



MEMORANDUM

TO: Mary Fabisiak, City of Westminster
FROM: Christine Hawley and Jean Marie Boyer, PhD, PE, Hydros Consulting Inc.
SUBJECT: Offsite Human Health Risk Assessment Findings from Rocky Flats
DATE: June 3, 2014

This memorandum summarizes key information to support the City of Westminster (City) in communicating to the public the understanding of current human health risks in offsite areas associated with plutonium-239,240 and americium-241 from the Rocky Flats Site. The Rocky Flats Site (RFS) is a former nuclear weapons component manufacturing facility located west of the City of Westminster and Standley Lake, a key drinking water source for Westminster, Thornton, and Northglenn. Cleanup and closure of the site were completed in 2006, and current site activities include only monitoring and maintenance.

The City tracks RFS activities, critically reviews sampling results and interpretation, and consistently communicates with regulators for ongoing protection of the communities proximal the RFS. Periodically, the City receives questions and comments from the public regarding current health risks related to the RFS. The City has asked Hydros Consulting to compile this memorandum to support concise and accurate response to such inquiries. This review focuses primarily on well-documented and, where possible, peer reviewed investigations. The compiled information presented here may be useful to inform City staff and/or to support development of public information materials, such as fact sheets or informational pamphlets.

This memorandum is organized into four main sections:

1. **Rocky Flats Site Background** - First a high-level history of RFS is presented, including major historical events releasing materials to offsite areas and key regulatory steps.
2. **Human Health Risks in Offsite Areas (OU3)** – Second, findings from key studies of human health risks in offsite areas are summarized. The discussion is organized by sampling media, followed by a summary of key epidemiological studies.
3. **Summary and Recommendations** – Third, a bullet summary of major findings is provided to support development of risk communication tools.
4. **References** – Finally, a list of references evaluated is presented.

1 Rocky Flats Site Background

The Rocky Flats site was selected in 1951 by the Atomic Energy Commission to serve as part of the nation's nuclear weapons manufacturing complex. The site is located 16 miles northwest of

downtown Denver, Colorado in Jefferson County, on a plateau just east of the Front Range foothills of the Rocky Mountains. Originally, the site was 2,600 acres. Additional parcels of land were acquired subsequently for a maximum size of roughly 6,500 acres, including a small area extending into Boulder County. The site was first operated by Dow Chemical. Operations began at Rocky Flats in 1952, and processing and machining of plutonium into detonators (aka triggers) began at the site in 1953. Components were formed from beryllium, plutonium, stainless steel, uranium, and other metals. The plant also produced military components from depleted uranium and processed plutonium for reuse (Department of Energy [DOE], 2011).

Beginning in the 1970's, several major protests occurred, some with thousands to tens of thousands of demonstrators. Various incidents and accidental releases occurred at the site during the roughly four decades of production. Key recorded releases of radionuclides affecting offsite areas include the following:

- **1957 – Fire in Building 771.** A fire occurred in a glovebox in plutonium processing Building 771.
- **1958-1969 – Windblown Contamination from the 903 Pad.** Surface soils contaminated by leaking waste-storage drums at the 903 Pad were transported by wind to areas east of the site. More than 3,500 55-gallon drums were stored at the 903 Pad, and many were found to have corroded and leaked contents onto surrounding soils. Drum contents of key concern included plutonium-contaminated lathe coolant. An asphalt pad was placed over the site in 1969.
- **1969 – Fire in Building 776/777.** There was a major fire in a glovebox in Building 776/777.
- **1970 to 1973 - Release of Detention Pond Sediments to Walnut Creek.** Sediments from Walnut Creek A- and B-series detention ponds were released offsite during a re-engineering project. These sediments flowed into Great Western Reservoir.
- **1973 – Tritium Release to Walnut Creek.** Contaminated scrap material from Lawrence Livermore National Laboratory was blamed for release of tritium to Walnut Creek, flowing into Great Western Reservoir, then a water supply for Broomfield.

On June 6, 1989, the FBI and the EPA conducted an armed raid of Rocky Flats, operated at the time by Rockwell International, in search of evidence of environmental crimes. Later in 1989, the site was listed on EPA's National Priorities List based on investigations indicating release of materials defined as hazardous substances under CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) and RCRA (Resource Conservation and Recovery Act), and the Colorado Hazardous Waste Act (CHWA).

In 1992, then-President George H. W. Bush cancelled the W-88 Trident Warhead program, terminating Rocky Flats' production mission. In 1994, nonnuclear production at the site was also terminated. This changed the site mission to one of cleanup and closure. At this time, there were more than 800 structures in the industrial area, including 150 buildings and 90 trailers. By this time, the site was divided into three areas: the Industrial Area (IA), the Protected Area (PA), and the Buffer Zone (BZ). The IA (385 acres at the center of the site) contained buildings and structures. The PA, located within the northern portion of the IA, was even more heavily fenced and guarded than the IA since it contained the complex of plutonium production facilities. The BZ was the land surrounding the IA. It was also fenced and guarded to protect the site from incursion.

In 1996, the Woman Creek Reservoir (WCR) was constructed on Woman Creek using Federal funding as part of the Standley Lake Protection Project (SLPP). The WCR physically separates Standley Lake, the drinking water source for the Cities of Northglenn, Thornton, and Westminster, from surface water leaving Rocky Flats. The WCR captures flow from Woman Creek as it exits the RFS and subsequently pumps that water to Walnut Creek, thereby bypassing Standley Lake. Prior to WCR construction, Woman Creek water from Rocky Flats had been diverted to Church Ditch, thereby bypassing Standley Lake since the late 1980's (D. Strietelmeier, personal communication, 2014).

In 1997, while clean-up and closure work continued at the site, a Corrective Action Decision/Record of Decision (CAD/ROD) was issued for Offsite Areas at Rocky Flats (DOE, 1997). Based on the investigation results and risk assessment, this CAD/ROD found risks to be below minimum thresholds of concern set by the Environmental Protection Agency (EPA) and the Colorado Department of Public Health and Environment (CDPHE). The CAD/ROD concluded that the appropriate remedial action for Offsite Areas was no action (DOE, 1996 and EPA, 1997). The investigation and findings are discussed in greater detail in Section 2 of this memorandum.

Characterization, clean-up, and closure activities at the site itself continued through 2005. During that time, 21 tons of weapons-grade nuclear material were removed, structures were demolished, storage and waste sites were remediated, some drainages were reconfigured, and more than 1.3 million cubic meters of waste were removed (Kaiser-Hill, 2006). Following completion of cleanup in October 2005, the remedial investigation and comprehensive risk assessment were completed to support selection of the final remedy for the Site (Kaiser-Hill, 2006 and EPA, 2006).

In September 2006, the CAD/ROD for the Site (EPA, 2006) was released. The RFS was regrouped into two operable units: the Central OU and Peripheral OU. The Central OU consisted of 1,300 acres, inclusive of the former PA and IA and site terminal ponds. The remaining, surrounding 4,900 acres were designated as the Peripheral OU. These areas are shown on Figure 1, along with Standley Lake, Great Western Reservoir, and Mower Reservoir. The CAD/ROD indicated no action as the appropriate response action for the Peripheral OU. For the Central OU, the CAD/ROD indicated institutional controls (to limit access and soil disturbance) and continued monitoring as the response action.

In March of 2007, the Rocky Flats Legacy Management Agreement (RFLMA) was signed by DOE, EPA, and CDPHE. The purpose of RFLMA is to define the regulatory framework for implementing the final remedy to ensure that conditions remain protective of human health and the environment. RFLMA includes monitoring, maintenance, and reporting requirements. Long-term care of the Central OU and adherence to RFLMA is the responsibility of the DOE Office of Legacy Management (LM). This includes monitoring and maintenance of two closed landfills and four groundwater treatment systems. The Peripheral OU was transferred to the U.S. Department of Interior for management by the U.S. Fish and Wildlife Service in July 2007.

There are numerous sources of information on the history of Rocky Flats. The following key sources were reviewed in development of this brief history: Buffer (2003), Rocky Flats Stewardship Council (RFSC; 2008), and DOE (2011). Figure 2 presents a timeline of these key releases and regulatory events.

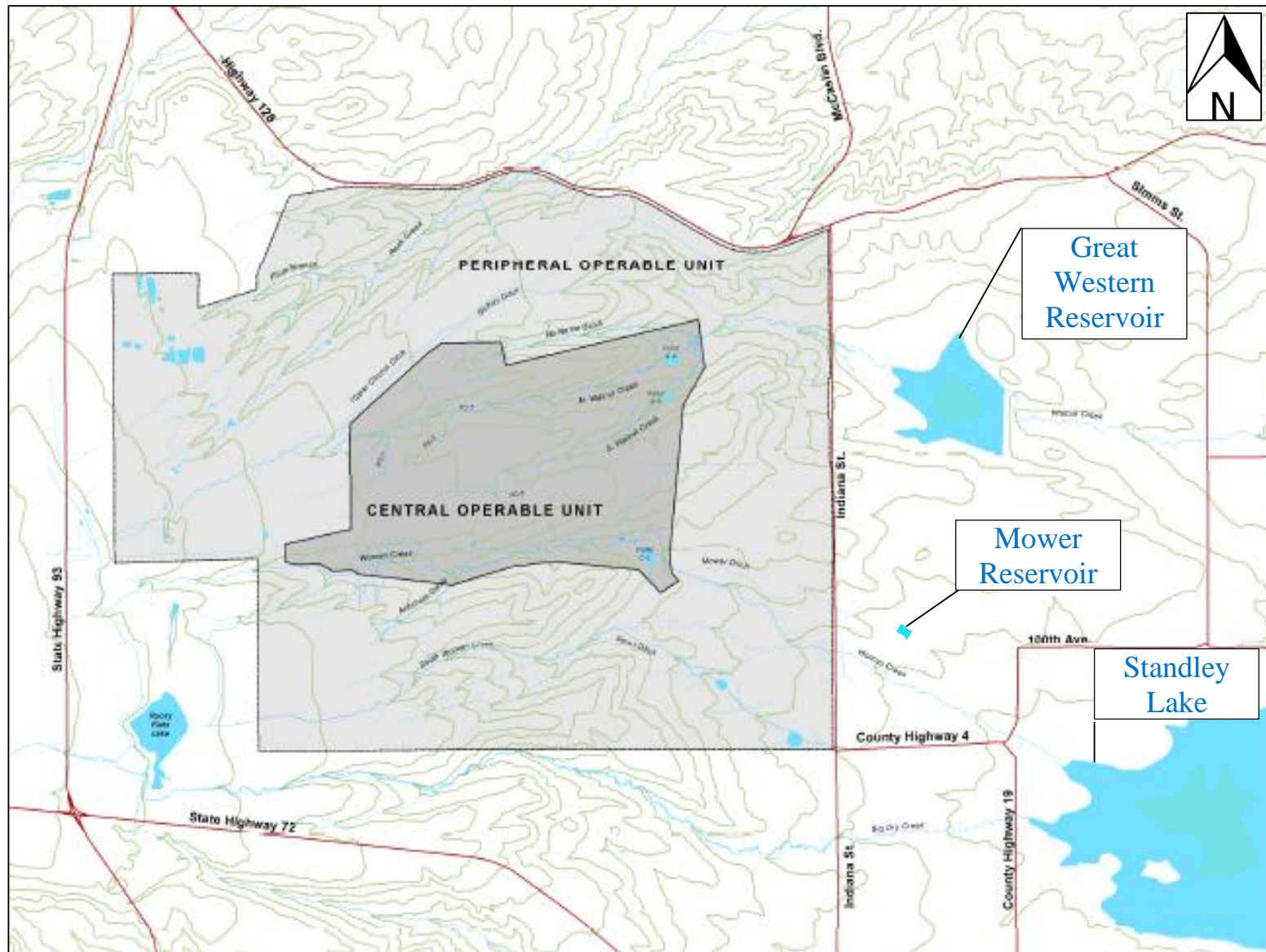


Figure 1. Rocky Flats Site Central OU, Peripheral OU, and Surrounding Areas (Image modified from RFLMA [DOE, 2007])

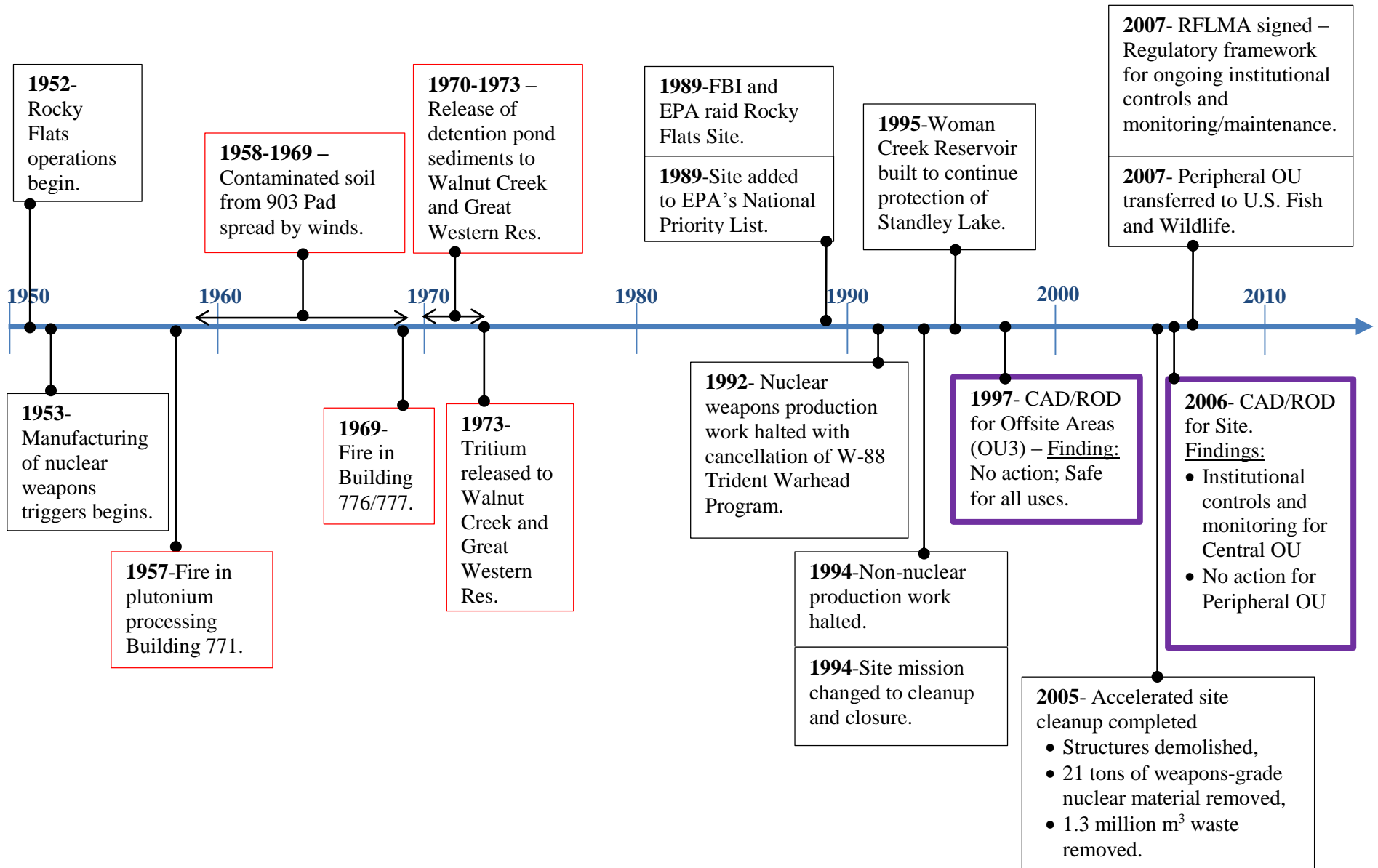


Figure 2. Timeline of Select Key Events at the Rocky Flats Site

2 Human Health Risks in Offsite Areas (OU3)

As noted in Section 1, a CAD/ROD was issued for Offsite Areas (OU3) in 1997 (EPA, 1997), concluding no remedial actions were needed offsite. The no action finding was based on the finding that all offsite areas were already in a condition acceptable for all uses without restriction and in a state protective of human health and the environment. The CAD/ROD finding was based on analysis of previous assessments and data collected for the Resource Conservation and Recovery Act Facility Investigation/Remedial Investigation Report (RFI/RI; DOE, 1996), including the risk assessment within that document.

In the 1996 RFI/RI, OU3 was defined simply as offsite areas; however, the investigation focused on 38 square miles north, south, and primarily east (down-gradient and downwind) of Rocky Flats. Within this area, four Individual Hazardous Substance Sites (IHSSs) were identified. IHSSs are locations where a release of contamination into the environment is believed to have occurred and investigations are focused. The four OU3 IHSSs are Great Western Reservoir (IHSS 200), Standley Lake (IHSS 201), Mower Reservoir (IHSS 202), and surrounding surficial soils (IHSS 199). The following subsections summarize finding for surface soils, groundwater and subsurface soils, air, sediment, and surface water in offsite areas, including key studies conducted subsequent to the 1997 CAD/ROD. These subsections are followed by a short discussion of key epidemiological studies. The discussions focus on plutonium-239,240 and americium-241¹, since these are the most prevalent transuranic contaminants in the soil at Rocky Flats (Litaor et al., 1994) and the subject of most of the OU3 investigative work.

2.1 Surface Soils in OU3

Surface soil contamination beyond the boundary of the Rocky Flats site exists due to eolian (windborne) transport from the site and subsequent deposition. Soil contamination from the 903 Pad is known to have been spread by winds. The 903 Pad site was used for storage of plutonium-contaminated lathe coolant in 55-gallon drums from 1958 to 1969. The drums corroded and leaked their contents onto the soils. The contaminated soils were then eroded by the wind and transported to the eastern side of the site and beyond. Additionally, radionuclides may have been transported by air during the fires of 1957 and 1969; however, data suggest that the primary source of offsite surface soil contamination is the 903 Pad (Krey and Hardy, 1970; CHEMRISK, 1994; Litaor et al., 1995).

An early attempt to characterize and contour offsite surface soils contaminated by radionuclides was conducted by Krey and Hardy (1970). With a total of 33 observation locations, Krey and Hardy (1970) generated a contour map of plutonium in surface soils extending over a large area, with concentrations above background extending into the cities of Arvada and Denver. Krey (1976) produced a second contour map using even fewer samples (22) taken as far as 60 km north

¹ The half-life of plutonium-239 is 24,100 years. The half life of plutonium-240 is 6,560 years. The half-life of plutonium -241 is 14.4 years. Americium-241 is a decay product of plutonium -241, and it has a half-life of 433 years. Plutonium -239,240 and americium-241 are primarily alpha emitters.

and southeast of the site. The goal of this second contouring effort by Krey was to identify plutonium attributable directly to Rocky Flats, as opposed to that from global fallout from nuclear testing. These contours were the basis for the cancer-incidence assessment for the Denver area, generated by Johnson (1981) that caused a great deal of public concern and was the subject of scientific scrutiny (discussed further in Section 2.6).

Subsequent analysis by Litaor et al. (1995) demonstrated with a much larger comprehensive dataset and more advanced analysis techniques that the Krey and Hardy (1970) and Krey (1976) contour maps were not reliable. Specific issues noted were the small dataset and poorly-spaced sample locations (Litaor et al., 1995). Soil activity contours for plutonium, using roughly 750 data points, are presented in Figure 3.

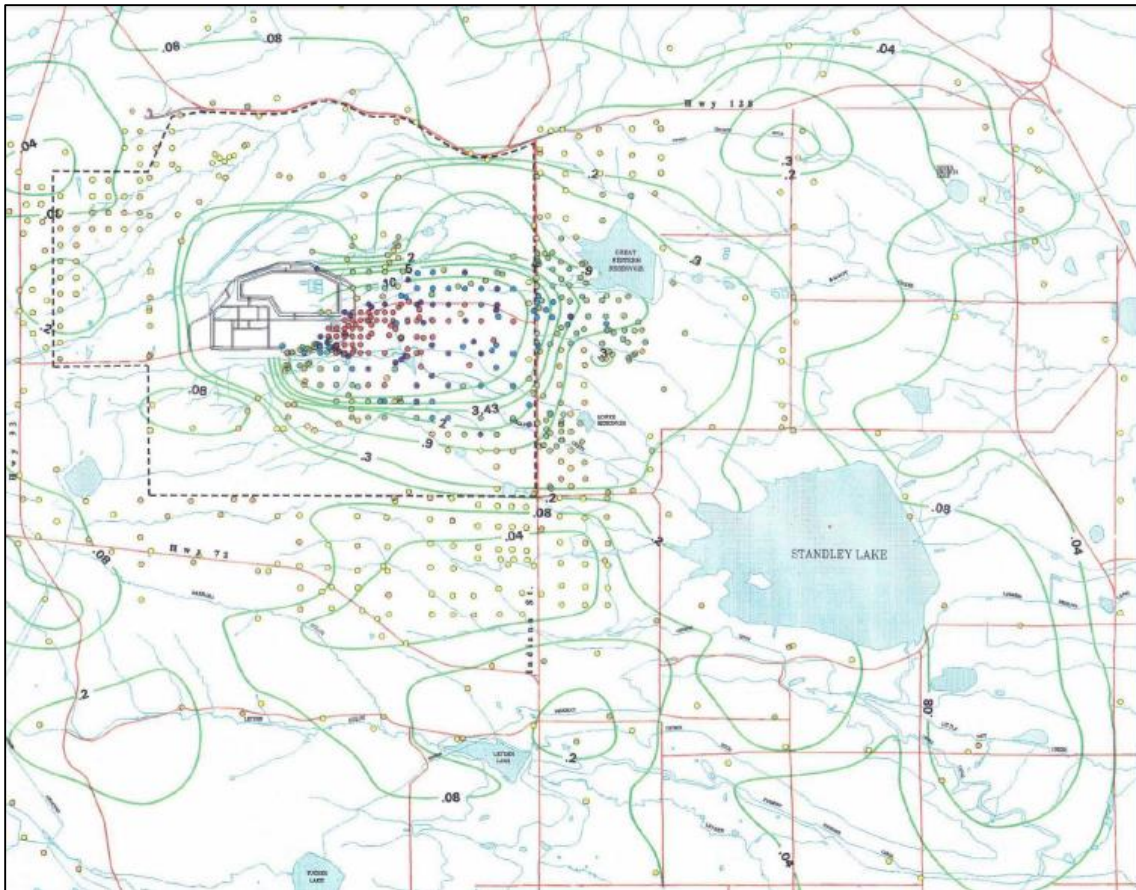


Figure 3. Iso-Contours of Plutonium-239,240 (all pCi/g) in Surface Soils (Image from DOE [1996])

Assuming a background value of 0.09 pCi/g (based on background developed from Rock Creek data [DOE, 1996]), the contour plot in Figure 3 shows surface soil concentrations above this background value to be present over an area extending two to three miles east of the site. This is a much smaller area than that identified by Krey and Hardy (1970) or Krey (1976). The distribution patterns, combined with comparison to sediment patterns in drainages, support the expected mechanism of contaminant transport – transport by wind primarily originating from soil contamination at the 903 Pad (Litaor et al. 1995).

The same analysis was conducted for americium-241 for the RFI/RI (Litaor and Allen, 1995). Conclusions about transport mechanisms matched those found for plutonium. The RFI-RI assumed a background value for americium-241 of 0.04 pCi/g (based on background developed from Rock Creek data [DOE, 1996]). The contour plot in Figure 4 shows surface soil concentrations above this background value cover a similarly-shaped but slightly smaller area than above-background concentrations for plutonium in surface soils.

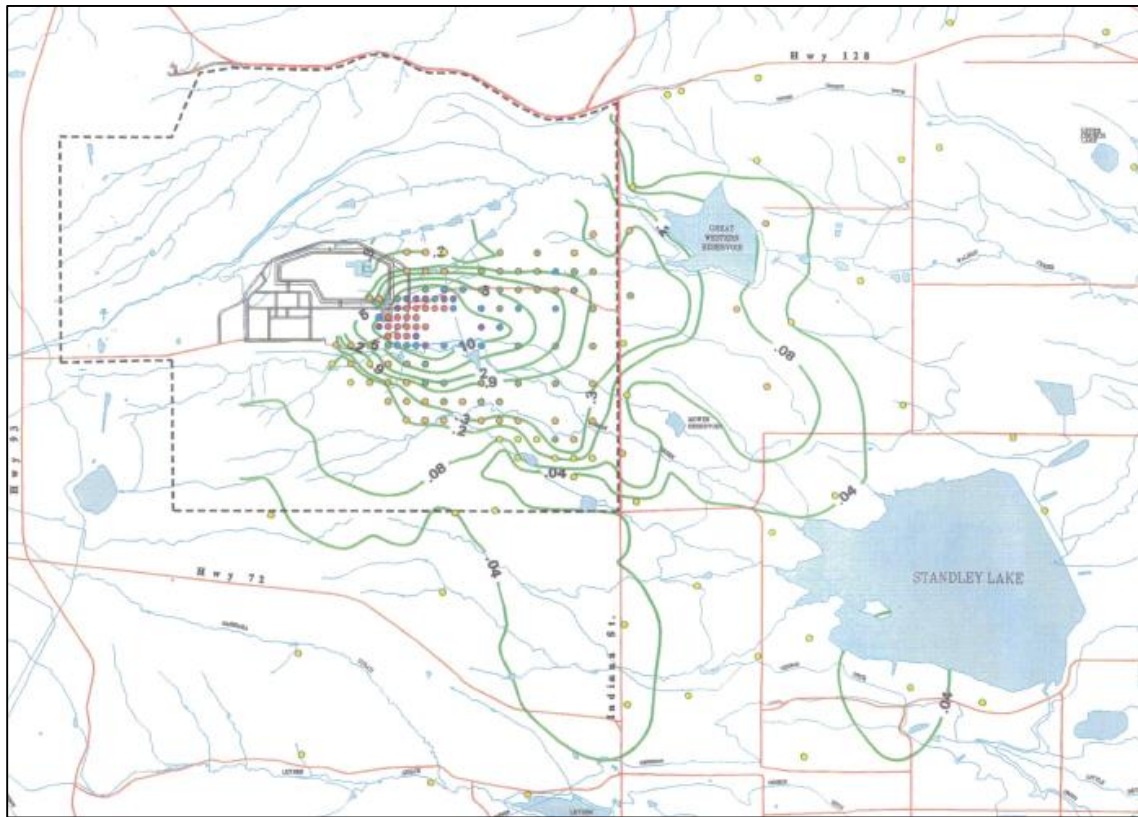


Figure 4. Iso-Contours of Americium-241 (all pCi/g) in Surface Soils (Image from DOE [1996])

The maximum concentrations of plutonium-239,240 and americium-241 in OU3 reported in the RFI/RI were 6.5 pCi/g and 0.5 pCi/g, respectively. These samples were both located near the Rocky Flats site eastern boundary. The arithmetic mean activities of plutonium-239,240 and americium-241 in OU3 were 0.035 pCi/g and 0.16 pCi/g.

A subsequent sampling of surface soils in OU3 was conducted by concerned citizens skeptical of results presented by DOE (CDPHE, 1996). CDPHE created and supported the Citizen Environmental Sampling Committee in 1992. Leaders from public interest groups, neighborhood associations near Rocky Flats, county health departments, and concerned individuals were invited to join the committee. The group created and implemented a sampling plan including selection of 60 sampling locations, sampling methods, and the laboratory for analysis of results. This provided an opportunity for these concerned people to test theories in the public debate about transport pathways. For example, a local meteorologist hypothesized that small particles of plutonium might have followed air flow patterns many miles north along the South Platte River, so sampling sites were included in that area (Lockhart et al., 1998). Sampling was conducted in 1994. Soil and sediment sampling results agreed with results presented in the RFI/RI for OU3

(CDPHE, 1996; Lockhart et al., 1998; Margulies et al., 2004). Likewise, recent (2011) sampling results collected along Indiana St., under funding from the Rocky Mountain Peace and Justice Center, exhibit concentrations of plutonium that are lower than or within corresponding contours on Figure 3 (Moore, 2012). It should be noted, however, that information on quality control, analytical methods, or sampling method for these data were not readily available.

For additional perspective in reviewing Figure 3 and Figure 4, the risk screening levels for soils for OU3 were calculated to be 3.43 pCi/g and 2.37 pCi/g for plutonium-239,240 and americium-241, respectively (DOE, 1996, Appendix A). These values are conservatively calculated thresholds representing an increased cancer risk of one in one million for residential exposure. This means that the value represents a concentration that could result in a one in one million increased chance of getting cancer if one lived on a plot of soil with this activity level, considering potential exposure by inhalation, ingestion, and external exposure. Screening levels are used to screen data to assess the need for more detailed risk calculations. For americium-241 all OU3 contours are below the corresponding risk screening threshold. For plutonium-239,240, there is a small area directly east of the site that falls within the 3.43 pCi/g contour. This area is centered on the eastern site boundary and extends a few hundred yards to the east. For this reason, plutonium-239,240 in surface soils in OU3 was further assessed in the Human Health Risk Assessment (HHRA; DOE 1996, Appendix A).

As part of the HHRA, conservative estimates of exposure and risk were calculated for surface soil contamination in OU3 (DOE, 1996, Appendix A). No one currently lives in the small area due east of the site with the highest surface soil contamination in OU3, but DOE calculated conservative radiation exposure doses that a hypothetical resident living in that area would experience. The calculation assumed all surrounding soils were at a value equal the 95% upper confidence limit (UCL) of the observed surface soil data, an estimation of reasonable maximum exposure used for human health risk assessments. For plutonium-239,240, the 95% UCL was 3.27 pCi/g, and for americium-241 it was 0.52 pCi/g. The calculations included exposures by soil ingestion, inhalation, external radiation from the soil, and ingestion of vegetables, milk, and meat raised and grown on the same soil. This scenario was designed to conservatively assess maximum potential exposure dose due to surface soil contamination in OU3 for the combined set of all of the exposure pathways just noted. The maximum annual dose was found to be for a child in this scenario. The corresponding maximum total effective dose was 0.14 millirem per year (mrem/yr; DOE, 1996 Appendix A).

This value of 0.14 mrem/yr is well below the Agency for Toxic Substances and Disease Registry's (ATSDR's) Minimum Risk Level of 100 mrem/yr and well below the reported national average annual exposure to ionizing radiation of 360 mrem/yr (ATSDR, 1999). For perspective, 0.14 mrem/yr can be compared to the following common exposures to ionizing radiation (sources: DOE, 2012 and Nuclear Regulatory Commission [NRC], 2014):

- One chest x-ray = 10 mrem
- Use of natural gas in the home = 9 mrem/yr
- One airplane flight of 2,000 miles = 1 mrem
- Mammogram = 30 mrem
- Smoking cigarettes = 15-20 mrem/yr
- Living at an elevation of 5,000 to 6,000 ft above sea level = 29 mrem/yr.

The reasonable maximum increased lifetime cancer risk for a resident living (inhalation, ingestion, external exposure, and mean, milk and vegetable consumption pathways included) on the plot of land with the highest observed surface soil concentrations was calculated to be 3×10^{-6} or three in one million (DOE, 1996). This is below the threshold EPA uses to define unacceptable increased lifetime cancer risk (1×10^{-4} to 1×10^{-6} , or between 1 in 10,000 and 1 in a million; EPA, 1990). Calculated risks for other soil source areas above background range from 1×10^{-6} (1 in one million) to 6×10^{-8} (six in 100 million). Risks based on recreational exposure are even lower. An independent review of the dose and risk calculations was conducted by the ATSDR. The ATSDR concurred with the approach and findings (ATSDR, 2005).

In summary, trace amounts of contamination by windblown plutonium and americium remain in surface soils in offsite areas east and southeast of the site. The primary original source of this contamination was leakage from drums at the 903 Pad on the Rocky Flats site. Extensive characterization and conservative assessments of potential risk have been conducted, and results show activity levels do not pose a public health concern.

2.2 Subsurface Soils and Groundwater

There is no known direct pathway for plutonium and americium from the Rocky Flats site to contaminate subsurface soils in OU3 or groundwater in OU3. A ten-year study was conducted by the Actinide Migration Evaluation (AME), a group of subject experts convened to determine relevant transport mechanisms for radionuclides, to help guide the cleanup and closure of Rocky Flats. This group found that plutonium and americium form insoluble oxides and colloids that sorb to small organic and mineral particles in the environment. Therefore, dissolution in water and subsequent transport from surface soils to subsurface soils or groundwater is not a viable migration pathway (Clark et al., 2006).

To investigate subsurface soils in OU3, eleven trenches were excavated as part of the investigation for the RFI/RI (DOE, 1996). Samples were collected at 3 cm intervals to a depth of 96 cm in each trench to evaluate any vertical migration of plutonium and americium in soils. As expected, plutonium and americium activities were at or below background below a depth of 10 cm in all trenches. Litaor (1994, 1995) evaluated data from trench sampling in OU3 and concluded that, with more than 90% of the contamination present in the upper 12 cm of the soil in all soil types, little downward migration had occurred within offsite soils over the preceding 25 years, though it was speculated that earthworms could cause some redistribution. This finding is consistent with the subsequent findings of the AME (Clark et al., 2006).

Groundwater data from the site, including data from the site's eastern boundary were evaluated for the OU3 RFI/RI and show no indication of groundwater transport of plutonium and americium. This finding is consistent with the subsequent findings of the AME (Clark et al., 2006). Two groundwater wells were installed down-gradient of Great Western Reservoir and Standley Lake during the OU3 field investigation. The wells were sampled eight times in 1993 to see if there was any migration of plutonium and americium contamination from sediments in those two water bodies. Results show no indication that plutonium and americium are migrating from reservoir sediments (DOE, 1996). An external review of groundwater data was conducted by the ATSDR, which concurred with the OU3 RFI/RI finding of no offsite groundwater

contamination or groundwater-related public health hazard due to the Rocky Flats site (ATSDR, 2005).

In summary, there is no indication of plutonium or americium contamination of subsurface soils or groundwater in offsite areas (OU3). This finding is consistent with the understanding of relevant transport mechanisms for plutonium and americium (Clark et al., 2006).

2.3 Air

Contamination of air can occur when winds erode and suspend surface particulate material containing plutonium-239,240 and americium-241, resulting in an inhalation risk. Air contamination was evaluated by air sampling in OU3 (DOE, 1996). Air sampling data in OU3 consists of 10 years of Radioactive Ambient Air Monitoring Program (RAAMP) sampler data (roughly ten years of record) and ultra-high-volume sampler data beginning in 1995. Three ultra-high-volume air samplers were installed in OU3 in 1995 to improve resolution of results from the RAAMP sampler data. Because of the low concentrations of plutonium and americium in the air, the RAAMP samplers produced results with poor resolution (reported uncertainty exceeded the sampling result values in OU3 samples [DOE, 1996]).

The ultra-high-volume air samplers were located southeast of Standley Lake (SW corner of 86th Avenue and Kipling St.), northwest of Standley Lake (100th Ave.), and southwest of Standley Lake (north of 88th St.). These locations were selected to represent air quality encountered by residents and recreational users. Results reported in the RFI/RI exhibit very low concentrations (average plutonium-239,240 = 1.9×10^{-8} pCi/m³; average americium-241 = 4.9×10^{-8} pCi/m³).

External review of air quality results by the ATSDR (ATSDR, 2005) produced the following statement:

Since 1989 all three radionuclides [plutonium, americium, and uranium] have never been measured at concentrations greater than their health-based comparison values. In fact, americium, plutonium, and uranium concentrations have consistently been several orders of magnitude below levels of health concern...Overall, ambient-air monitoring data collected since 1989 quite clearly indicate that the air near RFETS [Rocky Flats site] has been safe to breathe.

In summary, air data, including high resolution, ultra-high-volume sampler data show no concentrations approach levels of potential health concerns for inhalation of plutonium or americium.

2.4 Sediments – Standley Lake, Great Western Reservoir, and Mower Reservoir

Contamination of sediments in OU3 by plutonium and americium from Rocky Flats is expected to have occurred by one or two mechanisms, depending on the location. First, windblown contamination affecting surface soils is also expected to have impacted sediments. As was the case for surface soil contamination, the key original source of this contamination is expected to be the 903 Pad, with a primary window of deposition from 1958 to 1969. Second, transport of suspended particulate material in surface water and subsequent settling is also expected to have

caused sediment contamination. This second mechanism is primarily expected to have impacted Great Western Reservoir due to release of sediments to Walnut Creek during “re-engineering” work in drainages at the Rocky Flats site between 1970 and 1973 (DOE, 1996).

There have been several investigations of sediment contamination by plutonium and americium in the water bodies down-gradient from Rocky Flats (Standley Lake and Great Western Reservoir, and the much smaller Mower Reservoir). In most cases, plutonium-239,240 and americium-241 exhibited prominent concentration peaks at the same depth (USGS, 1995), with more plutonium-239,240 than americium-241. The following summarizes major investigations, including notes on the patterns in plutonium-239,240:

- **1970 and 1973, Sediment Grabs in Standley Lake-** The EPA collected sediment grab samples for plutonium-239,240 from the bottom of Standley Lake. Core samples were not collected at this time, but the surface sediment grab sampling results showed concentrations to be close to background levels attributed to atmospheric fallout from global nuclear testing. Results were less than or equal to 0.1 pCi/g (as reported in USGS [1995] from EPA, 1973, 1975).
- **1974, Sediment Cores from Standley Lake and Great Western Reservoir-** Battelle Laboratory collected sediment core samples from Standley Lake and Great Western Reservoir in 1974. The maximum concentration for plutonium-239,240 in a core from Standley Lake was 0.39 pCi/g, and the maximum in Great Western Reservoir was 6.09 pCi/g (as reported in USGS [1995] from Thomas and Robertson, 1981).
- **1983 and 1984, Sediment Grab and Core Samples from Standley Lake and Great Western Reservoir-** A total of 114 grab and core samples were collected from Great Western Reservoir and Standley Lake by Rockwell International in 1983 and 1984, respectively. The maximum concentration from Standley Lake sediment sediments from this sampling event were 0.61 pCi/g for plutonium -239,240 from cores. The maximum concentration from Great Western Reservoir from this sampling event were 4.5 pCi/g for plutonium -239,240 from cores (as reported in USGS [1995] from Setlock, 1983 and Setlock and Paracio, 1984). These maximum values are similar in range to values found in the 1974 core sampling.
- **1992, Sediment Grab and Core Samples from Standley Lake, Great Western Reservoir, and Mower Reservoir-** As part of the OU3 RFI/RI investigation, the USGS collected a total of 94 reservoir sediment samples (36 from Great Western Reservoir, 43 from Standley Lake, and 15 from Mower Reservoir), including two cores in Great Western and Standley Lake that were purposefully collocated with 1983/1984 sampling locations for comparison (USGS, 1995). The maximum reported plutonium-239,240 concentration in core samples in Standley Lake was 0.38 pCi/g. In Great Western Reservoir the maximum plutonium was 4.03 pCi/g. These concentrations compare well with previous sampling results.

Sediments in nearshore areas around Standley Lake and Great Western Reservoir were found to be at or near background levels in 1992 sampling for both plutonium and americium. Results for plutonium are presented in Figure 5 and Figure 6. This finding makes sense in terms of typical sediment migration patterns within typically-low-energy lakes and reservoirs. Specifically, sediment in shallower areas can be subject to resuspension and resorting of fine-grained materials through wave action and other mechanical shoreline disturbances. In contrast undisturbed sediments, typically in deeper areas in lakes and reservoirs, can serve as a stratigraphic record of conservative contaminants.

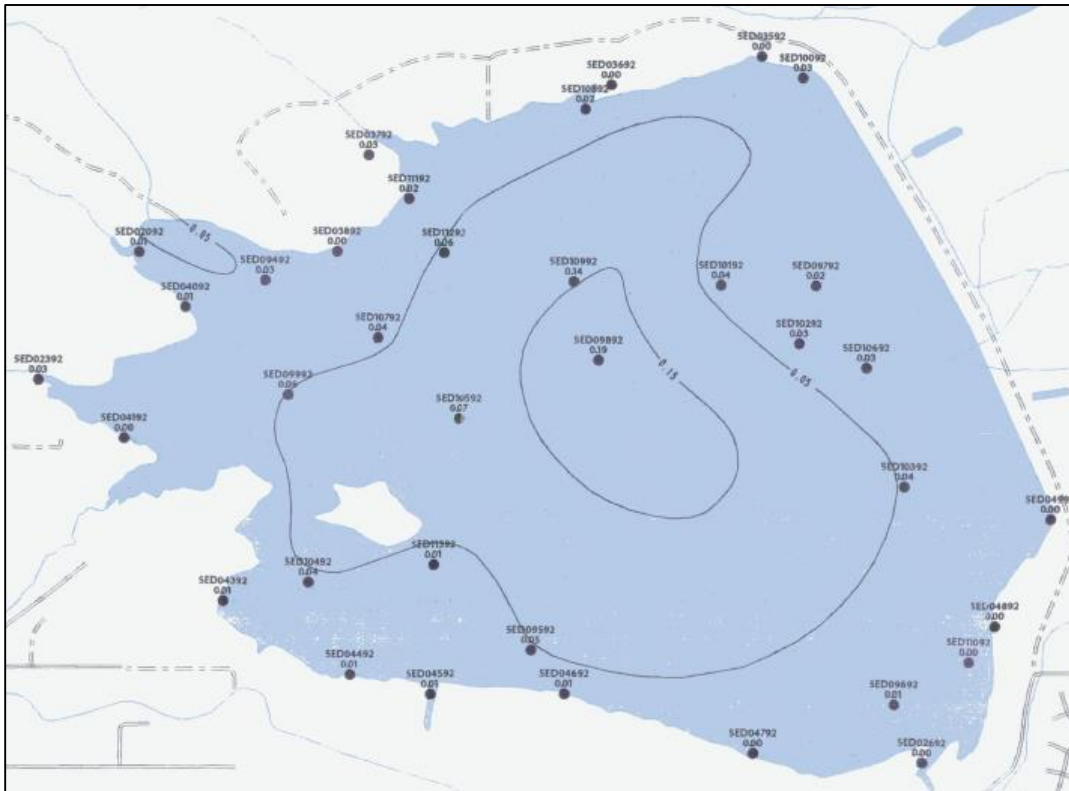


Figure 5. Plutonium-239,240 Iso-Contours from 1984 and 1992 Standley Lake Sediment Grab Sampling (Surface Sediment Concentrations; all pCi/g); Image from DOE (1996)

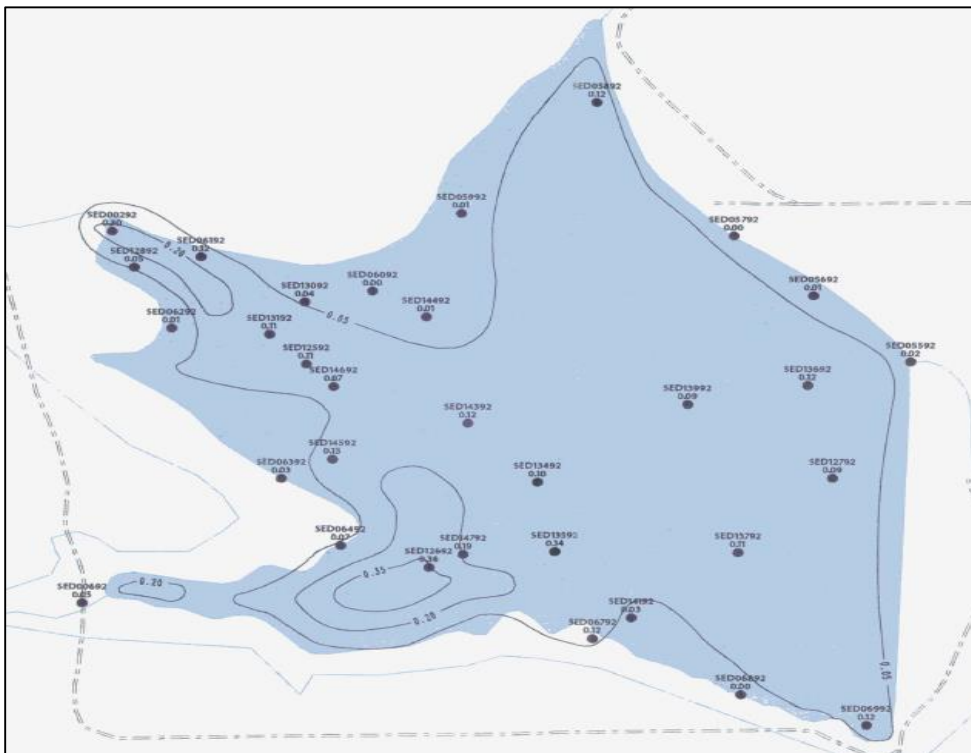


Figure 6. Plutonium-239,240 Iso-Contours from 1983 and 1992 Great Western Reservoir Sediment Grab Sampling (Surface Sediment Concentrations; all pCi/g); Image from DOE (1996)

Maximum plutonium and americium activities found in sediment in each water body are presented in Table 1, along with depth below the sediment surface for the corresponding observation. Results show that sediment contamination, likely from the 1960's to early 1970's, is buried under 16 to 30 inches of sediment in Standley Lake and Great Western Reservoir. Because plutonium-239,240 and americium-241 do not migrate in soluble forms (Clark et al., 2006), there is no anticipated mechanism for exposure to these buried sediments. This is supported by the results of comparison of the collocated cores from 1983/1984 to those collected in 1992, which show relatively consistent results for the two sampling events roughly ten years apart (USGS, 1995).

Table 1. Maximum Plutonium-239,240 and Americium-241 Concentrations in Subsurface Sediment from 1992 Sampling Event, Presented with Corresponding Sediment Depth

Reservoir	Max Pu-239,240 in Sediment Core Subsample (pCi/g)	Depth Below Sediment Surface	Max Am-241 in Sediment Core Subsample (pCi/g)	Depth Below Sediment Surface
Standley Lake	0.38	16-18 inches	0.10	30-32 inches
Great Western Reservoir	4.03	18-20 inches	1.02	26-28 inches
Mower Reservoir	1.11	4-6 inches	0.17	4-6 inches

Considering risk-based screening concentrations from the soil analysis (2.37 pCi/g for americium-241 and 3.43 pCi/g for plutonium-239,240; see discussion in Section 2.1), only sediments from Great Western Reservoir were retained for risk assessment. Risk was assessed under the hypothetical scenario that Great Western Reservoir would be drained in the future and used for recreation or residential use. Risk calculations show that this residential scenario corresponds to an increased lifetime cancer risk of 9×10^{-7} , or nine in ten million, which is less than 1 on one million (DOE, 1996, Appendix A). An external review of surface and subsurface sediment data was conducted by the ATSDR, which concurred with the OU3 RFI/RI finding of no public health hazard for residents or recreational users in OU3 (ATSDR, 2005).

In summary, trace amounts of plutonium and americium contamination from wind and, in some cases, historical inflows remain in Great Western Reservoir, Standley Lake, and Mower Reservoir. Sampling in the 1970's, 1980's, and 1990's show that the contamination is present at low levels in buried sediments. Sampling results also show that contamination is not migrating into the lake water (see Section 2.5) or into the groundwater (see Section 2.2). Shoreline sediments show concentrations comparable to background concentrations attributable to global fallout from nuclear testing, and do not pose a public health hazard to residents or recreational users. Even under the hypothetical event of draining of Great Western Reservoir (the reservoir where the highest sediment contamination concentrations were observed) and conversion of the bottom of the reservoir to residential use, existing activity levels would not pose a public health concern.

2.5 Surface Water

As part of the OU3 investigation, DOE and the USGS sampled surface water, including water in Standley Lake, Great Western Reservoir, and Mower Reservoir for plutonium-239,240 and

americium-241 in 1992 (DOE, 1996 and USGS, 1995). A total of 53 surface water samples were collected at 33 locations in OU3. 29 of those locations were in the reservoirs. Samples locations in Standley Lake, Great Western Reservoir, and Mower Reservoir are shown in Figure 7. Sampling included collection of samples from 1 to 1.5 ft above the bottom of the reservoir at each location. Near-bottom samples were collected to see if contamination from sediment was affecting water quality. Additionally, sampling was conducted in September, at a time when seasonal anoxic conditions were present at the bottom of Standley Lake. Such reducing conditions can mobilize some metals from sediments, so sampling under these conditions was targeted.

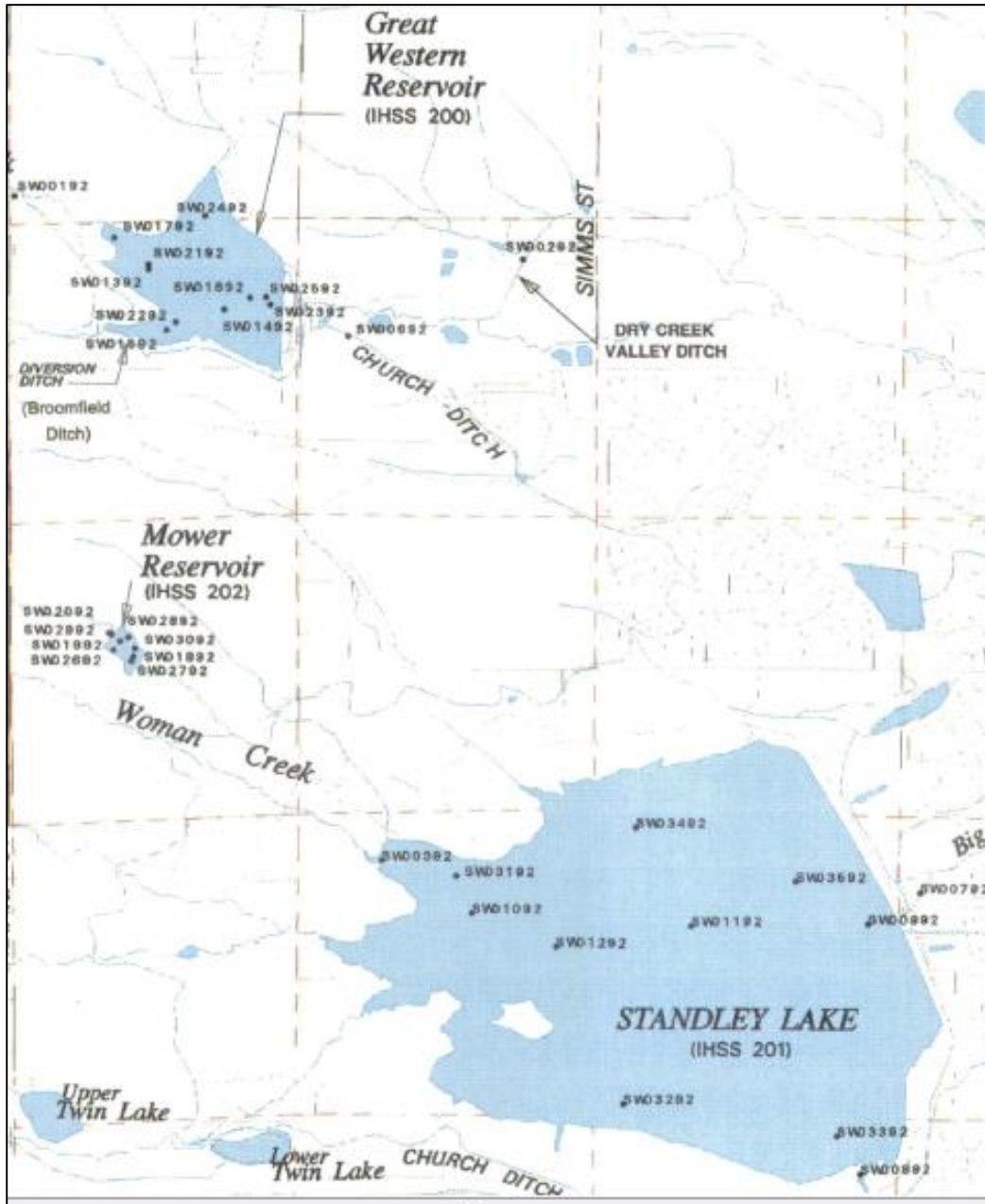


Figure 7. 1992 Surface Water Sampling Locations in Standley Lake, Great Western Reservoir, and Mower Reservoir; Image from DOE (1996)

Surface water sampling results from all three reservoirs exhibited very low concentrations of plutonium and americium. Mean and average results from all samples are summarized in Table 2. DOE (1996) reported that results were at or below background concentrations, and there was no indication of contamination of surface water by low concentrations present in buried sediments. This finding is consistent with the findings from the sediment investigations (Section 2.4) and groundwater investigation (Section 2.2), as well as the understanding of fate and transport mechanisms developed by the AME (Clark et al., 2006).

Table 2. Maximum and Average Plutonium-239,240 and Americium-241 Concentrations in Total (Unfiltered) Surface Water from 1992 Sampling Event (USGS, 1995)

<i>Reservoir</i>	<i>Plutonium-239,240</i>		<i>Americium-241</i>	
	Maximum (pCi/L)	Average (pCi/L)	Maximum (pCi/L)	Average (pCi/L)
Standley Lake	0.009	0.003	0.026	0.007
Great Western Reservoir	0.005	0.003	0.017	0.006
Mower Reservoir	0.030	0.005	0.017	0.006

In Standley Lake, the only current drinking water source among the three reservoirs, the maximum plutonium-239,240 concentration was 0.009 pCi/L, and the maximum americium-241 concentration was 0.026 pCi/L. These values combined are more than two orders of magnitude below the CDPHE and National Drinking Water standard for gross alpha (15 pCi/L). These values are also below the much stricter and protective site-specific standards in place for Standley Lake (0.03 pCi/L for Pu-239,240 and 0.03 pCi/L for Am-241; CDPHE, 2014).

Additionally, lake water is routinely sampled for gross alpha by the City of Westminster, and no issues have been observed. As an additional precaution, water from the Rocky Flats site has been diverted around Standley Lake since the 1980's, at first by engineered passive diversion to Church Ditch (D. Strietelmeier, personal communication, 2014), then by pumping from Woman Creek Reservoir to Walnut Creek, since construction of Woman Creek Reservoir in 1995.

In summary, sampling results show no indication of significant contamination of surface water in any of the three reservoirs by plutonium-239,240 or americium-241. Observed surface water concentrations for plutonium-239,240 and americium-241 are more than two orders of magnitude below National Drinking Water standards for gross alpha (there are no National Drinking Water Standards specific to plutonium-239,240 and americium-241, both of which are primarily gross alpha emitters). Results also show no indication of migration of low-levels of buried sediment contamination into surface waters. Further, highly conservative and protective site-specific standards for plutonium-239,240, americium-241, and gross alpha are in place for Standley Lake. Finally, runoff from the Rocky Flats site does not flow into Standley Lake; instead it is diverted north to Walnut Creek. In short, data indicate that Standley Lake is a safe source of raw water, in terms of contaminant concerns from Rocky Flats, for treatment and distribution as drinking water.

2.6 Epidemiological Studies

Epidemiological studies have been conducted to assess whether there is evidence of increased cancer incidence among communities surrounding Rocky Flats, presumably due to exposures to

contaminants from Rocky Flats. In 1981, Johnson published a study of trends in cancer diagnoses between 1969 and 1971 in four areas near Rocky Flats. These areas were defined based on the Krey and Hardy (1970) soil plutonium concentration contours, which were subsequently refuted due to limited data. Johnson (1981) found that overall cancer incidence in the areas closest to Rocky Flats were higher for both men and women. Subsequent studies disputed this finding.

Subsequent studies disputing the Johnson (1981) study include Crump et al. (1987). Crump et al. (1987) reanalyzed the data and did not find an increase in the likelihood of developing cancer due to living in OU3 near Rocky Flats. Crump et al. (1987) found that distance from downtown Denver was strongly correlated with cancer incidence, and explained the different results by pointing out that Johnson (1981) failed to consider confounding urban factors in design of his earlier study. Colorado Central Cancer Registry (CCCR) also conducted a study to see if cancer incidence was related to distance from Rocky Flats. CCCR (1998) used data from 1980 to 1989 and concluded that its data “show that communities in the general vicinity of Rocky Flats has cancer incidence during 1980-1989 that was comparable to the remainder of the Denver Metro Area”.

In summary, recent epidemiological studies have not shown a definitive link between cancer incidence and proximity of populations to Rocky Flats. There is generally significant uncertainty associated with epidemiological studies; however, the finding agrees with estimations of risk based on soil, air, and water characterization results discussed above.

3 Summary and Recommendations

In 1997, while clean-up and closure work continued at the Rocky Flats site, a Corrective Action Decision/Record of Decision (CAD/ROD) was issued for Offsite Areas (DOE, 1997). Based on the investigation results and risk assessment, the CAD/ROD found risks to be lower than minimum thresholds set by EPA and CDPHE and concluded that the appropriate remedial action for Offsite Areas was no action (DOE, 1996 and EPA, 1997). Calculated maximum increased lifetime cancer risks ranged from 3×10^{-6} (three in one million) to 6×10^{-8} (six in 100 million). Risks based on recreational exposure were even lower. These findings were supported by an external review of available data conducted by ATSDR (ATSDR, 2005). The investigation evaluated surface soils, subsurface soils, groundwater, air, sediments, and surface water in offsite areas (OU3). The offsite area of focus for the OU3 investigation was approximately 38 square miles of land and surface water east and southeast of the site.

Relevant major studies were reviewed to gain an understanding of current human health risks in OU3 from plutonium-239,240 and americium-241 originating from Rocky Flats. For each medium noted above, findings for plutonium-239,240 and americium-241 are as follows:

Surface Soils

- Trace contamination by plutonium-239,240 and americium-241 (above background nuclear fallout levels) exists in surface soils east and southeast of the site
- This contamination is due primarily to the spread of soil contamination from the 903 Pad on the Rocky Flats site prior to 1970.

- The highest offsite surface soil concentrations of plutonium-239,240 and americium-241 are due east of the Rocky Flats site boundary, within a few hundred yards of Indiana St.
- General magnitudes and distribution patterns of plutonium-239,240 and americium-241 in surface soils have been confirmed by subsequent sampling by entities unassociated with DOE.
- A conservative assessment of risk due to surface soil contamination in these areas showed a maximum increased lifetime risk, for living on a plot with the highest observed soil concentrations, of getting cancer of three in a million.
 - This scenario assumed future residential use, including children, of the currently uninhabited land with the highest concentrations.
 - The scenario also assumed inhalation, ingestion, external radiation exposure, consumption of vegetables grown in the soil, and consumption milk and meat raised at the same location.

Subsurface Soils and Groundwater

- There is no indication of contamination of subsurface soils or groundwater from plutonium-239,240 and americium-241 from the Rocky Flats site.
- This finding is based on onsite and offsite observations of groundwater and subsurface soils.
- This finding is in agreement with the scientific understanding² of fate and transport mechanisms for plutonium-239,240 and americium-241.

Air

- Air concentration data, including ultra-high-volume air sampler data collected at three locations around Standley Lake, show no concentrations of plutonium-239,240 or americium-241 approaching levels of public health concern.
- Per ATSDR (2005), “Ambient-air monitoring data collected since 1989 quite clearly indicate that the air near RFETS [Rocky Flats] has been safe to breathe.”

Sediments

- Surface and subsurface sediment have been sampled several times in Standley Lake and Great Western Reservoir (1970s, 1980’s, and 1990’s) and once in Mower Reservoir (1990’s).
- Results show that low levels of plutonium-239,240 and americium-241 contamination are present in buried sediments in all three water bodies.

² Plutonium-239,240 and americium-241 form insoluble compounds are not subject to dissolved transport by water (Clark et al., 2006).

- The buried contamination is likely from windblown contamination from the 903 Pad before 1970 and contaminated sediment transported through Walnut Creek to Great Western Reservoir in the early 1970's.
- Sampling results also show that contamination from buried sediments is not migrating into the surface water or groundwater, matching the scientific understanding of how plutonium-239,240 and americium-241 can move in the environment.
- Risk calculations show that even if reservoirs were drained and converted to recreational or residential use, existing sediment contamination levels would pose no public health threat.
- Shoreline sediments are at concentrations similar to background concentrations for plutonium-239,240 and americium-241.

Surface Water

- Surface water was sampled at 29 locations in Standley Lake, Great Western Reservoir, and Mower Reservoir in 1992 for plutonium-239,240 and americium-241 as part of the OU3 characterization.
- Results showed no apparent contamination of surface water in these reservoirs by plutonium-239,240 and americium-241. Sampling results were all at or below background concentrations and well below minimum risk thresholds.
- Results showed no migration of contamination from buried sediment to surface water. Sampling included near-bottom sampling during stratified conditions in Standley Lake.
- The City of Westminster routinely samples water from Standley Lake for gross alpha contamination (both plutonium-239,240 and americium-241 are primarily gross alpha emitters).
- Standley Lake is subject to highly conservative and protective standards for plutonium-239,240, americium-241, and gross alpha contamination.
- Runoff from Rocky Flats does not enter Standley Lake. This water has been diverted away from Standley Lake since the 1980's. Since 1995, the Woman Creek Reservoir has been in place, just upstream of Standley Lake and downstream of Rocky Flats, diverting water from Rocky Flats around Standley Lake, via Walnut Creek.
- Data indicate that Standley Lake is a safe source of raw water, in terms of contamination concerns related to Rocky Flats, for treatment and distribution as drinking water.

Several epidemiological studies have been conducted to assess whether there is evidence of increased cancer incidence among communities surrounding Rocky Flats, presumably due to exposures to contaminants from Rocky Flats. An early study (Johnson, 1981) reported a link; however, subsequent studies challenged this result and the methods used. More recent epidemiological studies do not show a definitive link between cancer incidence and proximity of populations to Rocky Flats. This finding agrees with the RFI/RI estimations of very low risk based on soil, air, and water characterization results.

In summary, extensive sampling results from soils, sediment, water, and air indicate that trace amounts of plutonium-239,240 and americium-241 present in surface soils and buried sediments in OU3 from previous Rocky Flats releases do not pose a public health concern to those living in or recreating in this area. All conservatively-estimated risks are well below EPA significance thresholds, and the offsite areas are suitable for all uses, without restriction.

Based on the findings of this review, no additional sampling is recommended at this time. It may be prudent, largely in the interest of being responsive to public concern (as opposed to in anticipation of actual risk), to consider additional soil sampling prior to any major earthwork or dredging project.

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