jan 2001
M7S	0.071	ND	NA	Reactors <sup>b</sup>	598 to 628	Oct 2000
M7S	0.047	ND	NA	Reactors <sup>b</sup>	598 to 628	Oct 2000
M10S	0.018	ND	NA	Reactors <sup>b</sup>	617 to 647	Oct 2000
M11S	0.026	ND	NA	Reactors <sup>b</sup>	559 to 569, 604 to 624	Oct 2000
M11S	0.030	ND	NA	Reactors <sup>b</sup>	559 to 569, 604 to 624	Oct 2000
USGS-87	0.040 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	585 to 673	April 1973
USGS-87	0.029 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	585 to 673	May 1973
USGS-87	0.080 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	585 to 673	Nov 1973
USGS-88	0.028 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	584 to 635	April 1973
USGS-88	0.27 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	584 to 635	May 1973
USGS-88	0.040 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	584 to 635	Dec 1973
USGS-88	0.033 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	584 to 635	April 1974
USGS-88	ND	0.04	NA	Weapons <sup>a</sup>	584 to 635	Oct 1976
USGS-88	0.81	ND	NA	Reactors <sup>b</sup>	584 to 635	April 1983
USGS-89	0.040 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	576 to 646	Sept 1973
USGS-89	0.021 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	576 to 646	Nov 1973
USGS-89	0.040 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	576 to 646	April 1974
USGS-89	0.040 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	576 to 646	May 1974
USGS-90	0.96 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	577 to 626	Feb 1972
USGS-90	9.00 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	577 to 626	Sept 1972

Table 4-75. (continued).

Aquifer Well	Pu-238 pCi/L	Pu-239/240 pCi/L	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process <sup>a,b</sup>	Sample Depth Screened Interval (ft)	Date
USGS-90	0.13 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	577 to 626	July 1973
USGS-90	0.035 <sup>c</sup>	ND	NA	Reactors <sup>b</sup>	577 to 626	Feb 1974

a. Positive Pu-239/240 detections, without detections of Pu-238 are indicative of weapons (manufacturing waste or fallout). The Pu-239/240 activity in weapons manufacturing waste is approximately 40 times higher than the Pu-238 activity. Therefore, the Pu-238:Pu-239/240 ratio for weapons manufacturing waste is 0.02 to 0.03.

b. Positive Pu-238 detections without detections of Pu-239/240 are indicative of high burnup reactor fuel and fuel processing waste. The Pu-238 activity in high burnup reactor fuel and fuel processing waste is approximately 11 times higher than the Pu-239/240 activity. Therefore, the Pu-238:Pu-239/240 ratio for fuel is approximately 11. In many cases presented in this table, the concentration of expected Pu-239/240 would be too low to detect.

c. The 1972 to 1974 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

**4.6.13.6.4 Summary of Plutonium in Aquifer Samples**—Plutonium is detected sporadically in RWMC aquifer samples and has been confirmed via reanalysis in some cases. With 10 detections out of 264 analyses, the detection rate is around 4%. Of the 10 detections, only the October 2000 results from M7S and M11S were confirmed with reanalysis. Both wells with confirmed detections are upgradient of the SDA, with Well M11S a couple of miles away. The recurring detections coupled with occasional confirmation of positive detections suggest that Pu-238 is present in the aquifer, though not as a widespread or continuous plume but rather as randomly occurring particles. Plutonium-238 was detected in all the wells near the SDA except for Well M17S, which is located inside the SDA fence line.

Plutonium-239/240 detections in the aquifer wells are rare, with a detection rate around 1%. Two detections were identified in aquifer Well M4D (821-ft deep) in 1993 but no other detections in the 11 sampling events since the November 1993. A Pu-239/240 detection recently occurred in aquifer Well M3S, which previously had no detectable concentrations.

#### 4.6.14 Plutonium Special Study

Because of the sporadic nature of plutonium detections over the years, it was hypothesized that plutonium may exist in the aquifer beneath the SDA at concentrations just below the detection sensitivity of routine radioanalytical methodology (approximately 0.02 to 0.03 pCi/L). Therefore, some RWMC aquifer samples were analyzed using more sensitive analytical methodology. The Isotope Dilution-Thermal Ionization Mass Spectrometry (ID-TIMS) method with its ultra-low detection capability was intended to: (a) determine if ultra low (background) levels of plutonium are present in the aquifer, (b) and if so, identify the sources of plutonium (e.g., fallout, nuclear weapons manufacturing waste, reactor waste) using Pu-239/240 ratios and, (c) determine if sample results that were previously identified as statistically positive (greater than  $2\sigma$  but  $> 3\sigma$ ) actually contained low levels of plutonium. The TIMS analysis can achieve detection limits on water samples approximately 10 to 100 times lower than standard radioanalytical methods. The TIMS is capable of attaining detection levels around 0.002 to 0.0002 pCi/L.

Nine shallow lysimeter water samples (i.e., PA01-L15, PA02-L16, PA03-L33, W23-L08, D06-L01, D06-L02, 98-4L38, 98-5L39, and W25-L28) were collected from the shallow surficial sediments in 1999 and sent for TIMS analysis. The water samples were filtered and both the filtrate and filtered material were analyzed for Pu-239. None of the samples yielded evidence of the presence of Pu-239 above 0.002 pCi/L, with the exception of a statistical anomaly on the PA03 lysimeter well-filter

result (Roback et al. 2000). The statistical irregularity does not prove the presence of Pu-239 on the Well PA03 lysimeter well filter; it only suggests the possibility that Pu-239 may be present.

Four intermediate-depth lysimeter samples were collected from the B and C basalt flows and B-C interbed (D06-DL01, D06-DL02, TW1-DL04, and D15-DL06) in 1999 and sent for TIMS analyses. The water samples were filtered and both the filtrate and filtered material were analyzed for Pu-239. The results from filter sample lysimeter well TW1-DL04 has statistically higher Pu-239 concentrations than the other lysimeter well samples, which suggests the possibility that Pu-239 may be present in the sample (Roback et al. 2000).

Two water samples collected from perched Wells USGS-92 and 8802D in 1999 (deep vadose zone) were sent for TIMS analysis. The water samples were filtered and both the filtrate and filtered material were analyzed for Pu-239. The Pu-239 result from the 8802D filtered fraction was statistically higher than the other samples, which suggests the possibility that Pu-239 may be present in the sample (Roback et al. 2000).

Nine aquifer samples collected in 1999 from RWMC aquifer Wells M1S, M3S, M7S, M10S, M14S, USGS-87, USGS-117, USGS-119, and USGS-120 and sent for TIMS analysis. The water samples were filtered and both the filtrate and filtered material were analyzed for Pu-239. None of the aquifer samples contained Pu-239 above 0.0002 pCi/L (Roback et al. 2000).

The INEEL plans to continue the TIMS analysis for plutonium (including Pu-238) for selected RWMC aquifer samples. Because the TIMS is capable of identifying plutonium from fallout, it can be used to identify background levels of plutonium in the SRPA below the INEEL.

#### **4.6.15 Summary of Plutonium**

Plutonium-238 and Pu-239/240 occur sporadically in the vadose zone and aquifer wells, and there are no obvious trends. Plutonium-238 detection rates for the various media, summarized in Table 4-76, range from 0% in the deep core samples to 7.5% in the intermediate-depth lysimeter samples. There is no apparent correlation between detection rates and media or depth. Figure 4-36 shows the distribution of Pu-238 detections in the various sampling media.

Plutonium-239/240 detection rates range from 0.5% in the aquifer to 13.6% in the intermediate-depth core samples (see Table 4-77). The Pu-239/240 detection rate is highest in the intermediate-depth core samples, however, the result is somewhat misleading because there were so many duplicate analyses of core samples from the 100 to 110-ft depth interval, many of which showed up as detections. Figure 4-37 shows the distribution of Pu-239/240 detections in the various sampling media.

Some of the boreholes associated with the vadose zone core samples were instrumented with lysimeters (i.e., TW1) or bailers (i.e., 8802D, USGS-92) and sampled after the core analysis program was completed. Results from the two programs combined are inconclusive. At TW1, Pu-238 was detected at the 100-ft depth in the core sample, but not detected in the soil moisture sample; Pu-239/240 was detected in both the core and the moisture samples. At the USGS-92 perched water well, no plutonium isotopes were detected in the core samples, but Pu-238 was detected in the filtered perched water and Pu-239/240 was detected in the filtered sediment sample from the bailed perched water.

Results from aquifer monitoring are also inconclusive. There were several plutonium detections in USGS wells from 1972 through 1974, suggesting that Pu-238 and Pu-239/240 may have been widespread at low levels in the aquifer at that time, but those data are highly suspect because of potential cross-contamination concerns. Subsequent sampling results from the USGS from the same wells show no detected concentrations of Pu-239/240 since 1976, and only one sample with detected Pu-238 since 1974. The Pu-238 detection occurred in 1983. There have been no additional plutonium detections in the USGS wells in the 30 sampling events since these low-level detections of the 1970s and 1983. Low-level detections of Pu-238 occurred in INEEL aquifer samples in 2000 and 2001, but there were no Pu-238 detections in the most recent sampling event in any of the INEEL wells.

The last 30 years of monitoring data from the vadose zone and aquifer suggest that plutonium exists not as a widespread or continuous plume in the subsurface of the RWMC, but rather as randomly occurring particles (see Figures 4-36 and 4-37).

Table 4-76. Detection rates for Pu-238 in the sampled media.

Media	Detection Rate (%)	Concentration Range	Number of Detections Higher than the Risk-Based Concentration <sup>a</sup>	Wells Higher than the Risk-Based Concentration
Vadose zone 0 to 35 ft:				
Cores	6.1	0.0149 to 0.26 pCi/g	0	None
Soil moisture	6.7	0.9 to 24 pCi/L	4	PA01, PA02, PA03, 98-5
Vadose zone 35 to 140 ft:				
Cores	7.8	0.0031 to 0.17 pCi/g	0	None
Soil moisture	7.5	3.1 to 11.6 pCi/L	1	D06
Vadose zone greater than 140 ft:				
Cores	3.2	0.0015 to 0.033 pCi/g	0	None
Soil moisture	5.4	0.39 to 4.8 pCi/L	1	USGS-92
Aquifer-Idaho National Engineering and Environmental Laboratory	3.8	0.019 to 0.37 pCi/L	0	
Aquifer-U.S. Geological Survey	3.3	0.03 to 9.00 pCi/L	1	USGS-90

a. For cores, the concentrations are compared to the risk-based concentrations (RBCs) of 29.2 pCi/g. The soil moisture and aquifer results are compared to a 1E-05 aquifer RBC of 3.6 pCi/L. The RBCs do not apply to soil moisture data but are used here as a basis of comparison.

Table 4-77. Detection rates for Pu-239/240 in the sampled media.

Media	Detection Rate (%)	Concentration Range	Number of Detections Higher than the Risk-Based Concentration <sup>a</sup>	Wells Higher than the Risk-Based Concentration
Vadose zone 0 to 35 ft:				
Cores	8.1	0.026 to 1.13 pCi/g	0	None
Soil moisture	0.9	0.70 pCi/L	0	None
Vadose zone 35 to 140 ft:				
Cores	14.3	0.009 to 0.74 pCi/g	0	None
Soil moisture	7.7	0.34 to 3.3 pCi/L	0	None
Vadose zone 140 to 250 ft:				
Cores	2.5	0.013 to 0.14 pCi/g	0	None
Soil moisture	3.1	2.7 pCi/L	0	None
Vadose zone >250 ft:				
Cores	9.0	0.022 pCi/g	0	None
Aquifer-Idaho national Engineering and Environmental Laboratory	1.1	0.094 to 4.3 pCi/L	1	M4D
Aquifer-U.S. Geological Survey	1.2	0.030 to 0.29 pCi/L	0	None

a. The concentrations for cores are compared to the risk-based concentration (RBC) of 28.7 pCi/g. The soil moisture and aquifer results are compared to a 1E-05 aquifer RBC of 3.5 pCi/L. The RBCs do not apply to soil moisture data but are used here as a basis of comparison.

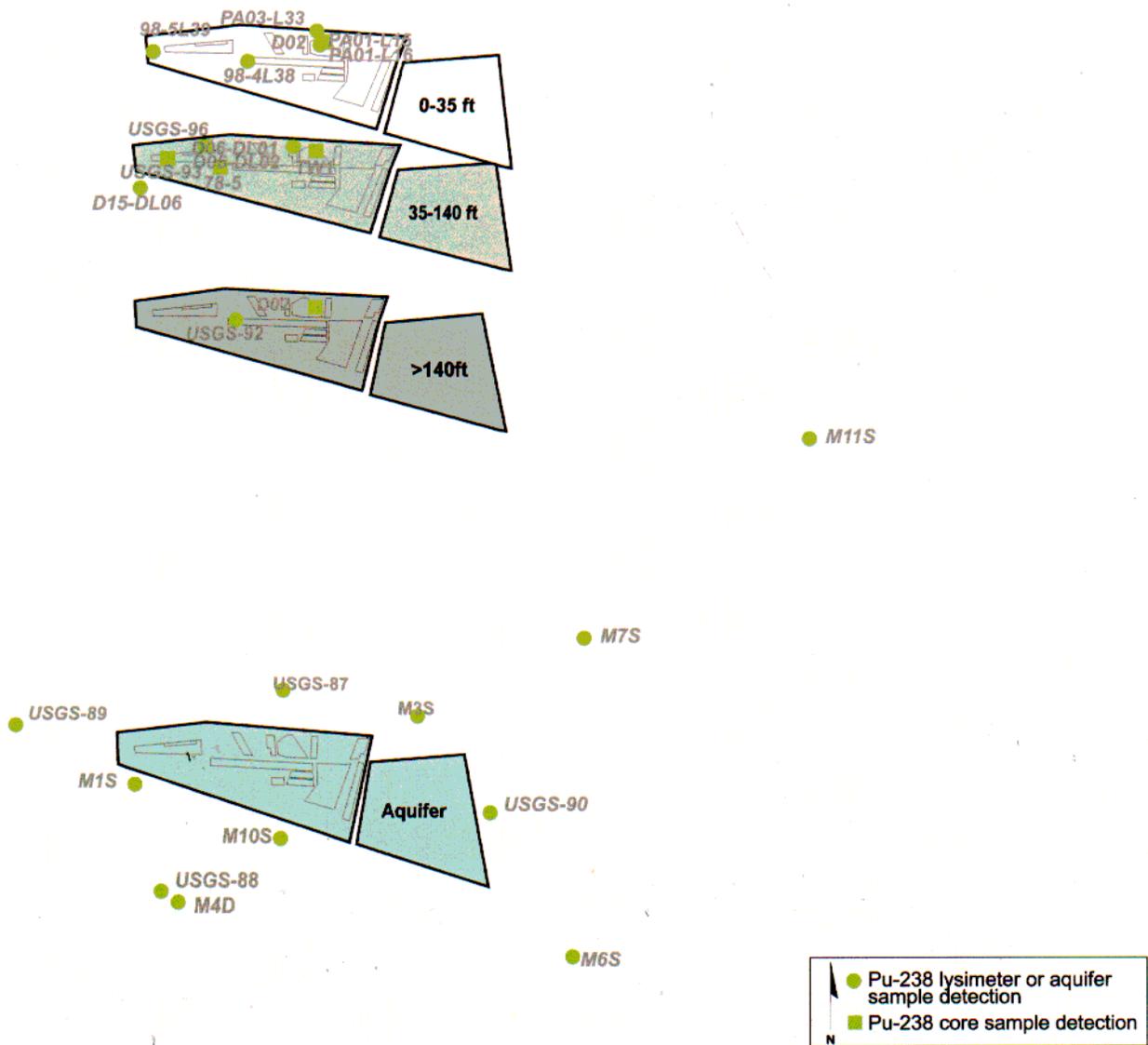


Figure 4-36. Distribution of Plutonium-238 detections in the various sampled media.

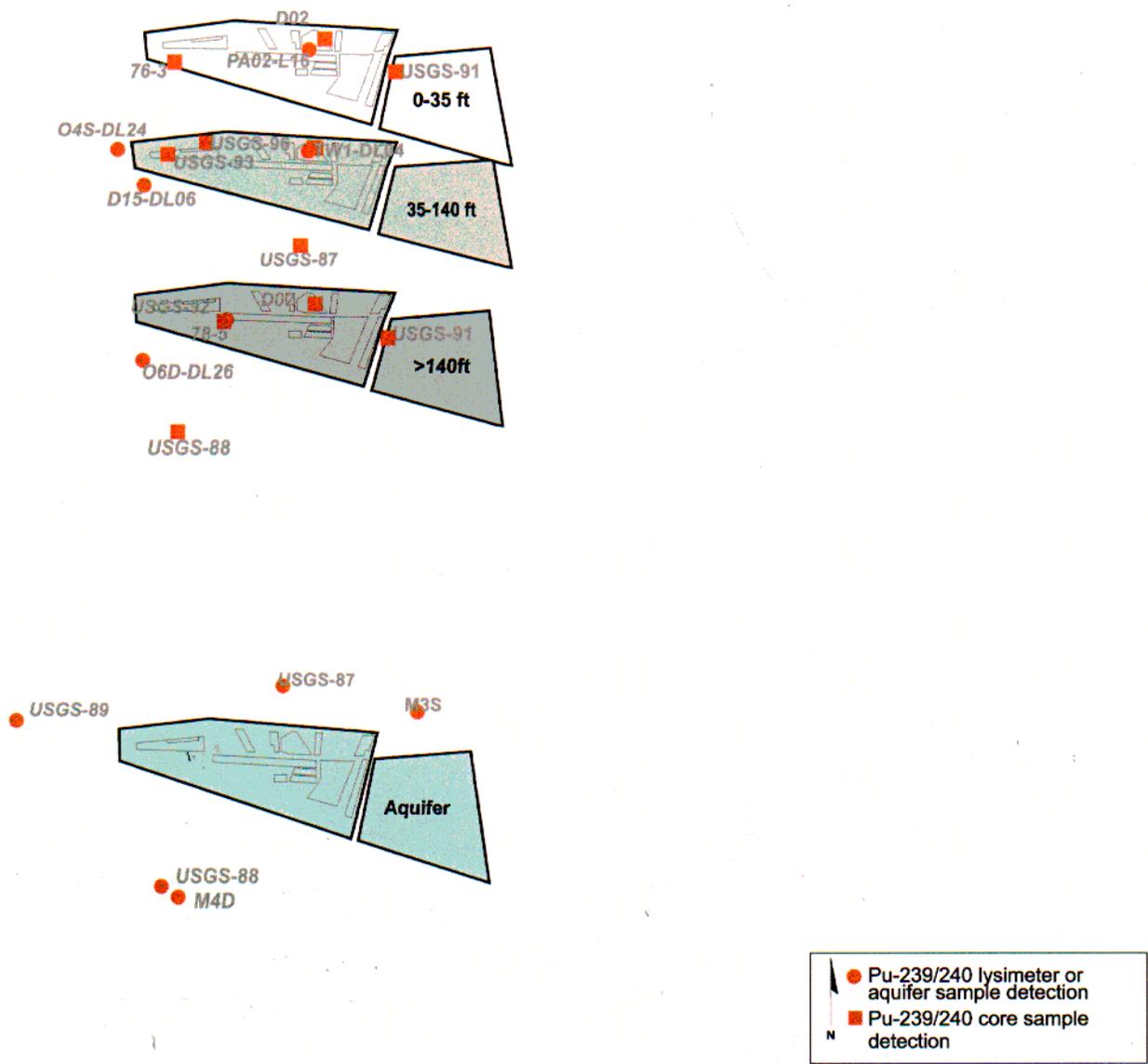


Figure 4-37. Distribution of Pu-239/240 detections in the various sampled media.

#### 4.6.16 Radium-226

Radium-226 is a radioactive decay product in the naturally occurring U-238 decay chain and in the Pu-238 decay chain. The Ra-226 concentrations produced from Pu-238 would be extremely low because of the long half-lives of the intermediary progeny (U-234 and Th-230). Ra-226 decays by the emission of alpha particles and gamma rays, has a half-life of 1.6E+03 years, and was identified in the IRA as a COPC, primarily from the external exposure pathway (Becker et al. 1998). Available information about the presence of Ra-226-bearing waste in the SDA and available Ra-226 monitoring data for all media were reviewed for this report and are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-78.

Table 4-78. Comparison concentrations for radium-226.

Surface Soil Background Concentration (pCi/g)	Risk-Based Soil Concentration <sup>a</sup> (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration <sup>a</sup> (pCi/L)
2.2 <sup>b</sup> 1.2 <sup>c</sup>	10.87	Not established	5	1.23

a. The calculated risk-based concentration is equivalent to an increased cancer risk of 1E-05.

b. The background value for gamma spectrometric analysis is unadjusted for U-235 interference (Giles 1998).

c. The background value for gamma spectrometric analysis is adjusted for U-235 interference (Giles 1998).

**4.6.16.1 Waste Zone.** About 60 Ci of Ra-226 was disposed of in the SDA. Table 4-79 identifies the waste streams containing the Ra-226 activity.

Additional quantities of Ra-226 are being generated over time through ingrowth (see Section 4.1.2). Table 4-79 identifies the amount of Ra-226 that would be produced if the entire parent decayed. Because of the long half-lives of the parent nuclides, it will be many thousands of years before substantial ingrowth occurs. However, for completeness, the amount of Ra-226 generated from parent nuclides is listed in Table 4-79. Percentages of the total Ra-226 from parent isotopes are not given because the amount of Ra-226 present is dependant on the timeframe assessed. Radium-226 decays into Pb-210 (see Section 4.6.12).

Spectral gamma logging data provided no information about Ra-226.

Table 4-79. Waste streams containing radium-226.

Waste Stream Code or Waste Generator	Waste Stream Description	Inventory (Ci)	Proportion of Total Activity (%)
OFF-USN-1H	Animal carcasses, waste paper towels, glassware, tools, and laboratory items	4.33E+01	72.3
OFF-ISC-1H	Magnesium-thorium scrap, sources and miscellaneous laboratory equipment	5.00E+00	8.3
OFF-AEF-1H	Wipes, gloves, glassware, and dry activated waste embedded in concrete	3.33E+00	5.6
OFF-DPG-1H	Biological waste	1.67E+00	2.8
TRA-603-8H	Two Ra-226 sources	1.25E+00	2.1
TRA-603-22H	Combustibles	1.25E+00	2.1

Table 4-79. (continued).

Waste Stream Code or Waste Generator	Waste Stream Description	Inventory (Ci)	Proportion of Total Activity (%)
ALE-317-2R	Combustibles	1.10E+00	1.8
TAN-640-1H	Radium-beryllium neutron source	1.00E+00	1.7
ALE-ALE-1H	Building rubble, electric wires, piping, machinery, tracers and sources, glass, gloves, paper, filters, and vermiculite	9.93E-01	1.7
Miscellaneous	Miscellaneous minor streams	1.02E+00	1.7
<b>Total Disposals</b>		5.99E+01	100
Pu-238 ingrowth	Half-life equals 8.78E+01 years. See Section 4.6.13	9.39E+02	NA
U-238 ingrowth	Half-life equals 4.47E+09 years. See Section 4.6.19	3.27E+08	NA
U-234 ingrowth	Half-life equals 2.45E+05 years. See Section 4.6.19	1.03E+04	NA
Th-230 ingrowth	Half-life equals 7.70E+04 years.	1.51E+00	NA

**4.6.16.2 Surface.** Because Ra-226 has not been a target analyte for surface monitoring, no surface data are available.

**4.6.16.3 Vadose Zone.** The distributions of Ra-226 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

Vadose zone core data were compared against one of two surface soil background concentrations, depending on the analytical method used to obtain the result (see Table 4-78). The vadose zone core samples analyzed between 1971 and 1993 were equilibrated and the Ra-226 daughters were measured by gamma spectrometry. Therefore, the 1971 to 1993 Ra-226 data were compared to a background of 1.2 pCi/g. The results from the 1999 and 2000 analyses were obtained by direct measurement of Ra-226 by gamma spectroscopy, unadjusted for U-235 interference, and the 2.1 pCi/g background value was used for comparison.

Radium-226 from the lysimeter samples was analyzed by gamma spectrometric analysis, and the detection limits vary from about 25 pCi/L for an 80-mL sample to 1,000 pCi/L for a 25-mL sample. When larger sample volumes are available, a lower detection limit is achievable, but low concentrations equivalent to the MCL of 5 pCi/L cannot be detected.

**4.6.16.3.1 Vadose Zone Core Samples—**A total of 109 vadose zone core samples were analyzed for Ra-226 between 1971 and 2000. Seventeen samples yielded Ra-226 concentrations greater than the background concentration for surface soil. All of the samples with relatively high Ra-226 were interbed sediments. Samples with positive detections are shown in Table 4-80.

The vadose zone core analyses between 1971 and 1993 included basalt and interbed samples from 26 cores. Of 32 samples from 26 cores, three results exceeded the applicable background concentrations of 2.2 pCi/g. These three samples were from adjacent Wells 76-4 and 76-4A.

Table 4-80. Positive detections of radium-226 greater than the surface soil background concentration in vadose zone core samples.

Borehole Identification	Sample Depth (ft)	Concentration $\pm 1\sigma$ (pCi/g)	Date
76-4	98.6 to 101.1	$3.05 \pm 0.17$	1976
78-4A	97.8 to 100.2	$2.10 \pm 0.02$	1993
	223.3 to 224.7	$2.60 \pm 0.02$	1993
I-1S	101.6 to 102.0	$7.3 \pm 1.8$	1999 and 2000
	110.6 to 111.0	$7.7 \pm 1.8$	1999 and 2000
I-1D	224.5 to 225.0	$7.9 \pm 1.6$	1999 and 2000
	237.6 to 238.0	$6 \pm 2$	1999 and 2000
I-2S	99.0 to 100.0	$5.8 \pm 1.5$	1999 and 2000
	111.0	$8 \pm 2$	1999 and 2000
I-2D	223.5 to 224.0	$4.3 \pm 0.8$	1999 and 2000
I-3D	228.5 to 229.0	$6.5 \pm 1.4$	1999 and 2000
I-4S	98.2 to 98.8	$3.8 \pm 1.2$	1999 and 2000
I-4D	229.6 to 230.0	$6.4 \pm 1.4$	1999 and 2000
	237.0 to 237.5	$6.1 \pm 1.4$	1999 and 2000
	237.5 to 238.0	$5.2 \pm 1.4$	1999 and 2000
I-5S	103.5 to 104.0	$4.9 \pm 1.3$	1999 and 2000

The 1999 and 2000 vadose zone core analyses included 32 interbed samples collected from wells inside and outside of the SDA. The 13 samples collected outside the SDA all contained background concentrations. Sixteen of the 19 samples collected from cores inside the SDA exceeded background values. A summary is provided in Table 4-81 of Ra-226 detections in excess of background concentrations in vadose zone cores by depth interval.

Table 4-81. Radium-226 detections in excess of background concentrations in vadose zone cores by depth interval.

Depth Interval (ft)	Detection Greater Than Background/Number of Samples (%)	Range (pCi/g)	Wells or Boreholes with Detections
0 to 35	1/13 (7.7)	1.7	USGS-93
35 to 140	8/55 (14.6)	2.10 to 8	76-4, 76-4A, I-1S, I-2S, I-4S, I-5S
140 to 250	8/38 (21.1)	2.60 to 7.9	76-4A, I-1D, I-2D, I-3D, I-4D
More than 250	0/3 (0)	Not applicable	Not applicable

**4.6.16.3.2 Lysimeter Samples at Depths of 0 to 35 ft**—A total of 100 shallow lysimeter samples were analyzed for Ra-226 between 1997 and May 2001 with two (2%) positive detections (see Table 4-82). The detections exceed the MCL for the aquifer, and their occurrence relative to the other shallow lysimeter sampling events is shown in Figure 4-38.

Table 4-82. Positive detections of radium-226 in shallow lysimeters.

Lysimeter	Depth (ft)	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
PA01-L15	14.3	<b>34 <math>\pm</math> 10</b>	B	September 2000
98-5L39 (SDA10)	10.5	<b>46 <math>\pm</math> 11</b>	B	May 2001

a. Confirmation flag:

B = Reanalysis performed, no confirmation.

Note: Concentrations in red bold exceed the maximum contaminant level of 5 pCi/L.

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01-L15	PA02-L16	PA03-L33	W06-L27	W08-L13	W08-L14	W23-L08	W23-L09	W25-L28
1997	1												
	2												
	3												
	4												
1998	1												
	2												
	3												
	4												
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3				34								
	4												
2001	1												
	2			46									
	3												
	4												
Key		Ra-226 was analyzed for but not detected.											
		Ra-226 was detected (pCi/L).											
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.											

Figure 4-38. Shallow lysimeter monitoring results for radium-226.

**4.6.16.3.3 Lysimeter Samples at Depths of 35 to 140 ft**—Thirty-eight samples were collected from 12 lysimeters wells in the 35 to 40-ft depth interval between June 1997 and May 2001 with no positive detections.

**4.6.16.3.4 Lysimeter and Perched Water Samples at Depths Greater than 140 ft**—A total of 18 water samples and five filtered sediment samples from perched water wells were analyzed for Ra-226 between 1997 and September 2000 with no positive detections. No data are available for the other lysimeter samples obtained at depths greater than 140 ft because the volumes of water collected were insufficient to perform the analysis. The USGS does not analyze samples from perched water Well USGS-92 for Ra-226.

**4.6.16.4 Aquifer.** A total of 191 samples were analyzed from 15 aquifer wells in the vicinity of the RWMC, with three positive detections of Ra-226 between 1996, when Ra-226 monitoring was initiated, and April 2001 (see Table 4-83). All of the detections exceed the aquifer 1E-05 risk-based concentration of 1.83 pCi/L, and one result of  $5.4 \pm 1.5$  pCi/L exceeds the MCL of 5 pCi/L. The USGS does not analyze for Ra-226 in the eight RWMC wells it manages, controls, and routinely samples. Figure 4-39 shows when samples were taken from each of the 15 wells and when Ra-226 was positively detected. As shown, Ra-226 was not detected in any of the wells in at least two subsequent sampling events following the September 2000 detection.

All sample results for Ra-226 were obtained by direct gamma spectrometric analysis, which provides an adequate screening analysis but is not suitable for drinking water compliance purposes. Because drinking water compliance is required only for the RWMC Production Well, the MCL is used for the other wells as a guideline for comparison.

**4.6.16.5 Summary of Radium-226.** Vadose zone core samples were collected inside and outside the SDA. Results from cores outside the SDA were near background concentrations. Cores taken from the B-C and C-D interbeds inside the SDA contained Ra-226 above the background concentration of about 1 pCi/g. The samples did not contain elevated U-235, which is known to interfere with Ra-226 results. Therefore, the vadose zone core sample results suggest that Ra-226 is present in the vadose zone above background concentrations.

Table 4-83. Positive detections of radium-226 in aquifer wells.

Aquifer Well	Concentration $\pm 1\sigma$ (pCi/L)	Confirmation Flag <sup>a</sup>	Date
OW-2 (1 mi south of SDA)	4.0 $\pm$ 1.3	A	October 2000
M11S (upgradient)	4.8 $\pm$ 1.3	A	September 2000
M17S	<b>5.4 <math>\pm</math> 1.5</b>	A	September 2000

a. Confirmation flag:  
 A = No second sample collected, no reanalysis performed.  
 Note: Concentrations in red bold exceed the maximum contaminant level of 5 pCi/L.

Year	Quarter	M1S	M3S	M4D	M6S	M7S	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	OW-2	A11 A31
1996	1															
	2															
	3															
	4															
1997	1															
	2															
	3															
	4															
1998	1															
	2															
	3															
	4															
1999	1															
	2															
	3															
	4															
2000	1															
	2															
	3							4.8						5.4		
	4														4.0	
2001	1															
	2															
	3															
	4															
Key			Ra-226 was analyzed for, but not detected.													
			Ra-226 was detected (pCi/L).													
			If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.													

Figure 4-39. Aquifer monitoring detections for radium-226.