Section 4

SOIL AND SEDIMENT MONITORING PROGRAM

INTRODUCTION

This section presents a summary of the soil and sediment monitoring activities that were conducted at and around Rocky Flats. Presently there is no routine soil or sediment monitoring program at Rocky Flats. The previous Site-wide Soil Monitoring Program was discontinued in 1994. At present, soil and sediment monitoring activities are limited to project-specific monitoring, source location studies, pre-remediation investigations, and special focus studies.

Numerous soils studies have been performed at the Site and in the surrounding area by universities, government agencies, citizens groups, and Department of Energy contractors. Because plutonium is the primary contaminant of concern at Rocky Flats, the majority of these studies focused on the nature and occurrence of plutonium in the environment. Some of these studies were controversial. An actinide migration study sponsored by the Department of Energy is currently in progress to increase the understanding of actinide mobility and transport in the Rocky Flats environs.

An overview of the key studies, investigations, and surveys of the soils and sediments at Rocky Flats is presented.

SUMMARY OF MAJOR SOIL CONTAMINATION EVENTS

During the years of production, radioactive materials and hazardous substances were released to the environment around Rocky Flats during normal operating activities, such as stack exhaust releases from process buildings, waste management procedures, and storage and disposal practices. Several non-routine events also resulted in the release of significant quantities of plutonium and other contaminants from Rocky Flats. These events include accidents, fires, spills, disposal practices, and other operating procedures.

The routine and non-routine releases at Rocky Flats have contaminated onsite and offsite soils and sediments by dispersion from wind and water, infiltration to soils, sediments and groundwater, discharges to surface water. On the Site alone, a total of 173 individual onsite locations where solid wastes, pollutants, contaminants, or hazardous substances and wastes may have been disposed or released to the environment have been identified for future cleanup.

A summary of some of the major non-routine releases and accidents are presented below:

- A plutonium fire and explosion occurred on September 11, 1957 in Building 771 (Plutonium Recovery Operations) from the spontaneous ignition of plutonium casting residues in a glovebox. The fire spread to an exhaust filter plenum and consumed a large number of filters. The fire released significant quantities of plutonium to the atmosphere.

- A plutonium fire in 1965 at Building 777 (Assembly Building) occurred from the ignition of plutonium chips in a plugged glovebox drain. The flash fire spread through the ventilation systems of Buildings 776 and 777 and exposed operations staff to radioactive contaminants. This release reportedly released more gross alpha activity than the notorious 1969 fire.

- A plutonium fire on May 11, 1969 occurred from the spontaneous ignition of plutonium briquettes in Building 776 (Manufacturing Building) and released plutonium to the environment, which augmented the deposition levels from previous airborne releases at Rocky Flats.

- Radioactive particulates were released from a roof exhaust vent on Building 707 (Plutonium Fabrication/Pyrochemical Operations) due to a control valve failure in April 1974. Plutonium was released to the atmosphere.

- Gaseous tritium was released from a stack during a special project in 1968. In 1973, a mislabeled batch of scrap plutonium containing an unknown amount of tritium was processed for non-tritiated plutonium in Building 779A (Plutonium Development Building), resulting in a significant tritium release to Walnut Creek and contaminated exhaust air.

- In February 1989, a chromic acid bath overflowed into an acid waste drain system, filled a collection tank in Building 444 (Depleted Uranium and Beryllium Metallurgy), then overflowed into the foundation drain system. The spill was pumped to the Sewage Treatment Plant, then discharged to Pond B-3. The acid-contaminated water was then pumped to the East Spray Field and sprayed over frozen ground. The sprayed water ran off the frozen slope and collected in onsite impoundment ponds.

- A serious leak occurred in July 1993 when an overhead oxalic acid line ruptured, which sprayed plutonium-contaminated liquid over an estimated radius of 25 feet.

- The 903 Pad, established in 1958, was used as an outside storage field for drums containing plutonium-contaminated cutting oil and carbon tetrachloride from machining operations. Leaking drums were detected in 1964 and contaminated the soils in the 903 Pad area. The leaks continued until the drums were removed in 1968. The 903 Pad area was stabilized with fill material and soil sterilant, then sealed with an asphalt cover in 1969. Much of the plutonium-contaminated soil was resuspended and carried offsite east of Rocky Flats.

BACKGROUND CONCENTRATIONS IN SOILS

The background concentrations of naturally occurring radionuclides, inorganic compounds, metals, and organic compounds in the environment must be considered to determine the extent of contamination from Rocky Flats. Several studies were conducted to characterize the background concentrations of various constituents in surface and subsurface soils within the Site vicinity.

In addition to naturally occurring radionuclides, the background concentration in soils includes contributions from global radioactive fallout due to worldwide nuclear weapons testing conducted from 1945 to 1980, and the 1964 atmospheric burnup of a satellite. Plutonium, which does not occur naturally in the environment, is found worldwide from the radioactive fallout.

Nuclear weapons radioactive contamination spread worldwide as atmospheric fallout, which resulted in a fairly even distribution of radionuclide contamination over most of the earth's surface. Peak concentrations of fallout occurred in the 1960s, after which fallout rates declined.

Background surface soil concentrations are shown below for the Rock Creek and Background Soils Characterization Program (BSCP). Table I presents the background contribution from fallout radionuclides, and Table II lists the background population of naturally occurring compounds and constituents.

TABLE I
FALLOUT RADIONUCLIDES IN SOILS[2]

ISOTOPE	MINIMUM (pCi/g)		MAXIMUM (pCi/g)		MEAN (pCi/g)		UTL[1] (pCi/g)	
Soils	BSCP	Rock Ck	BSCP	Rock Ck	BSCP	Rock Ck	BSCP	Rock Ck
Plutonium-239, 240	0.017	0.026	0.072	0.1	0.038	0.055	0.084	0.110446
Americium-241	0.001	0.0095	0.025	0.036	0.0107	0.02	0.037	4.3372
Strontium-89, 90	0.065	0.095	0.64	1	0..254	0.618	0.708	2.23892
Cesium-134	0.05	0.071	0.3	0.1	0.2	0.084	0.369	0.148667
Cesium-137	0.3	0.71	1.7	2.5	0.941	1.41	2.25	3.68017

(1) UTL (Upper Tolerance Level) is a statistical estimate of the 99% upper confidence limit of all results
(2) Adapted from Geochemical Characterization of Background Surface Soils: Background Soils Characterization Program, (BSCP) Final Report, May 1995

TABLE II
SOIL BACKGROUND CONCENTRATIONS FOR NATURALLY OCCURRING COMPOUNDS AND RADIONUCLIDES

ANALYTE	MINIMUM (mg/kg)		MAXIMUM (mg/kg)		MEAN (mg/kg)		UTL[1] (mg/kg)	
	BSCP	Rock Ck	BSCP	Rock Ck	BSCP	Rock Ck	BSCP	Rock Ck
Aluminum	4,050	8,550	17,100	17,950	10,244	12,993	22,999	21,910
Antimony	0.19U	4.2U	0.47	7.3U				
Arsenic	2.3	2.1	9.6	8.5	6.09	5.82	13.75	12.86
Barium	45.7	120	134	470	102.4	195	176	481.1
Beryllium	.24	0.44	0.9	1.1	0.66	0.681	1.25	1.1523
Cadmium	39	0.3U	0.295U	1.8	2.3	0.732	2.335	2.45
Calcium	1,450	2,260	4,550	8,810	2,969	5,068.1	5,839	13,862
Cesium	6.05U	0.225U	7U	75U		31.29		831.6
Chromium	5.5	10.5	16.9	20.2	22.21	15.029	22.21	24.85
Cobalt	3.4	4.4	11.2	24	7.29	7.778	14.22	24.839
Copper	5.2	7.7	15.85	18.45	12.94	12.964	22.75	27.34
Iron	7,390	10,400	18,100	24,900	12,549	15,382	23,063	28,160
Lead	8.6	29.35	53.3	51	33.6	37.535	73.87	61.392
Lithium	4.8	7.1	11.6	14.95	7.69	10.981	15.08	19.97
Magnesium	1,310	1.440	2,800	5,195	1,913.1	2,853.3	3,707	7,011.6
Manganese	129	188.5	357	2,220	237.3	443.6	482.1	2,328.1
Mercury	65	0.03U	0.04U	0.075U	0.12		0.191	
Molybdenum	0.29U	0.7U	0.9U	2.7				
Nickel	3.8	7.8	14	18.7	9.63	12.578	19.74	26.8
Potassium	1,110	1,950	2,830	4,205	2,061.2	2,977.9	3,797	5,157
Selenium	0.29U	0.105U	1.4	0.76	0.634	0.43	1.76	1.21
Silicon	934	54.8	1,650	1,845	1,383.5	780.96	2,069	8,180
Silver	100	0.5U	0.19U	1.45U	0.22U			
Sodium	43.8	56.9	105	192.5	62.16	115.37	119.02	248.67
Strontium	8.6	20.9	45.2	79.05	28.44	35.335	67.92	90.072
Thallium	0.385U	0.105U	0.445U	0.41		0.23		0.563
Tin	1.35U	10.75U	2.9	58.5		32.541		83.79
Vanadium	10.8	20.95	45.8	45.6	27.85	31.603	61.84	55.56
Zinc	21.1	41.4	75.9	70.58	46.56	55.818	95.92	86.646
Radium-226	0.1	0.75	0.805	1.1	0.619	0.945	1.20	1.5944
Radium-238	0.2	1.3	2.3	2.9	1.35	2.177	3.189	4.874
Uranium-233/234	0.6	0.91	3.1	1.472	1.097	1.145	3.31	1.7882
Uranium-235	0.11	0.011	0.34	0.12	0.0539	0.053	0.16	0.1891
Uranium-238	0.74	0.9	2.6	1.521	1.09	1.183	2.83	1.9582

[1] UTL (Upper Tolerance Level) is a statistical estimate of the 99% upper confidence limit of all results
[2] Adapted from Geochemical Characterization of Background Surface Soils: Background SoilsCharacterization Program, Final Report (BSCP), May 1995

The primary source of background plutonium and cesium-137 concentrations around Rocky Flats is global radionuclide fallout from nuclear testing. The concentration of cesium-137 is sometimes analyzed along with other radionuclides to help age date a deposition event.

Because large quantities of plutonium were handled at the Site, it is important to differentiate between the plutonium background sources. The isotopic ratio for plutonium can be used to determine if the contaminant source is derived from Rocky Flats or radioactive fallout. The average mass-isotope ratio for plutonium-239 to plutonium-240 in the background soils was determined to be 0.155 ± 0.019 pCi/g during the Background Soils Characterization Program (BSCP). The average plutonium-240 to plutonium-239 ratio was 0.0030 ± 0.0004 pCi/g.

BACKGROUND CONCENTRATIONS IN SEDIMENTS

Background measurements of plutonium concentrations were determined from sediment samples collected from lakes and reservoirs located in the Colorado Front Range and are presented in Table III. These measurements represent the plutonium contribution from global radioactive fallout. With the exception of Boyd Lake, background plutonium concentrations were determined from single sediment samples.

TABLE III
BACKGROUND CONCENTRATIONS FROM COLORADO FRONT RANGE
LAKE AND RESERVOIR SEDIMENTS

Location	Sample Date	Sample Type	Pu-239, 240 Concentration (in pCi/g)[1]	References
Calkins Lake	8/69	Not reported	0.049	Poet & Martell (1972)
Boulder Reservoir	9/69	Not reported	0.007	Poet & Martell (1972)
Boyd Lake	9/69	Not reported	0.006	Poet & Martell (1972)
Calkins Lake	2/70	Grab or Dredge	0.06	EPA (1971)
Autrey Reservoir	2/70	Grab or Dredge	0.03	EPA (1971)
Cherry Creek Reservoir	4/74	Grab or Dredge	<0.05	Lammering (1975)
Marston Lake	4/74	Grab or Dredge	0.13	Lammering (1975)
Ralston Reservoir	4/74	Grab or Dredge	1.06	Lammering (1975)
Halligan Reservoir	1988	Core 21-22 cm depth	0.07	Cohen et al. (1990)
Wellington Lake	1988	Core 10-11 cm depth	0.19	Cohen et al. (1990)
Boyd Lake	1992	Core	0.009[2]	Schoep and Whicker (1995)

Adapted from Historical Public Exposures Studies on Rocky Flats, Phase II, March 1997
[1] Maximum Plutonium Concentration
[2] Median concentration of 7 homogenized core samples

SOIL ACTION LEVELS

In accordance with the Rocky Flats Cleanup Agreement (RFCA), the Action Levels and Standards Framework for radionuclides in soils were established based on a radiation dose limit to a hypothetical human receptor of 15 and 85 millirem per year (a rem is a unit of equivalent or effective dose, or Roentgen Equivalent Man). Radiation dose was examined for a 1,000-year period of time.

Soil Action Levels were established for both surface and subsurface soils. The RFCA Action Levels and Standards Framework (ALF) defines surface soils to originate from the surface to a depth of 15 centimeters (6 inches). The ALF defines subsurface soils from a depth of 15 centimeters down to the top of the groundwater table.

There are two tiers of numeric Soil Action Levels. Tier I Action Levels trigger an evaluation, remedial action and/or management action when exceeded and require institutional controls. Tier II Action Levels do not require remedial action and/or institutional controls.

Surface Soil Action Levels are based on radiation exposure to a hypothetical future resident from an open space exposure scenario in the buffer zone and office worker exposure in the Industrial Area. The Action Levels for a single radionuclide in surface soils are described below:

Tier I Action Level for surface soils in the Industrial Area is 15 millirem (mrem) annual dose limit based on the office worker scenario.

Tier I Action Level for surface soils in the buffer zone is 85 mrem annual dose limit, based on the resident scenario.

Tier II Action Level for surface soils on the entire site is 15 mrem annual dose limit, based on the resident exposure.

The ALF requires the subsurface Soil Action Levels to be protective of surface water standards. Therefore, the subsurface Soil Action Levels are based on radionuclides leaching from subsurface soils into the groundwater, which discharges to the surface water. The Tier I and II surface Soil Action Levels also apply to the subsurface soils.

If there are multiple radionuclides in the surface or subsurface soils, then the sum of the dose for all the radionuclides present may not exceed the Tier I and Tier II Soil Action Levels.

REGULATORY DRIVERS

Federal, state, and local regulations, DOE Orders and agreements, and judicial orders govern all Rocky Flats activities. Federal regulations include the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Superfund Amendment and Reauthorization Act (SARA), and applicable sections of the Resource Conservation and Recovery Act (RCRA).

The following regulations and DOE Orders govern applicable standards that mandate radiation dose requirements:

- DOE Order 5400.5, "Radiation Protection of the Public and the Environment;"
- Proposed Title 10 of the Code of Federal Regulations, Part 834, "Radiation Protection of the Public and the Environment," revised August 25, 1995 (proposed 10 CFR 834);
- Draft Title 40 of the Code of Federal Regulations, Part 196, "Radiation Site Cleanup Regulations," dated October 21, 1993 (Draft 40 CFR 196);
- Proposed Title 10 of the Code of Federal Regulations, Parts 20, 30, 40, 50, 51, 70, & 72, "Radiological Criteria for Decommissioning," dated August 22, 1994 (Proposed 10 CFR-NRC).

SUMMARY OF PREVIOUS SOIL STUDIES

Prior to and after the commencement of the Site's former Soil Monitoring Program in 1972, universities, the Atomic Energy Commission, EPA, and DOE contractors performed several major soil research studies at Rocky Flats. Most of the earlier soil studies focused on the spatial distribution of plutonium in soils derived from Site releases. Later studies were performed to investigate the fate of plutonium in soils, transport mechanisms, deposition patterns, and to estimate plutonium inventories.

A few studies were also conducted to evaluate the contribution of beryllium contamination to the soils at and adjacent to Rocky Flats. Beryllium was used in process operations during the production of nuclear weapons.

A brief summary of the major soil investigations is presented below.

Plutonium Inventories

There were several efforts to estimate the total inventory of plutonium released from Rocky Flats. To determine the inventory, investigators collected soil samples within areas ranging from 12 to 40 miles east, south, and north of the Site. The soils were analyzed for plutonium and, in some cases, americium. Analytical results were plotted on contour maps to produce plutonium concentration maps. These maps showed a surface soil plutonium contaminant plume extending from the 903 Pad toward the east and southeast.

Table IV shows the estimated plutonium inventory within the 12-mile radius from various studies.

TABLE IV
HISTORICAL PLUTONIUM INVENTORY ESTIMATES

Reference	No of Samples	No. of Sample Sites	Depth	Estimated Plutonium Inventory (Ci)
Krey & Hardy (1970)	52	33	8 in	5.4 - 8.1
Seed et al (1971	135	35	1.2-2 in	0.88
Poet & Martell (1972)	80	18 sites	0.4 in	11
Krey & Krajewski (1972)	54	35	8 in	1.8 - 7.2
Krey (1976)	80	54	8 in	7.8 - 11.6
Webb (1996)	1400, including historical data		8 cm	2.7 - 3.6

Particle Size Distribution

Several researchers found evidence that plutonium binds tightly to the soil under normal oxygenated conditions, and would only be transported with the soil particle. The various efforts to correlate plutonium concentrations with soil particle size and frequencies were largely inconclusive.

Some studies linked the larger plutonium particle sizes with the 903 Pad releases, and attribute the smaller particle sizes with emission releases from building stacks. Other researchers hypothesized that weathering broke down the particles attached to plutonium, concluding that the larger particles remained fairly fixed in place while the smaller particles were resuspended.

In general, most researchers agreed that plutonium attached to the surface of a soil particle after it was released to the environment. Depending on the availability of the soil particle for transport, presumably the plutonium was either dispersed by resuspension or it moved slowly down the soil column. Studies confirmed that subsurface plutonium transport occurred slowly and was controlled primarily by physical/erosional forces and the availability of a pathway. Environmental deposits of plutonium contamination were generally found to decrease rapidly in concentration within a foot from the surface.

Secondary Resuspension

The mechanisms of plutonium dispersion around Rocky Flats were actively studied. The resuspension and dispersal of surface soil deposits via wind and overland water flow is considered a primary transport mechanism. Numerous studies concluded that contaminated soils resuspended from the 903 Pad area were an important source of plutonium contamination in onsite and offsite areas of Rocky Flats.

Various study results provided estimates of the plutonium levels in soils near the 903 Pad area. The following plutonium concentration estimates were reported:

- 1970 - 1975 - 2.43 Ci
- 1973 - 0.54 Ci (FIDLER survey)
- 1978 - 1.95 Ci
- 1991 - 1.2 Ci (ground gamma survey)

Most studies concurred that plutonium transport occurred primarily by resuspension of plutonium-contaminated soils by wind and water. Researchers observed that these transport mechanisms have slowly dispersed the contaminated surface soils to a wide area over time. As these erosional processes continued, the plutonium concentration levels in the surface soil gradually diminished.

Fate and Transport

Considerable research has been and continues to be conducted to determine the fate and mobility of actinides in the soils over time. Although other actinides are present at Rocky Flats, plutonium was the primary focus of most studies. Plutonium fate and transport studies in soils included investigations to determine the distribution by depth, physical/chemical transport mechanisms, plutonium binding, spatial and vertical distribution, and plutonium speciation.

Various studies were performed to determine the physical and chemical mechanisms that influence the transport of plutonium in soils. In most cases, surface soil plutonium contaminant levels were found to decrease over time, indicating soil resuspension and other erosional processes removed the plutonium-contaminated soils. Some researchers concluded that the residual plutonium has stabilized in the surface soil, others suggested that much of the plutonium originally released from Rocky Flats persists in the soil and has gradually transported further down the soil column.

Evidence for the downward movement of plutonium was inconclusive. Several soil profile studies found the vertical distribution of plutonium concentrations decreased rapidly with depth and that over 50 percent of the plutonium occurred in the upper few inches of soil. In other studies elevated plutonium concentrations were detected in the deeper soils. This occurence was partially explained by the physical transport mechanisms that influence particle movement, such as freeze/thaw cycles, soil cracks from drying, water flow, or biological activities from earth worms and burrowing animals.

The chemical form of environmental plutonium was studied. Many studies concluded that the plutonium is in an immobile oxide or hydroxide form in the subsurface soil. Some researchers theorized that plutonium from the 903 Pad was released as plutonium oxide. Others suggest it was initially the more mobile plutonium chloride, which moved rapidly downward through the soils and bound to the soil particles as it oxidized. One researcher found evidence that the oxide form of plutonium could partially dissolve and desorb under very wet conditions, such as the wet spring and summer of 1995, and become more mobile in the subsurface soils.

Although most studies suggested that plutonium occurs in the oxide (or hydroxide) form in the soils, results from the preliminary analysis of soils and sediments from an actinide migration study currently in progress suggest the plutonium resides in the more mobile organic form.

Beryllium in Soils

Beryllium was used in the main production operations since 1958, including casting (foundry), cutting, heat-treating, rolling, and machining operations. It was routinely exhausted to the atmosphere from the beryllium processing building stacks from 1958 to 1983. Additionally, two reported filter fires in 1978 released beryllium to the environment.

Studies were conducted to characterize and quantify the beryllium concentrations in the soils. A large number of surface soil samples were collected from the Site and adjacent areas to determine the beryllium concentrations in onsite and offsite soils. Deeper soil samples were analyzed to determine the geological background concentrations. Analytical results from these samples were used to estimate the total amount of beryllium released from the Site during plant operations.

Two areas of high beryllium concentration were identified, one near the stack of a beryllium process building, another in an area adjacent to the door for Building 444. However, most studies found that the beryllium concentrations in onsite and offsite soils could not be distinguished from the natural background and other outside beryllium sources, such as the nearby former beryllium ore processing facility.

SUMMARY OF PREVIOUS SEDIMENT STUDIES

Three intermittent streams and their tributaries drain the Site: Walnut Creek, Woman Creek, and Rock Creek. North Walnut Creek and South Walnut Creek flow toward the east through the A- and B-series detention ponds, and Woman Creek flows through the C-series ponds. Four downstream

reservoirs are located offsite east and southeast of the Site: Great Western Reservoir, Standley Lake, Mower Reservoir, and Woman Creek Reservoir. These water bodies may have received some contaminants from Site drainages and via air deposition.

Several universities, CDPHE, the U.S. Geological Service, EPA, and others performed a number of sediment studies. The majority of sediment studies examined the concentration levels and spatial distribution of plutonium in the reservoir sediments.

Detention Ponds

A series of holding ponds were constructed at North and South Walnut Creeks (A- and B-series ponds) and Woman Creek (C-series ponds) between 1952 and 1980 to control and collect surface water runoff and discharges from the Site.

Several studies were conducted between 1970 and 1973 to evaluate the impacts before, during, and after the repair and construction of the retention ponds, which was completed in 1972. Data was collected and compared to assess any changes in the pattern of plutonium concentrations in the sediments from resuspension and redistribution of the sediments during the construction activities. These studies showed increased plutonium concentrations in the waters and surface sediments of the ponds during and after the construction period. Elevated plutonium concentrations were also detected in Walnut Creek, indicating that contaminated sediments and surface water were discharged offsite during the construction activities.

Great Western Reservoir

Great Western Reservoir is located approximately 1.5 miles east of the Site boundary and is owned and operated by the City of Broomfield. From 1955 until recently, the City of Broomfield used the reservoir as a potable water supply.

Comparative sediment studies were conducted in Great Western Reservoir between 1970 and 1973 to evaluate the impacts from the pond reconstruction activities. These studies confirmed that plutonium-contaminated sediments were released from the Site via Walnut Creek during the construction activities, and deposited in the deepest reaches of Great Western Reservoir. The studies revealed there were substantial increases in plutonium concentrations during the pond reconstruction.

Other studies examined the Great Western Reservoir sediments to evaluate the deposition patterns and profile of plutonium contamination. Dredge and core sediment samples were collected and analyzed to determine the lateral and vertical distribution of plutonium, americium, and cesium. Cesium-137 was used to age date the sediment layers in order to estimate the peak periods of plutonium deposition. At least two large contaminant deposition events were identified. One event was attributed to airborne releases from the 903 Pad and plutonium fire in 1969. Another deposition event was correlated with controlled waterborne releases from the Site in the 1960s.

Major conclusions from the sediment profile studies in Great Western Reservoir indicated the plutonium contamination occurred in distinct layers during major historical release events, then were covered by younger, less contaminated sediments. Although plutonium concentrations in the sediments were found to be highly variable, studies determined that the highest contaminant concentrations occurred in the bottom sediments of the deepest portions of the reservoir. Several researchers estimated that more than 85 percent of the plutonium contamination in the Great Western Reservoir originated from Walnut Creek discharges.

Standley Lake

Standley Lake is a large reservoir located approximately 2.5 miles east of the Site boundary and provides drinking water for the cities of Westminster, Northglenn, and Thornton. Approximately two-thirds of the lake water is used for municipal water supplies and one-third for irrigation purposes. Standley Lake previously received discharge from Woman Creek, which included the flow from detention Pond C-1. Standley Lake may have received both waterborne and airborne contaminants from Rocky Flats.

Only a few sediment studies have been performed at Standley Lake. The sediments were evaluated to calculate the plutonium and americium inventory in the lake. Other studies evaluated lake sediment profiles to identify the time intervals plutonium contaminants were released from Rocky Flats. Study conclusions indicated that approximately 70 percent of the plutonium detected in the upper 12 inches of lake sediment originated from Rocky Flats. This plutonium contamination was attributed to releases from the 903 Pad. The remaining 30 percent of plutonium contamination was identified as radioactive fallout from the nuclear weapons testing conducted from 1950 through 1960.

Mower Reservoir

Mower Reservoir is located southeast of Rocky Flats approximately 1,500 feet from the east Site boundary, and is used for pasture land irrigation and livestock watering. Outflow from Mower Reservoir flows southeast toward Standley Lake, where it discharges. Mower Reservoir now receives water from the Woman Creek Reservoir. The water diverted from Woman Creek below Pond C-2 to fill Mower Reservoir once flowed through the Mower Ditch.

A few studies were performed at Mower Reservoir to determine plutonium concentrations in the sediment. Study results were variable, but most indicated the reservoir sediments contained slightly elevated concentrations of plutonium.

ROCKY FLATS SOIL AND SEDIMENT MONITORING PROGRAMS

As mentioned earlier, Rocky Flats does not currently have an established Soil or Sediment Monitoring Program in place. The most recent Soil Monitoring Program at the Site was discontinued in 1994. Sediment monitoring was previously conducted as part of the Site-wide Surface Water Monitoring Program and was not a separate monitoring program. Other than project-specific investigations and other specialized studies, sediments are not currently monitored by the Site.

The most recent Soil Monitoring Program and latest sediment monitoring activities in place at Rocky Flats are briefly described below.

RECENT SOIL MONITORING PROGRAM

Limited onsite and offsite soil sampling for gross alpha-emitting radionuclides was performed at Rocky Flats from the early 1950s until 1969. After the 1969 plutonium fire, soil monitoring activities at and around Rocky Flats were expanded. A routine Soil Monitoring Program was established in 1972 and, except from 1978 to 1983, continued until 1994.

The purpose of the previous Soil Monitoring Program at the Site was to evaluate changes in the plutonium contaminant levels over time, and to determine the lateral and vertical distribution of plutonium in specific remediation areas.

The Soil Monitoring Program consisted of two subprograms: Site-wide soil monitoring and remediation site soil monitoring. These subprograms are described below.

Site-Wide Monitoring

The Site-Wide Soil Monitoring Program was used to evaluate distribution patterns and changes in the plutonium concentrations due to the remobilization of plutonium and americium contaminated soils, and to compare the plutonium concentration levels in the soil on an annual basis.

Annual soil sampling was performed onsite in a radial pattern encircling the Site within an area extending outward one and two miles from the center of the Site. The soil samples were collected from 40 monitoring sites located along two concentric circles spaced at 18-degree intervals. There were no soil monitoring sites located within the Industrial Area. Figure 1, an excerpt from the 1994 Rocky Flats Annual Report, shows the soil monitoring locations.

The soil samples were collected from undisturbed soil down to a two-inch (five centimeter) depth by driving a four-inch square (10 x 10 centimeters) cutting tool into the soil. Ten subsamples were collected from the center and four corners of two 3-foot square (1 meter square) plots spaced three feet apart. The soil samples were composited and analyzed only for plutonium until 1988, then for plutonium and americium from 1988 until 1994, when the program was discontinued.

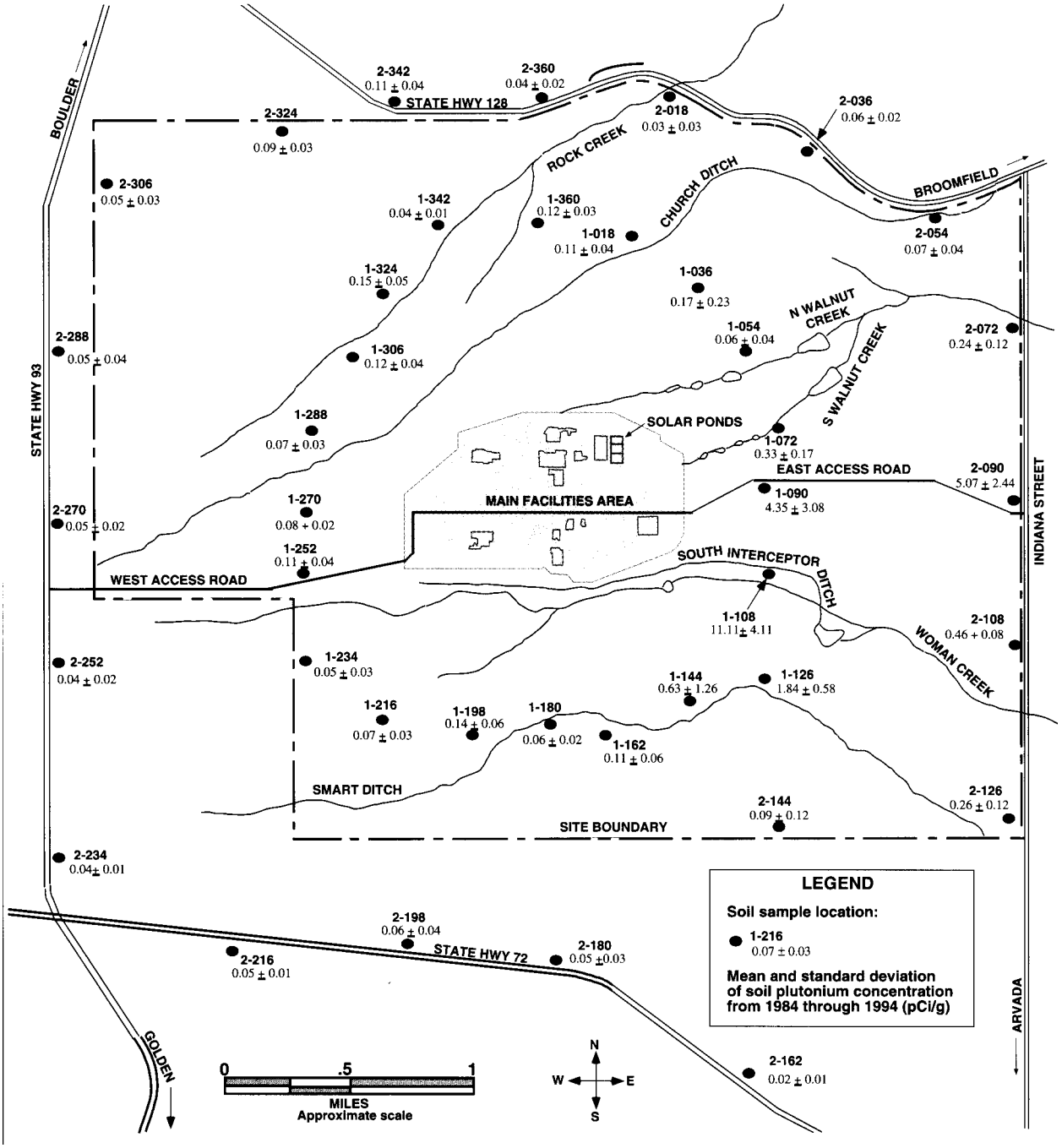
In addition to the Site's soil sampling regimen, the Colorado Department of Public Health and Environment (CDPHE) performed surface soil surveys in the Rocky Flats area. Composite samples were taken from 13 sectors within about seven miles (11 kilometers) around the Site. CDPHE surveys were conducted from 1970 to 1991.

Remediation Site Monitoring

The Remediation Site Soil Monitoring Program consisted of annual soil sampling in the eastern buffer zone and one-time soil sampling events for the Operable Unit (OU) remedial investigations. The intent of the remedial investigations for the OUs were to evaluate the nature and extent of organic, inorganic, and radionuclide contamination in the soils and sediments at the Individual Hazardous Substance Sites (IHSSs) within each OU.

The annual buffer zone soil monitoring was conducted to determine the spatial and vertical distribution of plutonium and americium in the soils.

FIGURE 1 - SOIL SAMPLING SITES



Measurements for the spatial distribution of contaminants in the surface soils were accomplished by collecting soil samples across an 800-acre area. The specific number and location of soil samples required for the OU remedial investigations were determined from an extensive literature review, radiological surveys, and geostatistical evaluations of the historical data.

CDPHE soil sampling procedures were used to sample surface soils in buffer zone areas east of the 903 Pad. Soils were collected from 25 subsample locations within a four to ten-acre plot. The samples were collected by removing soil from an approximate two-inch square area by driving a quarter-inch deep template into the soil. Because of the large variability in plutonium concentrations, the procedure was modified by using a 2.5-acre plot to sample soils in the general area immediately east of the 903 Pad and near the East Trenches area.

To assess the vertical distribution of contaminants, soil pits or trenches were excavated at selected locations in undisturbed areas to a depth of three feet (one meter). The soil profile in each pit or trench was described and sampled to determine the vertical profile of plutonium and americium. The location of the pits was determined in the field using aerial photographs, soil maps, topographic maps, ground penetrating surveys, and radiological surveys.

It is outside the scope of this project to evaluate the findings from the OU remediation monitoring activities. However, some of the more recent findings from the OU investigations and other studies are summarized below.

- During the OU2 RCRA Facility Investigation/Remedial Investigation (RFI/RI) in 1993, the Site assessed the vertical distribution of plutonium and americium in soils near the 903 Pad. Soil samples were collected from 26 excavated pits and analyzed. The study results indicated that 90 percent of the plutonium occurred in the upper 4.7 inches (12 centimeters) of the soil column. The study concluded that biological activities, such as those of earthworms and burrowing animals, were a significant transport pathway.

- The potential mobility of plutonium, americium, and uranium in soils was investigated during the RFI/RI for OU3. Undisturbed soil samples were collected in a vertical profile from 11 three-foot deep trenches located offsite east of Indiana Street. Soil characteristics and soil processes were also examined. Analytical results showed that the highest concentrations of plutonium and americium occurred in the top 1.2 inches (three centimeters) of soil. The concentrations detected below four inches (ten centimeters) in depth averaged 0.04 pCi/g for plutonium and 0.09 pCi/g for americium, which are close to the upper background values selected for the study.

- The distribution of beryllium in onsite surface soils was evaluated during the OU3 investigation to determine the spatial trends of airborne dispersion from the Site. Analytical results for the soil samples were compared to the background concentration determined from the Background Soils Characterization Program (BSCP) and the Rock Creek study. Analytical results indicated that the beryllium concentrations in onsite soils averaged 0.68 micrograms/gram, which was similar to the background concentrations. Based on these results, it was concluded that future offsite soil sampling for beryllium was unwarranted because there was no evidence of airborne contaminant dispersion.

- Volatile organic compounds, six metals (arsenic, barium, cadmium, cobalt, lead, and zinc), and plutonium were detected above background levels in subsurface soils from Trench T-2.

- Ten volatile organic compounds, four metals (chromium, copper, lead, and calcium), plutonium, and americium were detected above background levels in subsurface samples from the 903 Pad. The maximum detected plutonium concentration in the subsurface soils was 68 pCi/g, and 25 pCi/g for americium at a depth of two to eight feet. In the 903 Pad Lip area, the maximum plutonium concentration detected was 180 pCi/g and 22 pCi/g for americium.

- At the Mound Site, six volatile organic compounds, five metals (arsenic, cadmium, manganese, barium, and calcium), plutonium, americium, and cesium were detected above background levels in the subsurface soils. The maximum detected concentrations for plutonium were 2.6 pCi/g for plutonium, 0.48 pCi/g for americium, and 4.7 pCi/g for cesium.

- Lead was detected in more than five percent of surface and subsurface soil samples collected in OU5. Fifteen subsurface soil samples exceeded the background upper tolerance level of 70.52 ppm (mg/kg). The maximum detected lead concentration in OU5 surface soils was 129 ppm (mg/kg), and 935 ppm (mg/kg) in the subsurface soils.

RECENT SEDIMENT MONITORING PROGRAM

A limited amount of information is available regarding sediment monitoring. Although the Surface Water Monitoring Program presented in the *Interim Measures/Interim Remedial Action Decision Document for the Rocky Flats Industrial Area* (November 1994) included sediment monitoring as part of the program, it is not described.

Other than some routine sediment monitoring for radionuclides in the early 1950s and 1970s, most sediment monitoring by the Site is evidently performed either as a special study or as part of the remedial investigation studies for the OUs.

Earlier sediment studies conducted by the Site and other investigators were summarized in preceding sections. Various findings from the more recent OU remedial investigations and other studies are summarized below.

- Sediment samples were collected in the 1990s from various locations within the Woman Creek drainage and from Ponds C-1 and C-2 to develop depth profiles of the surface water sediment interface at both ponds. Several contaminants of concern were detected above background values in the sediments collected from locations in Woman Creek. In Woman Creek north of Pond C-2, concentrations of americium and uranium in sediments were detected above background levels. Pond sediment samples were detected above background levels for mercury, barium, calcium and zinc.

- Elevated levels of various contaminants of concern were detected in the surface water and sediments at a few locations in OU5. One sediment sample from the South Interceptor Ditch had concentrations of copper, mercury, and zinc above background levels.

- During the OU2 RFI/RI, five composite sediment samples were collected to a depth of two feet or less in each A-series pond to determine the nature and extent of contamination. Six metals (chromium, antimony, vanadium, zinc, magnesium, and potassium), uranium, and strontium were detected above background levels in all the pond sediments. Pond A-1 sediments contained elevated concentrations of americium (0.132 to 3.25 pCi/g) and plutonium (17.7 to 36.2 pCi/g).

- Five composite sediment samples were collected in each B-series pond at depths of two to four feet during the OU2 RFI/RI. Because sediments were deeper, two additional sediment samples were collected from Ponds B-1 and B-2, and three additional samples from Pond B-4. Low concentrations of volatile organic compounds, pesticides, and metals were detected in all B-series ponds. Americium and plutonium were detected in all ponds but B-5, with maximum concentrations of 389 pCi/g occurring in Pond B-1 and 180 pCi/g in Pond B-3. Gross alpha, gross beta, and uranium were also detected in Ponds B-1 and B-3 above background levels. Radionuclide concentrations were found to increase with depth in Ponds B-1 to B-4, but decreased with depth in Pond B-3.

- Plutonium concentrations up to 0.340 pCi/g were detected in the Central Avenue Ditch sediments upstream from gaging station SW022. Large accumulations of sediments were found in the ditch, which reduced the water carrying capacity.

- On the steep dirt road that drains runoff from the area west of Solar Pond 207C near Building 774 (East Hillside), a sediment sample containing 13 pCi/g of plutonium was detected. Other sediment measurements in this area detected 0.800 pCi/g of plutonium and 0.990 pCi/g of americium. A sediment sample from the bottom of the hill had a plutonium concentration of 0.650 pCi/g and 0.190 pCi/g for americium.

ACTINIDE MIGRATION STUDY

DOE has formed an Actinide Migration Expert Panel composed of recognized experts concerning the chemical behavior and mobility of actinides in the environment. The Panel was formed to develop and assess a conceptual model of actinide transport at Rocky Flats. The Panel recommended an Actinide Migration Study be conducted to support further development of the Site conceptual model.

The overall intent of the Actinide Migration Study is to acquire a better understanding of the chemical and physical mechanisms of actinide mobility and to determine the potential impacts to the Site environment. Information from this study will be used to design remedial actions that mitigate the migration of actinides after Site closure. The scope of activities planned for FY 1997 are as follows:

- Compile the available information concerning actinide migration, evaluate the existing data, and issue a final report;

- Collect preliminary sediment, soil, and water samples from selected locations of actinide contamination for analyses to determine the phase association and soil/water partitioning of plutonium;

- Conduct a preliminary assessment of actinide loadings to surface water from soil erosion and preferential flow in drainages from the Industrial Area and evaluate the long-term impacts to surface water quality.

Recently, Dr. Bruce Honeyman from the Colorado School of Mines performed preliminary actinide species studies. Soil samples were collected from the 903 Pad Lip area, and sediment core samples were collected from Ponds B-5 and C-2. These samples were analyzed to determine the different species of plutonium present in the soil and sediment samples. The five potential forms of plutonium species include chemically exchangeable, carbonate bound, sesquioxide, organically bound, and solid plutonium oxide.

The preliminary speciation analyses indicated that the largest fraction of plutonium found in the samples was in the soluble, relatively mobile organically bound form. These results conflict with the results from earlier studies, which determined that the plutonium occurred in the relatively insoluble, immobile sesquioxide form. Future studies will be performed to confirm these results and to determine actinide mobility rates.

This page intentionally left blank.

CRITICAL ANALYSIS AND RECOMMENDATIONS

ANALYSIS AND RECOMMENDED IMPROVEMENTS

Rocky Flats does not currently have a soil or sediment monitoring program in place. Presently, soils and sediments are evaluated only during remedial investigations, such as the pre-remedial investigation recently performed for the Mound Site source removal project, or to determine the source of a suspected contaminant release. For example, sediment samples were collected from Walnut Creek at Indiana Street in August 1997 to help locate the potential source of elevated plutonium concentrations detected in the surface water. The Site also occasionally conducts special focus studies for soils and sediments. For instance, sediment samples from two detention ponds (Ponds B-5 and C-2) and soils from the 903 Pad Lip area were recently collected for analysis to provide data for the new Actinide Migration Study currently in progress.

The *Final Interim Measures/Interim Remedial Action Decision Document* (IM/IRA 1994) for the Rocky Flats Industrial Area states that although soil sampling is useful for characterizing contaminated sites, it is unsuitable as a monitoring media because soils are not considered to be a transport medium. The IM/IRA acknowledged that soil is often the first environmental medium to receive contaminants during a release event. However, because soil contaminants were mostly remobilized by volatilization to the air, airborne transport, suspension in water, or by dissolving in the surface water or groundwater, the IM/IRA concluded that soil monitoring was less critical than other monitored environmental media. Lastly, the IM/IRA determined that routine soil sampling was not feasible because the sample locations were disturbed during sampling activities and new locations were needed for each soil sample event prevent sample bias. It was then stated that "Generally at RFP, the objective of a soil monitoring program is to track radionuclide contamination..."

Although these explanations have some merit, it is not enough justification to support the lack of a soil monitoring program at Rocky Flats. The Integrated Monitoring Plan for FY 1997 provided no rationale to reasonably justify the absence of soil and sediment monitoring at the Site.

The Site encompasses a large area, most of it covered by accessible soils. This provides an abundant selection of soil sample locations to support an annual soil monitoring program at the Site. With judicious planning and documentation, statistically valid random sampling grids can be set up along selected transects (arbitrary dividing lines) to produce a set of unbiased, representative surface and subsurface soil samples.

Various soil studies determined that when plutonium is released to the environment from Rocky Flats, it forms a close association within soils and binds to the soil particles. These plutonium-bound soil particles can then be transported by erosional processes, such as wind or water, or carried down the soil column via physical or chemical pathways. By these actions, soil can be considered a transport media that disperses contaminants throughout the environment, with air or water acting as the carrier.

The soils at Rocky Flats are continually subjected to forces of wind and water, which means some measure of material cycling occurs. Depending on the conditions, these processes can be very slow, as in the gradual weathering down of soil particle sizes, or rapid during spring flooding or high winds. In the case of plutonium and other contaminants that behave similarly in the environment, soils and sediments are both a transport media and effective sink for contaminant accumulations. Therefore, using the claim that soil is not a transport media as rationale for the lack of a periodic Site soil monitoring program cannot be substantiated.

The mobility of contaminants in soils and sediments, particularly plutonium, has been and continues to be studied extensively. However, dissimilar laboratory testing procedures, variations in sampling methods, and other differences provide seeming conflicting study results. Understanding the mobility of plutonium and other contaminants is essential in order to assess the fate of these contaminants in the environment and to determine any potential adverse impacts to other environmental media.

Based on the results of several studies, it has long been assumed that plutonium in the Site soils is present in the oxide form and essentially immobile. However, the oxide (sesquioxide) form of plutonium is extremely unstable under anoxic (no oxygen) conditions. Anoxic conditions may exist in subsurface soils, especially beneath building foundations, or in pockets of slow moving groundwater. Once introduced to the surface and exposed to the air, the plutonium may mobilize and spread the contamination. This should be a particular concern during building demolition activities.

More recently, preliminary results from the new Actinide Migration Study, and other past studies, suggest that the plutonium in the soils and sediments at the Site may exist in a more mobile organic form. It is important that the mobility of plutonium and other contaminants in the soils and sediments at the Site be determined under both anoxic and oxygenated conditions prior to planning and finalizing remediation decisions. Otherwise, the remedial activities could inadvertently

generate potential new sources of contamination by exposing an environment where the contaminants are stable to less favorable, unstable environmental conditions.

Over the years, the soils and sediments at the Site and surrounding area have received significant quantities of radioactive and hazardous contaminants from routine and accidental releases since the Site began operation. During the Operable Unit remedial investigation studies, soils and sediments (and other environmental media) were characterized, and several areas of contaminant accumulation were identified. Much of this assessment work was based on the findings from previous soil and sediment studies, even though some of the conclusions and results from many of the studies were contradictory or inconclusive. This historical data is important and should be used to guide future monitoring decisions, but confirmatory sampling should be performed.

Moreover, the Site is environmentally dynamic and the soils and sediments are subject to changing environmental conditions over time. Confirmatory monitoring and more updated data is required for effective remediation decisions.

There is an obvious need for a soil and sediment monitoring program at Rocky Flats. Soils and sediments are interactive with all environmental media, and therefore subject to cross contamination either as a source or a recipient. The soils and sediments at Rocky Flats are not static, and are subject to dispersal through erosional processes and transport by wind or water. It is possible that the plutonium release recently detected at Walnut Creek and Indiana Street (August 1997) would not have occurred if a sediment monitoring program were in place.

The Site should consider instituting a data collection program and a modeling investigation to determine the magnitude of contaminated sediment transport during flood periods and to develop strategies for controlling the offsite transport of contaminants.

The scope of the Actinide Migration Study needs to be finalized, and should include investigations of actinide mobility in all potential environmental conditions at Rocky Flats. The study should be expedited and completed for use in planning and strategizing remedial activities that will minimize contaminant migration and are protective of the environment.

With the accelerated pace for cleanup and closure of Rocky Flats, project activities involving environmental restoration, D&D, and construction will increase at the Site. As these activities are initiated, the risk for contaminant migration to the soils and sediments is increased. It is vital that soil and sediment monitoring programs are in place to monitor these potential contaminant impacts.