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Field investigation and laboratory report for:

LeRoy Moore, Ph.D.
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Prepared by:

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Summary of Key Findings

This revised report includes additional plutonium data by PACE Analytical. Six of nine soil samples tested by a commercial laboratory found plutonium at 30, 36, 37, 126, 270, and 1,579 pCi/Kg. The soils contained Pu-238 or Pu-239/Pu-240 or both. In a 1992 to 1994 study, offsite soil levels were found at 30 pCi/Kg, (Ref. 3, p. 177). The Litaor (1999) study as cited in reference 3 found 5.9 to 400 pCi/Kg in 42 soil samples adjacent to the site. A 2005 USDOE study found that soil background total plutonium concentrations at a community distant from Hanford, WA averaged between 3 and 4 pCi/Kg, and that further study found that contaminated Columbia River sediments at the Hanford Nuclear Reservation had between 1.6 and 10 pCi/Kg of plutonium, (Ref. 3, p. 178).

In addition to the nine soil samples commercially tested for plutonium, a sample of tree bark from opposite the site on Indiana Street was found to contain 32 pCi/Kg plutonium as Pu-238. Soil from that same location had 37 pCi/Kg of Pu-238, which was above the uncertainty level, but below the MDC. A study of trees in France, (Garrec, 1995, Applied Radiation and Isotopes, ref. 1), found a maximum of 0.25 pCi/Kg of plutonium in tree rings.

All of the locations with positive detections of plutonium were on the eastern side of the Rocky Flats site, and were on the right of way paralleling Indiana Street.

Reference samples taken at greater distances from the site than any of the remaining study samples showed high levels of thorium and uranium. In fact, the highest levels, (6.56 pCi/g Th and 2.13 pCi/g U), were found in the buried near subsurface soils of an eroding bank at Eldorado Canyon State Park. The data does not show that the presence of these isotopes is caused by activities at Rocky Flats. In fact, the Jamestown district of Boulder County, Colorado has been known since 1945 as a region that contains thorium and uranium bearing rare earth mineralizations. Total uranium and total thorium were therefore not usable as indicators of contamination from the Rocky Flats site.

This left plutonium as the sole radioactive element used as an indicator of contamination from the Rocky Flats site. However any individual uranium and thorium bearing particles that are found to be definitively anthropogenic in origin by SEM/EDS remain candidate indicators of contamination from the Rocky Flats site. The study samples with high total counts were found to contain thorium as the primary radioactive isotope, based on sodium iodide gamma spectrometry.

Trace levels of cesium-134 and cesium-137 were found in two offsite soil samples. Given the two-year half life of cesium-134, it is unlikely that the material related to this low level detection originated at Rocky Flats. While other sources, (USEPA Radnet data, 2011, and U. Calif. Berkeley, Dept. of Nuclear Engineering, 2011), have detected these isotopes in the US, presumably as a result of the Fukushima releases, this is beyond the scope of this study.

The SEM/EDS analyses by Microvision Laboratories were completed on January 17, 2012. This analysis determines the elemental composition and size of individual microscopic particles. The particles are identified for analysis by the presence of high z nuclei that are viewed in real time on the instrument's video monitoring system. These analyses confirmed that monazites containing thorium, uranium, and rare earths were present in the samples. Silicates containing uranium and thorium were also detected. Many, but not all, of these particles were in the respirable size fraction of 0.5 to 5.0 microns.

Microvision also detected particles containing plutonium and lead in its analysis of dust samples collected due East of the Rocky Flats site during 2010. A subset of these particles from the 2010 series also contained traces of americium.

The presence of hot particles, (see note below), containing plutonium is consistent with the gross analytical findings of plutonium in fine sediments particles at the ground surface around the eastern border of the former Rocky Flats facility.

Note:

> Hot particles are particles that contain substantially more activity than surrounding inert materials. When these particles are in the 0.5 to 5.0 micron size range, they can present a significant inhalation hazard, which is substantially different from that imposed by purely external electromagnetic radiation such as X-rays and gamma rays.
>
> (References: See Kaltofen, 2011, Tracking radiological plumes from the Fukushima Daiichi accident, Oct. 31, 2011 presentation at 139th annual meeting of the APHA, Washington, DC, Kaltofen, 2010, *Microanalysis of Workplace Dusts from the Mixed Waste Tank Farm of the Hanford Nuclear Reservation*, J. Environmental Engineering Science, and Kaltofen, 2009, Master's Research Report, Worcester Polytechnic Institute, Microanalysis of Heterogeneous Radiation in Particulate Matter.)

Methods

2010 study: In 2010 a total of four samples, two dusts and two soils, were received for testing via microanalytical suite for radionuclides. Samples were prepped, screened by standard gross radiochemical analyses, and autoradiographed to determine the degree of total activity and the potential number of radioactively-hot particles.

Samples were tested via scanning electron microscopy with energy dispersive X-ray analysis, SEM/EDS, for individual microparticles. This method detects both stable and radioactive isotopes. The presence of definitively radioactive elements including U, Pu, and Th are noted in the individual results sections. Antimony and lead were also reported.

Based on the detected heavy element particles in sample RFCO001D, many of the heavier elements in this dust were fused or melted aerosol spherical shot particles. Many of the large particles showed signs of having multiple phases, fused together like cement or heat-fused grains. The ¼ to ½ um thickness of lead screening on many of these shot particles will obscure the photon returns on any transuranic elements (TRUs) if they are present inside an aggregate. Epoxy-fixing and polishing would expose any obscured TRUs, but this procedure was beyond the scope of this project.

2011 follow up study: Based on these results a field investigation was undertaken from September 13, 2011 to September 15, 2011. Forty-five samples were collected, including seven biological specimens and thirty-eight surface and shallow buried soils. Three of the soils were from reference locations presumed to be subject to reduced influence from the study site at Rocky Flats, yet still close enough to share similar soil parent material. One additional sample was collected of sediment from a watercourse west of Indiana on March 16, 2011. This sample was collected prior to recent ground disturbance by construction at this location.

At the close of the investigation, a total of fifty samples, including the four 2010 samples, had been collected to date. The 2011 samples included soils and plant materials. Soil samples were collected from the top 1 inch, or from 0.5 or 1.0 feet below the ground surface. Plant materials included lichens and bark from mature trees.

All 2011 samples were collected with full chain of custody protocols. Mapping is via Google Earth Pro, 2011 edition. Samples were air dried prior to analysis. Reference samples were collected from three sites, two east and one west of the Rocky Flats site.

Samples were air dried prior to any analyses to reduce self-absorption of any radiation. All samples were measured for total surface alpha, beta, and gamma activity using a Victoreen counter and a pancake probe. All samples were scanned using a Ludlum model 702 sodium iodide gamma spectrometer, with follow-up analyses using either an Ortech 3 inch sodium iodide gamma spectrometer or a liquid nitrogen cooled germanium lithium detector. All gamma detectors used lead/copper multi element shields of various sizes to reduce background gamma levels. Gamma emission lines at 46, 73 and 234 keV were used to monitor thorium and uranium concentrations.

The concentrations of plutonium were presumed to be at levels below those of the naturally occurring nuclides of thorium and uranium. Plutonium analyses were therefore performed commercially at PACE Analytical of Pennsylvania.

Samples were prepared for SEM/EDS analyses by sieving to pass a standard ASTM 150 micron brass screen, and mounted using double sided mounting tape onto aluminum stubs.

Figure 1a: Area map, 2011 Rocky Flats sample study

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Analytical methods and instruments

Preparation: Air-dried whole samples, except for SEM/EDS which is prepared by drying then sieving to pass a 150 um screen prior to mounting and analysis

Counting: Two channel Ludlum model 3030 alpha/beta counter

Counting: Victoreen rate meter with pancake detector.

Gamma Spectrometry: Ludlum 1 inch portable sodium iodide detector with single wall lead shield

Gamma Spectrometry: Ortech 3 inch sodium iodide gamma detector with Canberra multiwall shield

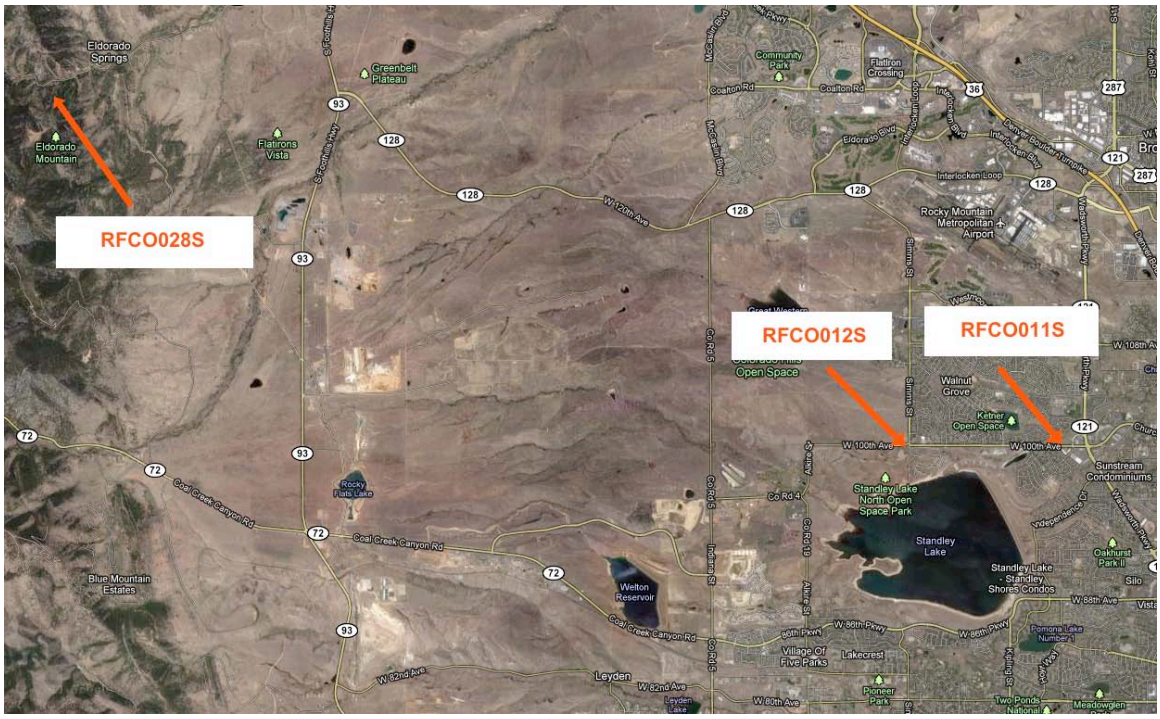
Gamma Spectrometry: LN_2 cooled germanium lithium gamma detector.

Gamma Spectrometry, commercial: PACE Analytical, Walter Miltz Laboratory, Pennsylvania, for uranium, thorium, and plutonium isotopic analysis.

SEM/EDS: Scanning electron microscopy / energy dispersive X-ray analysis at Microvision Laboratories of Chelmsford, Mass., using a LEO/Brucher system lithium-drifted silicon detector and high-z Robinson detector at 0.60 nAmperes and 0 to 60 keV acceleration voltage.

Calibration: Single element 5 nCi Am-241 metallic certified standard and multinuclide Eckert & Ziegler evaporated metallic salt 0.584 nCi standard source received on September 12, 2011 for Cd-109, Co-57, Ce-139, Hg-203, Sn-113, Sr-85, Cs-137, Y-88, and Co-60.

Figure 1b: Area map, location of reference samples



Results:

The total activity, measured as sodium iodide gamma counts per second, was measured for the set of three reference samples and randomly selected site fence line soil and biota samples. The mean and standard deviation of these results are below. Given that the offsite samples collected at a significant distance from Rocky Flats have higher gamma counts per second than the fence line samples, it's clear from the blank-corrected data below that total activity is not a reliable indicator of contamination from the Rocky Flats site.

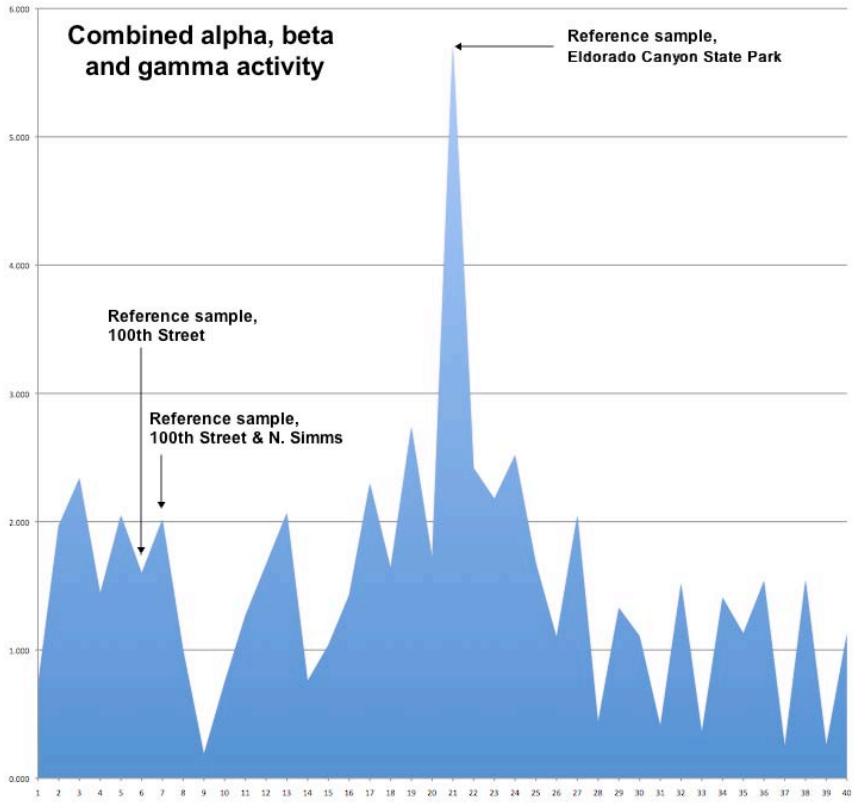
Reference samples: 3.9 gCPS with SD = 3.7

Biological samples: 0.2 gCPS with SD = 0.6

Fence line soils: 2.1 gCPS with SD = 1.6

Both the reference and fence line samples had gamma spectral lines, (73 keV and 234 keV), consistent with thorium. (See appendix) Some of the fence line samples also had a gamma spectral line at 46 keV, consistent with lead-210, a daughter isotope of nonfissile uranium-238. (See appendix)

Figure 2: Total activity in soil and plant material samples, 2011 Rocky Flats sample set



Seven samples of biological material, (lichen and bark from mature trees more than 6 inches ABH), were collected and analyzed along with the soils. Total activity in the biological samples was relatively low compared to both the reference soils and the fence line soils.

Gamma spectral peaks associated with uranium and thorium, (see previous page), were found in the soil samples. These were absent in the biological samples. This is confirmed in the data from PACE Analytical, which found an average of 4.36 pCi/g of thorium and 1.59 pCi/g of uranium in the soils, compared to 0.63 pCi/g of thorium and 0.08 pCi/g of uranium in the biological samples.

A sample of tree bark collected opposite the site on Indiana, (sample RFCO044B), contained a quantifiable amount of plutonium 238, at a concentration of 30. pCi/Kg. (Note units change.)

Notably, plutonium was not detected in the reference sample taken from Eldorado Canyon State Park. In fact, plutonium was only detected in samples that were along a line on the eastern edge of the Rocky Flats site.

Figure 3a: Locations of plutonium detections

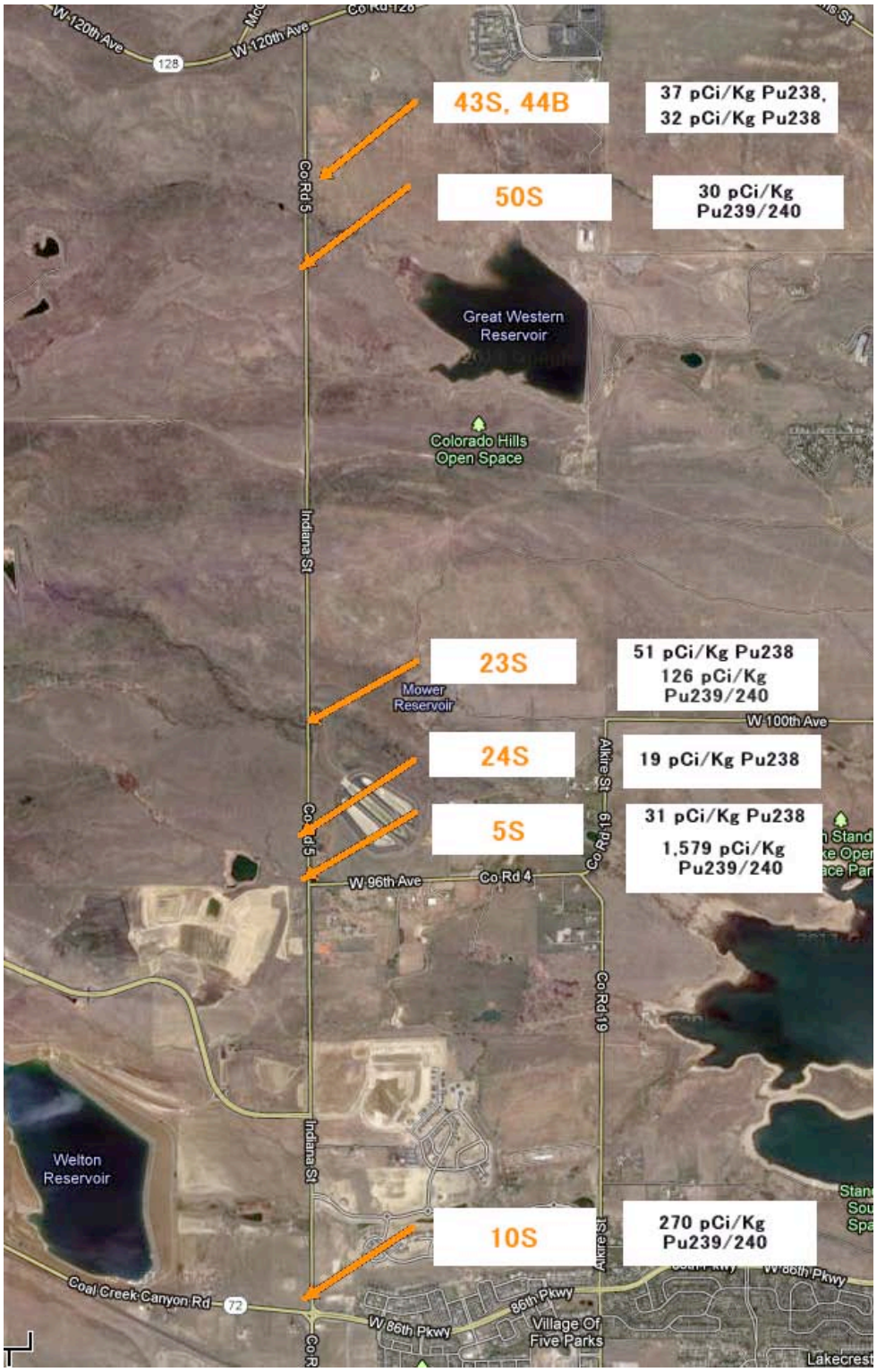
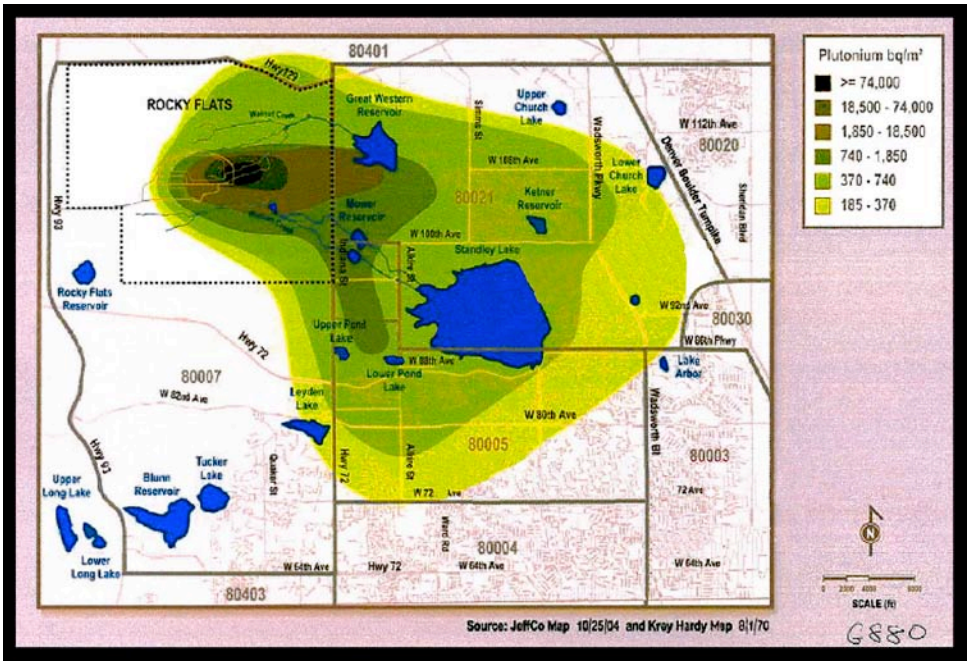


Figure 3b: Locations of plutonium nondetects

Figure 3c: Pu-239 distribution adapted from 1970 Krey-Hardy report



The plutonium concentrations faithfully follow the contours shown in the Krey- Hardy report, with positive detections along Indiana Street directly east of the site, but nondetects west and south of the site.

The following discussion of the plutonium test results is based on (a), Toxicological Profile For Plutonium, U.S. Department Of Health And Human Services Public Health Service Agency For Toxic Substances And Disease Registry, November 2010, (b), Argonne National Laboratory, *EVS Human Health Fact Sheet, Plutonium, August 2005,* http://www.evs.anl.gov/pub/doc/Plutonium.pdf, and (c), LaVelle et al, (2002), A Comparative Study of 239,240Pu in Soil Near the Former Rocky Flats Nuclear Weapons Facility, Golden, CO.

The dust inhalation vs. soil ingestion risk factors for plutonium are:

Lifetime Cancer Mortality Risk

Isotope	**Inhalation** *(pCi-1)*	**Ingestion** *(pCi-1)*
Plutonium-236	2.1 X 10-8	6.9 X 10-11
Plutonium-238	3.0 X 10-8	1.3 X 10-10
Plutonium-239	2.9 X 10-8	1.3 X 10-10
Plutonium-240	2.9 X 10-8	1.3 X 10-10
Plutonium-241	2.8 X 10-10	1.9 X 10-12
Plutonium-242	2.8 X 10-8	1.3 X 10-10
Plutonium-244	2.0 X 10-8	1.3 X 10-10

Based on these lifetime cancer mortality risk factors, inhalation of particles containing Plutonium is a more significant risk than contact with or ingestion of soils.

> *Overall the results of this sampling and analysis campaign are consistent with previous reported findings on the site including the following excerpts:*
>
> *Another source of soil contamination at Rocky Flats was the leakage of stored plutonium-contaminated oil. Plutonium was present as the dioxide when it was released. The dioxide was then adsorbed to the soil. Fugitive dust emissions caused plutonium-contaminated soil to be distributed away from the spill. Most of the plutonium remained on the surface, although some was released and migrated downward through the soil column (citing Little and Whicker 1978, P. 166).*

Plutonium has been identified in 6 soil and 9 sediment samples collected from 1,689 NPL hazardous waste sites, where it was detected in some environmental media (HazDat 2007). P. 166

The particle size expected to be released from either of the above mentioned sources, (nuclear testing, NPPs, fuel reprocessing), ranges from 0.3 to 1.1 μm p. 166

Soil samples collected at the RFETS during 1992–1994 were reported to range from 1.1 Bq/kg (30 pCi/kg) offsite to 57 Bq/kg (1,500 pCi/kg) onsite. P.177 (Note by M. Kaltofen, 0.03 pCi/g is not the background level, it is the average offsite level.)

Average Pu concentrations in the Hanford 100N, 200/600, and 300/400 areas were 0.004, 0.350, and 0.030 pCi/g respectively. The average Pu concentration was 0.0033 pCi/g in a community distant from Hanford, P.178

Pu in pCi/g was 0.0008 to 0.011 for Columbia River sediment, median Pu in pCi/g was 0.002 to 0.010 p. 178.

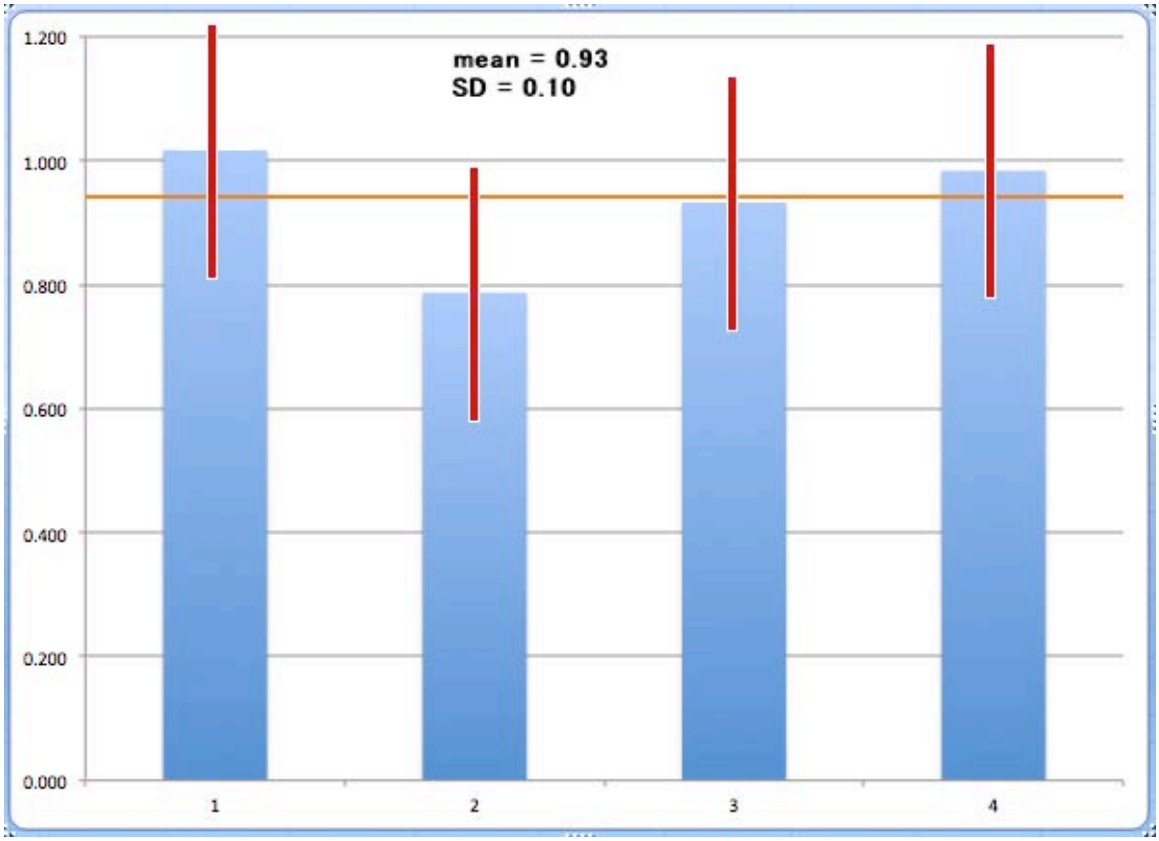
Liao 2008 as cited on P. 182 found an average of 0.008 pCi/g Pu239/240 from global fallout in the top 11 cm.

The median offsite soil plutonium concentration found in 2002 by LaVelle et al was 0.265 pCi/g. The mean offsite soil plutonium concentration found in this 2011 sample set was 0.226 pCi/g. These central values are within 1 standard deviation of each other, meaning that there is no statistically significant difference between these data sets. This result does not necessarily imply a static plutonium distribution, rather, it is likely that losses from the fence line area are offset by added inputs of plutonium from the former Rocky Flats site.

Subsurface results

Four subsurface samples taken at 12 inches below ground surface were collected while surface soil samples at these same locations. There was no significant difference in total activity or in gamma spectrometry results for thorium and uranium between surface and subsurface samples. The original intent was to determine whether total activity or uranium and thorium concentration were related to depth. Due to the high natural background levels of uranium and thorium, this analysis is not a meaningful method for investigating surface contamination related to activity at the Rocky Flats site.

Below: Ratio of surface to subsurface gamma activity showing mean (0.93) and 95 percent confidence limits, (2 times the standard deviation). The two sets are not significantly different.



Americium

Americium isotopes were not detected in the Rocky Flats soils, except for trace amounts in a handful of particles found by SEM/EDS. The sodium iodide and germanium lithium gamma detectors were standardized against a calibrated Am-241 source using the sensitive 59.54 keV gamma line. There were no detections of americium among the soils or biological samples.

Summation:

All 50 samples from the 2010 and 2011 sampling campaigns were tested for total activity and by gamma isotopic analysis. A subset of the samples was tested commercially for plutonium, radioactively-hot particles, along with confirmation testing for uranium and thorium.

Plutonium exceeded reported background levels by two orders of magnitude at locations that match those noted in the Krey Hardy report. (P. W. Krey and E. P. Hardy, 1970, "Plutonium in Soil Around the Rocky Flats Plant")

Naturally-occurring total activity, uranium, and thorium levels are elevated in this area, and were not used as indicators of contamination.

There was no statistically significant difference between this data set and the 1970 data set. Plutonium losses appear to be approximately equal in magnitude to plutonium inputs in the Indiana St. area.

The portion of the study area surrounding Indiana St. was contaminated with plutonium isotopes, traces of americium. This zone also contained uranium and thorium bearing monazite particles. Although monazites are naturally occurring, these particles nevertheless represent an inhalation hazard, as they were in the respirable size range of 0.5 to 5.0 microns. Particles of silicates containing uranium and thorium were also detected.

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Sample Record

ID	Depth (in.)	Description (soil unless noted)
RFCO001D	NA	(2010 collection) duct dust
RFCO002D	NA	(2010 collection) vac bag dust
RFCO002S	0	(2010 collection) open space soil
RFCO003S	0	(2010 collection) 96th St. & Indiana
RFCO005S	-6	Watercourse on Indiana
RFCO006S	0	Rte. 93S hiking trail
RFCO007S	0	McCaskin Hwy & Rte. 128
RFCO008S	0	McCaskin Hwy & Rte. 128
RFCO009S	0	Indiana and C.C. Canyon Rd.
RFCO010S	-12	Indiana and C.C. Canyon Rd.
RFCO011S	0	Reference: N. Garrison & 100th St.
RFCO012S	0	Reference: 100th & N. Simms
RFCO013S	0	Rte. 93 N and Rte. 128
RFCO014S	0	Rte. 128 @ creek bed
RFCO015S	-12	Rte. 128 @ creek bed
RFCO016S	0	Indiana southward 0.4 miles
RFCO017S	0	Indiana southward 0.8 miles
RFCO018S	0	Indiana southward 1.2 miles
RFCO019S	0	Indiana southward 1.6 miles
RFCO020S	-12	Indiana southward 1.6 miles
RFCO021S	0	Indiana southward 2.0 miles
RFCO022S	0	Indiana southward 2.4 miles
RFCO023S	0	Indiana southward 2.4 miles
RFCO024S	0	Indiana southward 2.8 miles
RFCO025S	-12	Indiana southward 2.8 miles

Sample Record (continued)

ID	Depth (in.)	Description (soil unless noted)
RFCO026S	0	Indiana southward 3.2 miles
RFCO027S	0	Indiana southward 3.6 miles
RFCO028S	-6	Reference: Eldorado Canyon State Park
RFCO029S	0	93N near plant gate
RFCO030S	0	93N near plant gate
RFCO031S	0	93N at RF entrance sign
RFCO032S	0	93N & Rte. 72
RFCO033B	NA	Lichen south side Rte. 72
RFCO034S	0	At south side Rte. 72
RFCO035S	0	At RR bridge south on Indiana
RFCO036Z	0	At RR bridge south on Indiana (stone)
RFCO037S	0	At RR bridge south on Indiana
RFCO038S	0	At RR bridge south on Indiana
RFCO039B	NA	Lichen Rte. 27, Gate 17
RFCO040S	0	Rte. 27, Gate 17
RFCO041B	NA	Bark, Rte. 128 near McCaslin
RFCO042S	0	Rte. 128 near McCaslin
RFCO043S	0	Indiana near culvert
RFCO044B	NA	Bark, large tree, Ind. @ culvert
RFCO045B	NA	Bark, Indiana near culvert
RFCO046B	NA	Bark, Indiana near culvert
RFCO047S	0	Indiana near culvert
RFCO048B	NA	Lichen - on tree W. of Indiana
RFCO049S	0	NE gate area soil on Indiana
RFCO050S	0	NE gate area soil on Indiana

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Total activity record

Sample #	Depth in inches	uR/1000 sec.	gCPS normalized	spectrum number	Date run
BLK mean		3.93	33.1	multiple	multiple
RFCO001D	NA				
RFCO002D	NA	3.77	33.0	328	11/17/11
RFCO002S	0				
RFCO003S	0				
RFCO005S	-6				
RFCO006S	0	4.63	34.0	322	11/17/11
RFCO007S	0	5.87	35.2	165	10/4/11
RFCO008S	0	6.24	36.1	247	10/21/11
RFCO009S	0	5.34	35.4	323	11/17/11
RFCO010S	-12	5.95	37.5	258	10/24/11
RFCO011S	0	5.50	34.5	246	10/24/11
RFC0012S	0	5.92	35.1	153	9/30/11
RFCO013S	0	4.90	33.9	238	10/20/11
RFCO014S	0	4.09	33.1	181	10/15/11
RFC0015S	-12	4.65	35.5	147	9/30/11
RFCO016S	0	5.17	35.0	250	10/24/11
RFCO017S	0	5.57	35.0	257	10/24/11
RFCO018S	0	5.97	35.6	239	10/20/11
RFCO019S	0	4.66	35.9	264	10/24/11
RFC0020S	-12	4.94	34.7	145	9/30/11
RFCO021S	0	5.33	33.9	182	10/5/11
RFCO022S	0	6.23	34.0	178	10/4/11
RFC0023S	0		36.0	150	9/30/11
RFC0024S	0	5.57	36.0	156	9/30/11
RFCO025S	-12		35.4	179	10/5/11
RFCO026S	0	6.67	33.2	170	10/4/11
RFC0027S	0	5.65	34.2	149	9/30/11
RFCO028S	-6	9.64	41.2		
RFCO029S	0	6.35	34.0	262	10/24/11
RFCO030S	0	6.11	34.2	180	10/5/11
RFCO031S	0	6.45	35.1	252	10/24/11
RFC0032S	0	5.61	33.5	154	9/30/11
RFCO033B	NA	5.03	31.0	174	10/4/11
RFCO034S	0	5.98	35.5	248	10/24/11
RFCO035S	0		36.0	140	9/30/11
RFC0036Z	0	4.37	33.2	152	9/30/11
RFCO037S	0	5.26	35.4	323	11/17/11
RFCO038S	0	5.04	34.7	261	10/24/11
RFC0039B	NA	4.34	31.0	155	9/30/11
RFCO040S	0	5.45	36.6	236	10/20/11
RFCO041B	NA	4.29	31.3	169	10/4/11
RFCO042S	0	5.34	34.7	259	10/24/11
RFC0043S	0		36.2	146	9/30/11
RFCO044B	NA	5.06	33.0	321	11/17/11
RFCO045B	NA	5.47	33.0	325	11/17/11
RFCO046B	NA	4.18	34.5	241	10/21/11
RFCO047S	0	5.48	32.3	263	10/24/11
RFCO048B	NA	4.19	31.2	168	10/4/11
RFCO049S	0	5.06	40.4	319	11/17/11
RFCO050S	0		39.2	144	9/30/11

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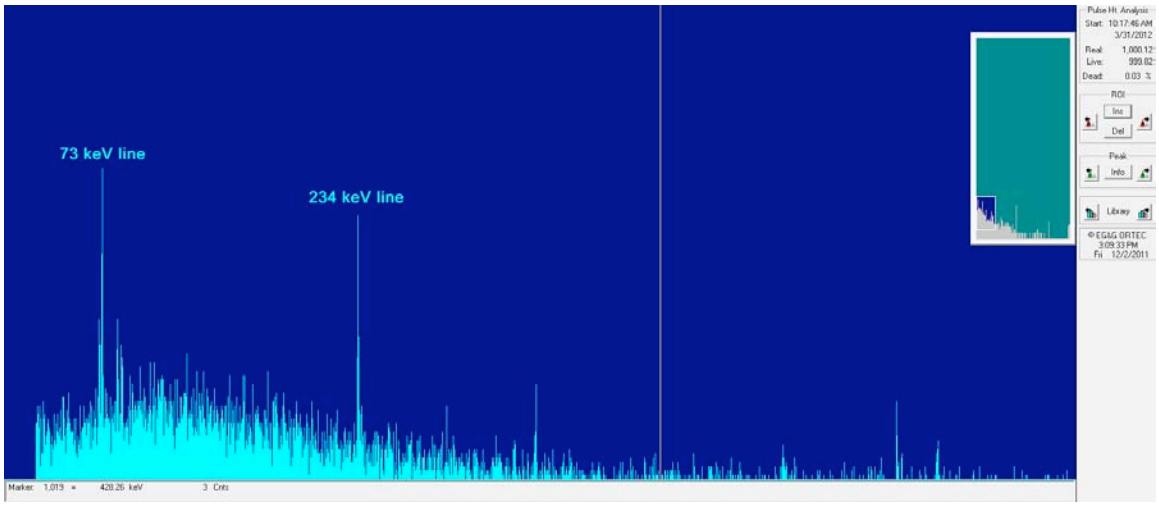
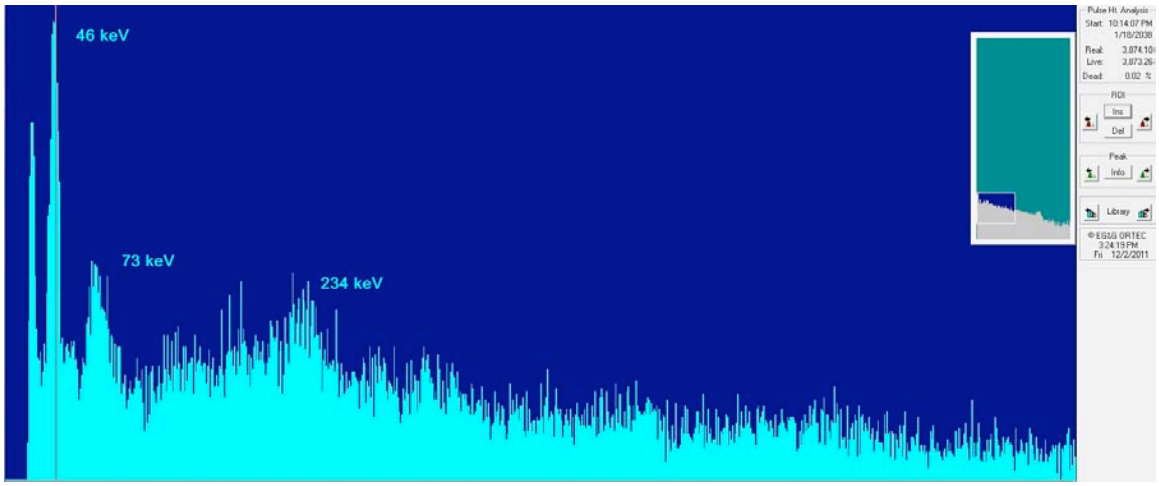
Appendix: Example gamma spectra

top – thorium present,
bottom – uranium and thorium present





Copy of isotopic Pu, Th, and U laboratory report pages (1 of 3)
(See PACE reports for full results)

Pace Analytical Services, Inc.
1638 Roseytown Road - Suites 2,3,4
Greensburg, PA 15601
(724)850-5600

ANALYTICAL RESULTS

Project: Boston Chemical Data RFCO
Pace Project No.: 3057331

Sample: RFCO043S **Lab ID: 3057331001** Collected: 09/15/11 00:01 Received: 11/09/11 09:45 Matrix: Solid
PWS: Site ID: Sample Type:
Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.037 ± 0.030 (0.044)**	pCi/g	12/08/11 16:07	13981-16-3	
Pu-239/240	HSL-300m	**0.016 ± 0.025 (0.044)**	pCi/g	12/08/11 16:07		
Plutonium-241	HSL-300m	**2.406 ± 3.396 (5.714)**	pCi/g	12/13/11 12:43	14119-32-5	

Sample: RFCO023S **Lab ID: 3057331002** Collected: 09/14/11 00:01 Received: 11/09/11 09:45 Matrix: Solid
PWS: Site ID: Sample Type:
Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.051 ± 0.031 (0.037)**	pCi/g	12/08/11 16:07	13981-16-3	
Pu-239/240	HSL-300m	**0.126 ± 0.046 (0.037)**	pCi/g	12/08/11 16:07		
Plutonium-241	HSL-300m	**3.631 ± 4.318 (7.188)**	pCi/g	12/13/11 13:15	14119-32-5	

Sample: RFCO005S **Lab ID: 3057331003** Collected: 03/17/11 00:01 Received: 11/09/11 09:45 Matrix: Solid
PWS: Site ID: Sample Type:
Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.031 ± 0.026 (0.040)**	pCi/g	12/08/11 16:07	13981-16-3	
Pu-239/240	HSL-300m	**1.579 ± 0.262 (0.045)**	pCi/g	12/08/11 16:07		
Plutonium-241	HSL-300m	**0.243 ± 3.266 (5.765)**	pCi/g	12/13/11 13:46	14119-32-5	
Thorium-228	HSL-300m	**2.038 ± 0.539 (0.181)**	pCi/g	12/14/11 07:04	14274-82-9	
Thorium-230	HSL-300m	**1.218 ± 0.384 (0.199)**	pCi/g	12/14/11 07:04	14269-63-7	
Thorium-232	HSL-300m	**2.084 ± 0.545 (0.144)**	pCi/g	12/14/11 07:04	7440-29-1	

Sample: RFCO0010 **Lab ID: 3057331004** Collected: 09/14/11 00:01 Received: 11/09/11 09:45 Matrix: Solid
PWS: Site ID: Sample Type:
Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.029 ± 0.032 (0.052)**	pCi/g	12/08/11 16:07	13981-16-3	
Pu-239/240	HSL-300m	**0.270 ± 0.076 (0.051)**	pCi/g	12/08/11 16:07		
Plutonium-241	HSL-300m	**0.652 ± 4.409 (7.741)**	pCi/g	12/13/11 14:17	14119-32-5	

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ANALYTICAL RESULTS

Project: RFCO
Pace Project No.: 3055210

Sample: RFCO0065 Trailhead **Lab ID: 3055210001** Collected: 09/14/11 12:02 Received: 10/06/11 10:30 Matrix: Solid
PWS: Site ID: Sample Type:

Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.020 ± 0.023 (0.037)**	pCi/g	10/26/11 13:15	13981-16-3	
Pu-239/240	HSL-300m	**0.016 ± 0.022 (0.037)**	pCi/g	10/26/11 13:15		
Plutonium-241	HSL-300m	**-1.525 ± 3.008 (5.475)**	pCi/g	10/27/11 11:38	14119-32-5	
Thorium-228	HSL-300m	**1.50 ± 0.403 (0.149)**	pCi/g	10/27/11 08:18	14274-82-9	
Thorium-230	HSL-300m	**0.835 ± 0.271 (0.102)**	pCi/g	10/27/11 08:18	14269-63-7	
Thorium-232	HSL-300m	**1.49 ± 0.393 (0.086)**	pCi/g	10/27/11 08:18	7440-29-1	
Uranium-234	HSL-300m	**0.663 ± 0.226 (0.134)**	pCi/g	10/26/11 17:31	13966-29-5	
Uranium-235	HSL-300m	**0.020 ± 0.072 (0.054)**	pCi/g	10/26/11 17:31	15117-96-1	
Uranium-238	HSL-300m	**0.816 ± 0.254 (0.102)**	pCi/g	10/26/11 17:31		

Sample: RFCO0245+2.8M Indiana **Lab ID: 3055210002** Collected: 09/14/11 13:00 Received: 10/06/11 10:30 Matrix: Solid
PWS: Site ID: Sample Type:

Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.019 ± 0.018 (0.027)**	pCi/g	10/26/11 13:15	13981-16-3	
Pu-239/240	HSL-300m	**0.017 ± 0.017 (0.027)**	pCi/g	10/26/11 13:15		
Plutonium-241	HSL-300m	**-1.142 ± 2.832 (5.125)**	pCi/g	10/27/11 12:09	14119-32-5	
Thorium-228	HSL-300m	**1.60 ± 0.429 (0.210)**	pCi/g	10/27/11 08:18	14274-82-9	
Thorium-230	HSL-300m	**0.781 ± 0.269 (0.173)**	pCi/g	10/27/11 08:18	14269-63-7	
Thorium-232	HSL-300m	**1.55 ± 0.409 (0.106)**	pCi/g	10/27/11 08:18	7440-29-1	
Uranium-234	HSL-300m	**0.701 ± 0.237 (0.124)**	pCi/g	10/26/11 17:31	13966-29-5	
Uranium-235	HSL-300m	**0.037 ± 0.075 (0.104)**	pCi/g	10/26/11 17:31	15117-96-1	
Uranium-238	HSL-300m	**0.752 ± 0.244 (0.043)**	pCi/g	10/26/11 17:31		

Sample: RFCO0285 Rattlesnake-Eldorado **Lab ID: 3055210003** Collected: 09/15/11 09:21 Received: 10/06/11 10:30 Matrix: Solid
PWS: Site ID: Sample Type:

Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.014 ± 0.018 (0.030)**	pCi/g	10/26/11 13:15	13981-16-3	
Pu-239/240	HSL-300m	**-0.005 ± 0.014 (0.032)**	pCi/g	10/26/11 13:15		
Plutonium-241	HSL-300m	**0.220 ± 3.208 (5.643)**	pCi/g	10/27/11 12:40	14119-32-5	
Thorium-228	HSL-300m	**3.01 ± 0.667 (0.154)**	pCi/g	10/27/11 08:18	14274-82-9	
Thorium-230	HSL-300m	**1.09 ± 0.326 (0.130)**	pCi/g	10/27/11 08:18	14269-63-7	
Thorium-232	HSL-300m	**2.46 ± 0.567 (0.088)**	pCi/g	10/27/11 08:18	7440-29-1	
Uranium-234	HSL-300m	**1.09 ± 0.328 (0.137)**	pCi/g	10/26/11 17:31	13966-29-5	
Uranium-235	HSL-300m	**0.066 ± 0.086 (0.119)**	pCi/g	10/26/11 17:31	15117-96-1	
Uranium-238	HSL-300m	**0.985 ± 0.305 (0.049)**	pCi/g	10/26/11 17:31		

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ANALYTICAL RESULTS

Project: RFCO
Pace Project No.: 3055210

Sample: RFCO0355 Soil Indiana + RR **Lab ID: 3055210004** Collected: 09/15/11 09:47 Received: 10/06/11 10:30 Matrix: Solid
PWS: Site ID: Sample Type:
Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.023 ± 0.025 (0.041)**	pCi/g	10/26/11 13:15	13981-16-3	
Pu-239/240	HSL-300m	**-0.007 ± 0.011 (0.029)**	pCi/g	10/26/11 13:15		
Plutonium-241	HSL-300m	**-0.400 ± 3.100 (5.520)**	pCi/g	10/27/11 13:11	14119-32-5	
Thorium-228	HSL-300m	**1.33 ± 0.390 (0.192)**	pCi/g	10/27/11 08:18	14274-82-9	
Thorium-230	HSL-300m	**0.643 ± 0.244 (0.129)**	pCi/g	10/27/11 08:18	14269-63-7	
Thorium-232	HSL-300m	**0.923 ± 0.301 (0.096)**	pCi/g	10/27/11 08:18	7440-29-1	
Uranium-234	HSL-300m	**0.546 ± 0.416 (0.620)**	pCi/g	10/26/11 17:31	13966-29-5	
Uranium-235	HSL-300m	**0.036 ± 0.249 (0.411)**	pCi/g	10/26/11 17:31	15117-96-1	
Uranium-238	HSL-300m	**0.956 ± 0.485 (0.300)**	pCi/g	10/26/11 17:31		

Sample: RFCO044B Indiana @ tree **Lab ID: 3055210005** Collected: 09/15/11 13:49 Received: 10/06/11 10:30 Matrix: Solid
PWS: Site ID: Sample Type:
Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.032 ± 0.023 (0.031)**	pCi/g	10/26/11 13:15	13981-16-3	
Pu-239/240	HSL-300m	**-0.002 ± 0.014 (0.029)**	pCi/g	10/26/11 13:15		
Plutonium-241	HSL-300m	**-2.842 ± 2.644 (4.952)**	pCi/g	10/27/11 13:42	14119-32-5	
Thorium-228	HSL-300m	**0.384 ± 0.204 (0.192)**	pCi/g	10/27/11 08:18	14274-82-9	
Thorium-230	HSL-300m	**0.045 ± 0.080 (0.162)**	pCi/g	10/27/11 08:18	14269-63-7	
Thorium-232	HSL-300m	**0.200 ± 0.135 (0.060)**	pCi/g	10/27/11 08:18	7440-29-1	
Uranium-234	HSL-300m	**0.021 ± 0.073 (0.179)**	pCi/g	10/26/11 17:31	13966-29-5	
Uranium-235	HSL-300m	**0.022 ± 0.081 (0.061)**	pCi/g	10/26/11 17:31	15117-96-1	
Uranium-238	HSL-300m	**0.040 ± 0.062 (0.111)**	pCi/g	10/26/11 17:31		

Sample: RFCO0505 Gate 25 Indiana Side **Lab ID: 3055210006** Collected: 09/15/11 13:57 Received: 10/06/11 10:30 Matrix: Solid
PWS: Site ID: Sample Type:
Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC)	Units	Analyzed	CAS No.	Qual
Plutonium-238	HSL-300m	**0.012 ± 0.022 (0.038)**	pCi/g	10/26/11 13:15	13981-16-3	
Pu-239/240	HSL-300m	**0.030 ± 0.021 (0.027)**	pCi/g	10/26/11 13:15		
Plutonium-241	HSL-300m	**-2.043 ± 3.173 (5.818)**	pCi/g	10/27/11 14:13	14119-32-5	
Thorium-228	HSL-300m	**1.96 ± 0.471 (0.179)**	pCi/g	10/27/11 08:18	14274-82-9	
Thorium-230	HSL-300m	**0.930 ± 0.277 (0.082)**	pCi/g	10/27/11 08:18	14269-63-7	
Thorium-232	HSL-300m	**1.73 ± 0.422 (0.042)**	pCi/g	10/27/11 08:18	7440-29-1	
Uranium-234	HSL-300m	**0.724 ± 0.248 (0.114)**	pCi/g	10/26/11 17:31	13966-29-5	
Uranium-235	HSL-300m	**0.022 ± 0.080 (0.061)**	pCi/g	10/26/11 17:31	15117-96-1	
Uranium-238	HSL-300m	**0.574 ± 0.215 (0.102)**	pCi/g	10/26/11 17:31		

References:

1) Applied Radiation and Isotopes
Volume 46, Issue 11, November 1995, Pages 1271-1278
Proceedings of Plutonium in the Environment
doi:10.1016/0969-8043(95)00170-I

Plutonium in tree rings from France and Japan
J.-P. Garrec, T. Suzuki, Y. Mahara, D.C. Santry, S. Miyahara, M. Sugahara, J. Zheng, A. Kudo

Abstract
Plutonium, along with other radionuclide concentrations, was measured in evergreen tree rings from two different locations. This was used as an information source for the past two centuries. Tree rings are a product of annual layers and thus chronological information is clearly visible. Three trees were harvested in 1988–1990: a French white fir (137 years old) and a spruce tree (177 years old) from the France-Germany border near Nancy, France and a sugi (78 years old) from Nagasaki, Japan. The uniform branchless part of the trunks from the harvested trees were immediately separated into a set of tree ring samples each of which contained 3–20 years of growth. The separated samples were mechanically powdered, dried at 105°C to obtain the dry weight, ashed at 350°C to measure 40K, 134Cs and 137Cs and ashed again at 600°C to determine 239+240Pu. The highest 239+240 Pu concentration of 30.0 mBq/kg of dry wood was obtained from the tree rings from Nagasaki, located at the centre of the local fallout of the Pu A-bomb detonated in 1945. This concentration peak was, however, observed in tree rings of 1965–1967. The concentration was only 2.9 mBq/kg for the tree rings of 1944–1946. The contribution of the local fallout on the surface soils from the A-bomb was 181 mBq/cm2 at the harvested area of the tree, while the contribution of global fallout by many weapons testing was 5.9 mBq/cm2 (or 3.3% total fallout in the region). The reason for the over 20 year time lag of 239+240Pu uptake by the tree rings is unknown because many factors influence the routes of Pu into the tree rings. Also the chemical form of Pu in surface soils may have been changed by the surrounding environment. The highest concentration in the tree rings from France was 9.4 mBq/kg which is about 31% of Nagasaki 239 + 240Pu concentration. The harvested area did not have any recorded Pu sources other than global fallout. An interesting result was that that distribution of 134Cs and 137Cs concentrations in the French white fir was different from Nagasaki. Data suggested that these new radionuclide inputs were from the Chernobyl accident. The mobility (or diffusion coefficient) of cesium is 2–8 cm2/yr. in the portion of heart-wood tree rings (1870–1955). Although tree rings can record chronological inputs of various trace elements, some elements cannot be used. These exceptions would be elements that: (1) are mobile within tree rings; (2) have little understood entry routes to the tree rings (via roots, leaves or barks); and (3) have unknown biogeochemical behaviour in the surrounding environment. Further investigation is warranted to use tree rings as a tool to record past environmental history.

2) Journal of Environmental Radioactivity
Volume 21, Issue 1, 1993, Pages 55-63

Effectiveness of tree rings for recording Pu history at Nagasaki, Japan, A. Kudo, T. Suzuki, D.C. Santry, Y. Mahara, S. Miyahara, J.P. Garrec

Abstract
A 78-year-old tree was harvested in 1988 at 2.8 km east of the Nagasaki Pu bomb hypocentre, where the local fallout of the 1945 blast was highest. The surface soil concentration of $^{239+240}$Pu was 64.5 mBq g^{-1} and that of ^{137}Cs was 87.4 mBq g^{-1}. The tree rings were analyzed for their concentrations of $^{239+240}$Pu, ^{137}Cs and ^{40}K. Interestingly, the concentration profiles over seven decades showed that the Pu was immobile, while Cs and K were mobile in the tree rings. In other words, the Pu concentration profile revealed a history of Pu in the surrounding environment of Nagasaki. However, the combined routes, via leaves from the atmospheric deposition and roots from surface soils to tree rings, made the record less clear. Surprisingly, the Pu from the Nagasaki Pu-bomb in the tree rings of 1946–44 played a minor role in the concentration profile compared to that from global fallout. This meant that the Pu in the local fallout was less bio-available compared to that of the global fallout.

3) **Toxicological Profile for Plutonium**, ATSDR,
(http://www.atsdr.cdc.gov/toxprofiles/tp143-c6.pdf, accessed 11/29/11)

"A fire on May 11, 1969, occurred at the plutonium processing facility at Rocky Flats, which caused concerns about possible contamination of the surrounding areas (Agency for Toxic Substances and Disease Registry 2005). Studies showed that while trace amounts of plutonium were present in soil, the distribution was not consistent with the wind direction at the time of the fire. It was determined that the major source of plutonium contamination was leakage from drums of machine oil containing plutonium that were being stored in an outdoor area (Eisenbud and Gesell 1997). Another source of soil contamination at Rocky Flats was the leakage of plutonium-contaminated oil. Plutonium was present as the dioxide when it was released. The dioxide was then adsorbed to the soil. Fugitive dust emissions caused plutonium-contaminated soil to be distributed away from the spill. Most of the plutonium remained on the surface, although some was released and migrated downward through the soil column (Little and Whicker 1978). "

January 20, 2012

Marco Kaltofen, PE, (Civil, Mass.)
For Boston Chemical Data Corp.

End of field investigation and laboratory report