

URANIUM MINE WASTE DUMP CHARACTERIZATION IN LATHROP CANYON, CANYONLANDS NATIONAL PARK, UTAH

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ABSTRACT

The National Park Service (NPS), Utah's Department of Natural Resources Abandoned Mine Reclamation Program (AMRP), and the U.S. Environmental Protection Agency (EPA) entered into a partnership to develop and implement a sampling procedure to evaluate the environmental risk of abandoned uranium mine waste rock. The NPS and AMRP have worked cooperatively since 1988 to evaluate and close hazardous openings at these sites throughout Utah, but mine waste rock piles at remote sites have often not been reclaimed for reasons such as limited funding, minimizing new impacts, and preserving historic mining fabric. The environmental risks of leaving uranium mine dumps unmitigated have not been fully assessed. EPA contributed funding and expertise to develop a sampling design to evaluate these risks. Representative sites on NPS lands were considered for this study, giving highest priority to those sites where there was evidence of contaminants being released to the environment. Criteria for site selection included size of mine waste rock piles, proximity to ephemeral desert washes, and evidence of waste rock pile erosion. Twelve abandoned uranium mines in the Lathrop Canyon area of Canyonlands National Park were selected for field analysis. Gamma and alpha radiation surveys were conducted onsite. EPA's National Air and Radiation Laboratory in Montgomery, Alabama analyzed solid and water samples for metals and radionuclides of the uranium-238 series. Field observations and analysis of sample data indicate that the Lathrop Canyon sites, abandoned in the 1950s, have stabilized over time and currently have minimal impact on the environment and potential biological receptors. From this analysis the NPS, AMRP, and EPA conclude that it is best not to attempt removal or onsite encapsulation of the waste rock piles.

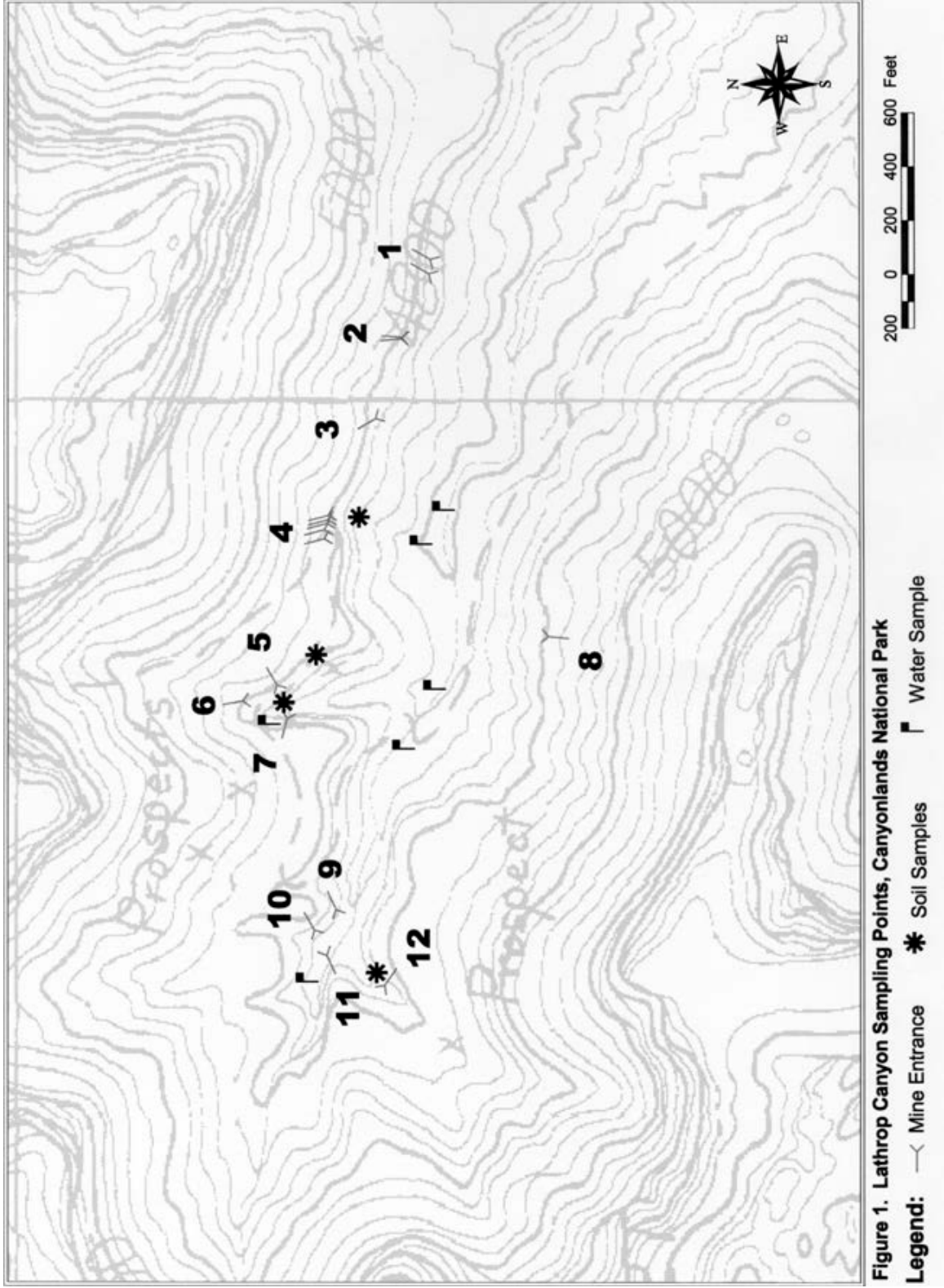
INTRODUCTION

The NPS has identified 80 abandoned mine land (AML) sites on its lands in Utah. These sites are, for the most part, vestiges of the uranium boom of the 1940s and 1950s: uranium mines or prospects consisting of adits, shafts, and their associated waste rock piles. They are often in remote settings that now receive minimal visitation. The mines are typically dry, having no

standing water or effluents draining from the mine portals. Spoils material in drainages has long-since been washed down the drainage, leaving a relatively static or stabilized landscape today. There are many sites of this type beyond NPS boundaries throughout the Colorado Plateau Region, a physiographic province centered on the "four corners" area of Utah, Colorado, New Mexico, and Arizona, which has been a major center of production for the nation's radioactive ores since 1900. Mostly these mines follow stratiform deposits in the Chinle (upper Triassic) or Morrison (upper Jurassic) formations: the two principle formations known to host significant uranium deposits in the Colorado Plateau.

The NPS and AMRP have worked cooperatively since 1988 to evaluate and close hazardous openings at these sites throughout Utah, but mine dumps have often not been reclaimed for reasons such as limited funding, minimizing new impacts, and preserving historic fabric. Reclamation standards for **active** uranium mines, based on returning the land to a residential use scenario, require cleanup of Radium-226 in the first 15 cm of the soil surface to 5 pCi/g above background, and each subsequent 15-cm layer of soil to within 15 pCi/g above background (40 CFR §192.12(a)). Certainly, these standards are appropriate and they should be enforced at active mines. However, the NPS and AMRP have taken the position that application of this standard to remote, arid, **abandoned** sites that will never see residential use is unnecessary, cost-prohibitive, and may in fact be counterproductive (Burghardt, 1996). These agencies contend that exposures to reclamation crews attempting removal or encapsulation of spoils material could far exceed minimal exposures to occasional visitors passing by the site. They further contend that in attempting to remove or encapsulate spoils piles, it is possible that far more contamination would be released into the environment than if the piles were left alone in their current condition. Oxidized, relatively stable material currently at the surface would be removed, exposing unoxidized, more mobile material. The NPS and AMRP have maintained that these disturbed landscapes have stabilized through time and are currently having little if any effect on the environment and potential biological receptors, although the environmental risks of leaving these dumps unmitigated have admittedly not been fully assessed. EPA has not completed its evaluation of the impacts from uranium AML sites, but is currently in the process of developing guidance for human and environmental health protection at such locations, including the needs for remediation. This guidance will be useful to various land management agencies as they determine their own policies to drive remediation efforts.

For this reason, the NPS, AMRP, and EPA-Region 8 entered into a partnership to develop and implement sampling protocols for evaluating the environmental risk of abandoned uranium mine waste dumps. Specifically, the objectives of this partnership were: 1) collocate waste rock, surface water samples, and field-measured external radiation exposures, in an attempt to evaluate the potential for the waste rock piles to leach contaminants into the environment, 2) evaluate potential of contaminants to adversely affect human and ecological receptors; and, 3) select field measurements, monitoring equipment, and monitoring criteria which would best enable NPS and AMRP to evaluate and prioritize sites for mitigation with minimal time and expense. As part of their Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) Program, the EPA contributed funding and expertise for this study. Representative sites on NPS lands were considered for field analysis, giving highest priority to those sites where there was evidence of contaminants being released to the environment. Criteria for site selection included size of mine spoils piles, proximity to active drainages, and evidence of erosion of the spoils piles. Twelve abandoned uranium adits in the Shinarump member of the Chinle formation within Lathrop Canyon, Canyonlands National Park, were selected (see site map, Figure 1). Previous ownership and production records for these mines have not been found to-date. Fieldwork was conducted by the co-authors for this report on March 28-29, 2000.



The extent of lateral workings and waste rock pile volumes for each mine are detailed in Table 1. Since this is a narrow, strata-bound deposit, the mines are all relatively horizontal adits on one stratigraphic level. There are no vertical workings except in localized areas of minor stoping several feet above the normal mine roof. The adits are typically 5 feet wide by 7 feet high with some areas broadening to as wide as 20 feet. Spoil pile volumes vary depending on mine size, the amount of material removed from the site for processing, and the amount of material transported down-gradient by erosive forces through time. Because of their size and distinct drainages leading to the main Lathrop Canyon drainage, field analysis focused on Mine 4, the Mine 5,6,7 Complex, and Mine 12.

Table 1. Lathrop Canyon mine workings and associated waste rock volumes.

Mine	1	2	3	4	5	6	7	8	9	10	11	12
Lateral Workings (feet)	82	28	75	865	450	230	215*	188	20	70	40	235
Waste (cubic yards)	120	-	-	800	470			220	35	165	100	400

* Visual estimate of adit length. Remote workings are flooded 115 feet in from portal.

MATERIALS AND METHODS

The original sampling plan was to take multiple cores throughout the spoils piles using 3-inch-diameter hand augers to a depth of 5 feet. Site access and budgetary restrictions precluded the use of mechanized sampling equipment. Once onsite it was quickly determined the coarse fraction in the piles precluded the effective use of hand augers. Since mine dumps are very similar to placer deposits, in that they are essentially horizontally stratified due to the method of emplacement through time, a very basic placer deposit sampling technique was adopted. Shovels were used to dig several vertical or near-vertical trenches through each pile sampled. These trenches were cut as deep as 3 feet into the piles to ensure sampling of relatively fresh, unweathered material. Each trench was cut perpendicularly across different layers in the pile, which represented the various mineralized zones encountered through the life of the mine. Each trench was swept clean of loose debris, then a sample of uniform width and depth was cut along the entire length of the trench. The material collected was reduced using a No. 8 sieve (nominal 0.0937-inch openings). The fines were homogenized, then approximately 2 kilograms (kg) were bagged for analysis. Equal portions from the fines of the various sample trenches in each spoils pile were also combined to form one 2-kg composite sample. A total of 13 trench samples and 3 composite samples were collected from the main spoils piles at Lathrop Canyon Mine 4, the Mine 5, 6, 7 complex, and at Mine 12. One composite background sample was collected in similar fashion from 3 sample trenches cut in an unmined exposure of the Shinarump member just west of Mine 4.

External gamma radiation measurements were recorded using both Mt. Sopris® SC-132 and Exploranium® GR-130 hand-held monitoring instruments. External alpha radiation readings from radon decay products (the primary source of alpha radiation in natural settings) were also recorded in the spoils pile sample trenches using an MDA® Model 811 Working Level Meter.

Since Lathrop Canyon is a semi-arid environment with approximately 12 inches of precipitation per annum, only opportunistic surface water sampling events were anticipated. Sufficient rainwater fell during the fieldwork, however, to create adequate drainage for opportunistic sampling both up-gradient and along the ephemeral water course evident through the spoils area. All water samples were collected in 200-milliliter (ml) sample bottles that were pre-acidified with nitric acid. Two background water samples were collected: one from drainage off an overhang immediately above the Shinarump member of the Chinle formation at Mine 6, and the other from drainage that had passed entirely through the Shinarump member up-gradient from the mined

area. Three aqueous samples were taken immediately down-gradient from the waste piles where the solid samples were taken, and a final aqueous sample was taken in the main Lathrop Canyon drainage down-gradient from the spoils piles sampled.

Both spoils solids and aqueous samples were analyzed for metals and radionuclides by the US Environmental Protection Agency National Air and Radiation Environmental Laboratory (EPA-NAREL), Montgomery, Alabama. Non-radiological metals were run using ICP-MS (EPA Total Analytical List Method ILM04.0). Appropriate quality assurance / quality controls (QA/QC) of the samples were run as duplicates and spike samples for each analytical sample batch for a total of 5% internal controls. All of the analytical duplicates or spikes met the recovery qualifications for analysis: Relative Percentage Difference for duplicates ranged 75-125%, and recovery of the spikes ranged 80-120%.

RESULTS

The spoil piles were divided by their physical locations within Lathrop Canyon drainage as pictured in Figure 1, above. Metals and U-238 series radionuclides were analyzed. The data was log-normally distributed with results for the various mines as shown in Tables 2A-C and 3A-C, below. The geometric standard deviation (GSD) and the 95% confidence interval (CI) about the geometric mean (GM) were also determined. The 95% confidence interval about the geometric mean defines the maximum concentration of each analyte of interest. The piles show obvious delineations of mineralization throughout their depth. With this mineral heterogeneity, composite sampling collected throughout each spoil pile was initially thought to be more representative of the pile's metal and radionuclide concentrations. Instead, laboratory analysis showed that compositing of the spoils samples may seriously underestimate copper, vanadium, and manganese concentrations in certain areas of each pile. However it appears that U-238 series radionuclide concentrations were more adequately characterized by composited sampling.

Each spoil pile was also analyzed for soil pH and soil electrical conductivity (EC) as shown in Table 2D. Soil EC reflects salinity content and potential for contaminants to be dissolved and transported into the neighboring streams. Soil pH reflects the potential for metal mobility or metal binding. Acidic soils (pH<7) and very basic soils (pH>10) tend to be more soluble than circum-neutral soils (pH=7).

Table 2A. Metals in Lathrop Mine 4 spoils piles (mg/kg-dry weight).

Analyte	Mine 4 Sample 1	Mine 4 Sample 2	Mine 4 Sample 3	Mine 4 Sample 4	Mine 4 Sample 5	GM	GSD	95% CI of GM	Mine 4 Composite ± 2 SD
Arsenic	42.3	24.8	19.1	46.5	38.0	34.8	13.7	46.8	50.7±5.7
Copper	601	216	79.3	900.0	499.0	544.8	678.3	1139.3	429± 79
Manganese	630	864.0	1150.0	701.0	605.0	794.5	214.5	982.5	850 ± 34
Selenium	0.4	1.2	0.7	0.8	0.3	0.7	0.4	1.1	0.7 ± 0.03
Vanadium	7.9	18.4	5.3	8.0	5.8	9.2	4.8	13.4	8.1 ± 0.8

Table 2B. Metals in Lathrop Mines 5, 6, 7 complex spoils piles (mg/kg-dry weight).

Analyte	Mines 5,6,7 Sample 1	Mines 5,6,7 Sample 2	Mines 5,6,7 Sample 3	Mines 5,6,7 Sample 4	Mines 5,6,7 Sample 5	GM	GSD	95% CI of GM	Mines 5,6,7 Composite ± 2 SD
Arsenic	115.0	374.0	75.6	109.0	91.7	154.1	107.1	248.0	124± 13.3
Copper	2310.0	7910.0	1430	3740.0	3250	3865.0	2708.3	6238.7	3500 ± 982
Manganese	962.0	842.0	1120.0	1060.0	1220	1043.1	150.0	1174.5	948 ± 119
Selenium	1.7	0.5 [*]	0.4	2.4	0.9	1.3	1.2	2.3	2.7 ± 0.8
Vanadium	8.8	25.4	12.6	10.0	12.8	14.1	6.0	19.3	9.8 ± 1.3

Table 2C. Metals in Lathrop Mine 12 spoils pile and reference site (mg/kg-dry weight).

Analyte	Mine 12 Sample 1	Mine 12 Sample 2	Mine 12 Sample 3	GM	GSD	95% CI of GM	Mine 12 Composite ± 2 SD	Reference Site ± 2 SD
Arsenic	24.5	18.7	9.2	18.4	9.9	29.6	19 ± 3.3	12.1± 1.9
Copper	112.0	289.0	192	205.9	103.7	323.2	130 ± 32	322 ± 25.7
Manganese	1250.0	1410.0	1270.0	1310.9	85.9	1408.1	1130 ± 107	702± 59.3
Selenium	0.3	1.2	0.3	0.7	0.6	1.4	1.7 ± 0.6	0.3 ± 0.02
Vanadium	20.2	17.3	35.6	24.9	9.8	36.0	19.6 ± 2.2	29.6 ± 2.5

Table 2D. Lathrop spoils pile pH and electrical conductivity (mmho/cm).

Sample Site	Sample Dry Weight (g)	pH	EC (mmhos/cm)
Mine 4—Sample 1	100	8.1	5.5
Mine 4 – Sample 2	100	8.6	12.5
Mine 4 - Sample 3	100	8.0	3.1
Mine 4 - Sample 4	100	8.1	2.9
Mine 4 - Sample 5	50	7.9	3.3
Mine 4 - Composite	100	8.5	13.7
Mines 5,6,7 - Sample 1	100	8.6	12.7
Mine 5,6,7 - Sample 2	100	8.2	8.5
Mine 5,6,7 - Sample 3	100	8.2	5.0
Mine 5,6,7 – Sample 4	100	8.2	8.2
Mine 5,6,7 – Sample 5	100	8.1	6.9
Mine 5,6,7 - Composite	100	8.3	8.8
Mine 5,6,7 - Background	100	8.4	19.0
Mine 12 – Sample 1	100	7.5	1.7
Mine 12 – Sample 2	100	8.1	5.2
Mine 12 - Sample 3	100	8.1	2.5
Mine 12 - Composite	97	8.1	5.3

Table 3A. Radionuclides in Lathrop Mine 4 spoils piles (pCi/g-dry weight).

Radionuclide	Mine 4 Sample 1	Mine 4 Sample 2	Mine 4 Sample 3	Mine 4 Sample 4	Mine 4 Sample 5	GM	GSD	95% CI of GM	Mine 4 Composite ± 2 SD
Gross Alpha	277	73.2	98.0	413.0	316.0	257.3	230.2	459	303± 24
Gross Beta	213	112.0	85.4	371.0	258.0	217.5	144.4	344	271± 13
Uranium-238 ¹	(37.6)	(16.6)	(15.5)	(54.0)	(32.5)	(32.3)	(18.8)	(48.8)	(33.8± 3)
Bismuth-214	32.0	13.5	14.2	51.7	29.8	29.3	18.3	45.3	31.3± 1.8
Protactinium-234m	44.3	20.7	16.7	58.7	37.1	36.7	20.7	55	37.1± 5.1
Lead-214	35.0	14.8	15.3	57.1	32.5	32.1	20.3	49.9	33.1± 1.9
Thorium-234	39.1	17.2	15.8	48.7	30.7	31.2	16.5	45.7	33.7± 2
Radium-226 ²	58.3	16.1	22.4	64.4	40.3	42.3	28	66.8	46± 2.8

Table 3B. Radionuclides in Lathrop Mines 5, 6, 7 complex spoils piles (pCi/g-dry weight).

Radionuclide	Mines 5,6,7 Sample 1	Mines 5,6,7 Sample 2	Mines 5,6,7 Sample 3	Mines 5,6,7 Sample 4	Mines 5,6,7 Sample 5	GM	GSD	95% CI of GM	Mines 5,6,7 Composite ± 2 SD
Gross Alpha	1920	1500	660.0	626.0	567.0	1083.7	663.4	1665.2	1110 ± 46
Gross Beta	1730	1350	660.0	532.0	458.0	976.8	626.9	1526.3	984 ± 24
Uranium-238 ¹	(329.8)	(246.3)	(95.4)	(117.3)	(91.9)	(181.4)	(115.9)	(283.0)	(167.8 ± 10)
Bismuth-214	327.0	248.0	93.1	106.0	90.8	178.5	118.4	282.3	174 ± 10
Protactinium-234m	320.0	240.0	97.1	127.0	90.1	179.9	109.9	276.3	183 ± 12
Lead-214	359.0	272.0	101.0	116.0	99.7	195.6	130.5	309.9	191 ± 11
Thorium-234	313.0	225.0	90.5	120.0	87.0	171.9	106.7	265.5	123 ± 7
Radium-226 ²	704.0	500.0	203	250.0	138.0	375.7	281.0	622.0	384 ± 22

Table 3C. Radionuclides in Lathrop Mine 12 spoils pile and reference site (pCi/g-dry weight).

Radionuclide	Mine 12 Sample 1	Mine 12 Sample 2	Mine 12 Sample 3	GM	GSD	95% CI of GM	Mine 12 Composite ± 2 SD	Reference Site ± 2 SD
Gross Alpha	22.0	17.3	11.8	19.8	3.4	23.6	11.6 ± 7	67.3 ± 12
Gross Beta	38.7	40.6	43.0	39.7	1.3	41.2	31.4 ± 6	90.6 ± 8
Uranium-238 ¹	(3.71)	(3.48)	(1.7)	(3.6)	(0.2)	(3.8)	(2.1 ± 0.6)	(15.1 ± 2)
Bismuth-214	3.42	3.38	1.85	3.4	0.03	3.4	2.00 ± 0.1	20.2 ± 1
Protactinium-234m	3.95	3.39	2.07	3.7	0.4	4.1	1.85 ± 2	10.1 ± 3
Lead-214	3.71	3.75	2.02	3.7	0.03	3.8	2.16 ± 0.1	21.9 ± 1
Thorium-234	3.76	3.39	0.66	3.6	0.26	3.9	2.36 ± 0.3	8.27 ± 1
Radium-226 ²	2.44	7.26	3.80	5.7	5.1	11.4	4.52 ± 0.4	26.4 ± 2

¹ Due to time limitations on this study, radionuclides were analyzed by gamma spectroscopy, which is faster than other analytical methods. Uranium-238 has no gamma emission, therefore EPA's lab was unable to measure it directly. The values in parentheses shown above were derived by averaging the values measured for Bismuth-214, Protactinium-234m, Pb-214, and Thorium-234, which seem to be in secular equilibrium. Radium 226 was not used for this average due to erratic values, as discussed below. [Richard – I realize you may want to treat this differently, or at least want to re-word what I've said here, but I did not want to misrepresent the data by implying that the U238 levels were measured directly.]

² Radium-226 does not appear to be in secular equilibrium with the other daughter products of radon. The authors believe the erratic values for Radium-226 are due to laboratory error. XXXX, which has an alpha activity of 4.1 MeV, was used as the standard for analyzing Radium-226. The other analytes were measured using XXXX as the standard, which has an alpha activity of 4.4 MeV, which would yield a lower number for Radium-226. Adding to this discrepancy, Uranium-235, which typically occurs as about 0.7% of total uranium, can easily be mistaken for Radium-226 in analysis due to its similar spectroscopic signature. If mis-analyzed, this could add to the values for Radium-226. [Richard – Again, edits welcome.]

The analytical results for water samples prior to the log transformation are shown in Table 4. Table 5 shows the geometric mean, geometric standard deviation, and the 95% confidence interval of the geometric mean for the collected samples. The results for water samples collected in the ephemeral stream running throughout the Lathrop Canyon drainage are log-normally distributed. The background or reference samples taken up-gradient from the spoil piles showed elevated levels of dissolved manganese and vanadium compared with water samples collected immediately down-gradient from the piles. The dissolved concentrations between the reference up-gradient samples and the in-stream samples immediately down-gradient from the spoils, though significantly different at the 95% confidence level, do not appear to cause impairment to terrestrial and aquatic ecological receptors within Lathrop Canyon, with the possible exception of copper and selenium. This conclusion is based upon comparison of the water concentrations to known human and ecological screening toxicity levels shown in Table 7. It is important to note, however, that copper levels down-gradient from the mines were lower than background, and both copper and selenium dropped off markedly just 150 feet down-gradient of the mined area.

Table 4. Water samples in Lathrop Canyon (µg/L).

Analyte	<u>Sample 1</u> Reference: Up-gradient of Chinle Formation	<u>Sample 2</u> Reference: down-gradient of Chinle Formation, before mines	<u>Sample 3</u> main Lathrop channel between Mines 9-12 and Mines 1-8	<u>Sample 4</u> Mines 5,6,7 drainage above main Lathrop channel	<u>Sample 5</u> Mine 4 drainage 125 feet above main Lathrop channel	<u>Sample 6</u> 150 feet down- gradient of Mine 4 drainage in main Lathrop channel
Arsenic	14.30	25.50	27.10	20.00	14.50	22.0
Copper	44.20	13.70	7.89	43.80	35.30	16.10
Manganese	556.0	856.0	9.11	2.10	88.20	65.40
Selenium	2.95	2.95	7.14	14.90	57.80	17.80
Vanadium	61.0	38.0	11.20	2.93	6.43	9.41

Table 5. Water sample results collected in Lathrop Canyon (µg/L) after log transformation.

Analyte	GM of Up-gradient Water Samples 1 and 2	GSD of up-gradient water Samples 1 and 2	95% CI of GM for up-gradient water Samples 1 and 2	GM of down-gradient water Samples 3 - 6	GSD of down-gradient water Samples 3 - 6	95% CI of GM for down-gradient water Samples 3 - 6
Arsenic	20.7	9.0	33.2	20.7	5.8	25.4
Copper	34.7	34.4	82.4	28.6	23.4	47.4
Manganese	722.8	255.8	1035.6	907.6	11652.9 (?)	13428.9 (?)
Selenium	2.95	0	2.95	19.3	32.3	45.1
Vanadium	51.0	17.5	75.2	24.4	39.3	55.8

[Richard – Could you please explain log transformation and what it means / does?]

Dissolved gross alpha and beta screening level tests were collected and analyzed as shown in Table 6. Although it appears that the spoil piles are leaching into the stream, a more detailed analysis of uranium-238 and radiological decay products in the U-238 series shows only minor radionuclide contributions from the piles based upon Radium-226 detections in Mine 4. Care must be taken as the screening level gross alpha test indicates all sources of naturally occurring radionuclides that emit alpha/beta particles. Incorrect assumptions can be made without detailed analysis for specific radionuclides that contribute to gross alpha or gross beta contamination. Further radiochemical analyses are currently being conducted to elucidate this study and the implications of potential environmental impacts from these uranium leachates.

Table 6. Radionuclide concentrations in Lathrop Canyon water (pCi/L).

Radionuclide	Sample 1 Reference: up-gradient of Chinle Formation	Sample 2 Reference: down-gradient of Chinle Formation, before mines	Sample 3 Main Lathrop channel between Mines 9-12 and Mines 1-8	Sample 4 Mines 5,6,7 drainage above main Lathrop channel	Sample 5 Mine 4 drainage 125 feet above main Lathrop channel	Sample 6 150 feet down- gradient of Mine 4 drainage in main Lathrop channel
Gross Alpha	34±18	14±12	62±24	210±56	554±200	255 ± 57
Gross Beta	48±26	13±21	67±28	224±40	983±190	335 ± 46
Uranium-238	ND*	ND	ND	ND	ND	ND
Lead-214	ND	ND	ND	ND	ND	ND
Thorium-234	ND	ND	ND	ND	ND	208±150
Protactinium-234m	ND	ND	ND	ND	703±1200	ND
Radium-226 ³	145±230	132±200	ND	224 ± 220	521±230	141±230

* ND - Non-detect: below analytical detection levels.

Table 7. Human and ecological receptor toxicity screening concentrations.

Analyte	Human – drinking water Ecological / Terrestrial (rats – NOAEL ⁴) Ecological / Aquatic (fish – NOAEL)	Reference
Arsenic	50 µg/L 5 mg/kg (mg/kg/day?) 190 µg/L	EPA Drinking Water Standards; NAWQC ⁵
Copper	1.3 mg/L 140 mg/kg (mg/kg/day?) 12+ µg/L	EPA Drinking Water Standards; Stoking, H.E. 1981; NAWQC
Manganese	50 µg/L 10 mg/kg (mg/kg/day?) 1100 µg/L	EPA Drinking Water Standards; ATSDR ⁶ , 1998; Suter, 1994.
Selenium	50 µg/L 6,700 mg/kg (mg/kg/day?) 5 µg/L	EPA Drinking Water Standards; Cummins and Kumura, 1971; Proposed EPA NAWQ, 1998.
Vanadium	5 mg/L 2 mg/kg (mg/kg/day?) 80 µg/L	ATSDR-1991; ATSDR-1991; Suter, 1994.
(Total?) Uranium	30 µg/L 0.05 mg/kg (mg/kg/day?) 200 µg/L	EPA Drinking Water Standards; ATSDR-1999 Hyne et al., 1991
Radium-226 ?	? ? ?	? ? ?

³ The high level of uncertainty of the Radium-226 values is due to the small sample sizes (200 ml). After the analysis was complete the lab stated that 1-gallon samples would have been necessary to achieve a more reasonable level of uncertainty.

⁴ No observable adverse effects level. Units are milligrams of contaminant per kilogram of the receptor (per day?).

⁵ National Ambient Water Quality Criteria – Effects on fish.

⁶ Agency for Toxic Substances and Disease Registry

Table 8 depicts calculated distribution coefficient (K_d) values for each sampled spoils pile in Lathrop Canyon. This value was determined using the 95% confidence interval of the geometric mean for both soil and water samples. K_d parameters are very important in estimating the potential for the adsorption of dissolved contaminants in contact with soils. K_d values are defined as the ratio of the contaminant concentration associated with the solid to the contaminant concentration in the aqueous solution, assuming equilibrium conditions.

Table 8. K_d values calculated in the Lathrop Canyon drainage
(95% CI spoils samples / 95% CI of surface water samples).

Analyte	Mine 4	Mines 5, 6, 7	Mine 12 Composite	Reference Site
Arsenic	1.8	9.4	1.1	0.4
Copper	21.0	115	6.0	4.0
Manganese	2.1	2.50	3.0	0.70
Selenium	0.02	0.04	0.03	0.10
Vanadium	1.03	1.5	2.8	0.40

External gamma and alpha radiation measurements taken in the sample trenches during the fieldwork are shown in Table 9. External gamma radiation results were recorded at ground level in both counts (disintegrations) per second (cps) as well as in microRoentgens per hour ($\mu\text{R/hr}$) radiological exposure units, as measured with Mt. Sopris® Model 132 and Exploranium® GR-130 hand-held radiation survey instruments, respectively. Alpha radiation levels from radon progeny were recorded in Working Levels (WL) units, where $1\text{WL} \approx 200 \text{ pCi/L}$. To obtain alpha readings, 5-liter air samples were passed through a filter paper using an air sampling pump (running 2 minutes at 2.5 liters per minute) under a tarp covering each trench, then the filter paper was analyzed onsite with an MDA® Model 811 Instant Working Level Meter.

Table 9. External radiation levels measured in Lathrop Canyon spoil piles.

Radiation Monitoring Instrument	Mine 4 Spoil Piles	Mines 5, 6, 7 Spoil Piles	Mine 12 Spoil Pile	Reference Site
Mt. Sopris® (cps)	600-680	3600-3800	150-180	80-120
Exploranium® ($\mu\text{R/hr}$)				
General range:	80-100	300-340	12-15	9-12
Maximum reading obtained:	220	440	20	
MDA® Model 811 (WL)	0.02	0.02	0.01	0.01

CONCLUSIONS

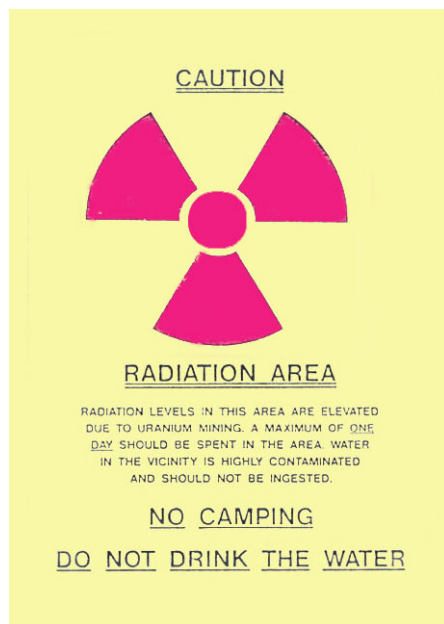
This study showed that the mineralized spoil piles were heterogeneous in nature as would be expected in most mining operations. Therefore sampling of piles with hand augers or composited augered samples would not be representative of mineral concentrations unless horizontal strata were sampled through the entire depth of the pile and analyzed. Uranium and uranium decay products were analyzed in this study with hand-held field instruments. Analysis of composited soils samples throughout the pile showed fairly good correlation with these external radiological readings. For instance, the external gamma radiological monitoring showed that the Mine 4 and the Mine 5, 6, 7 complex waste piles were elevated in uranium decay products (principally Ra-226 per “in situ” NaI(Tl) [What’s this?] detector in Exploranium®, GR-130), as borne out by soils sample analysis for those piles. However, external gamma radiological readings by themselves cannot be used to determine potential leachability and toxicity of the spoil piles.

Spoils mineral leaching was not evident in the opportunistic water samples analyzed during this sampling event. Whether erosional processes occurred immediately after the waste piles were deposited is unknown, but speculated. Spoil materials are not readily evident in the down-gradient drainages. Leaching maybe retarded due to circum-neutral soil pH. Without acid or basic soils modifying the sorption bonding of the mineral to the soil matrix, leaching may be minimized. Another factor that may reduce the leaching of minerals out of the spoils piles may be the elevated manganese concentrations in the background geological formations from which the ore was extracted. In the Lathrop Canyon area “desert varnish,” a micro-thin patina composed of manganese and iron oxides, may aid in covering the surfaces of rocks in the canyon country and inhibit the leaching process. The leaching process could further be inhibited by salts left behind from evapotranspiration of water from the surface of the spoils piles. In-situ K_d values show evidence, confirmed in water analysis, that copper may pose toxic concentrations to aquatic receptors. Manganese, although elevated approximately 5 times above reference site conditions, does not appear to indicate leachability, although water samples were elevated. Elevated selenium concentrations evidenced in the water samples was not confirmed by its corresponding K_d value.

Human and ecological risks were evaluated during this study using screening level toxicity values. The major source of impact from the spoil piles would arise, not from oral or inhalation pathways, but from drinking water near the spoils piles. However, by comparing human drinking water standards (which are health risk based) to the surface water concentrations sampled onsite, the data (within 2 standard deviations) indicate that human health is not impacted. The major human health concerns appear, instead, to be health and safety issues pertaining to underground mine features, spoil bank grades, and gamma radiation exposure emanating from radium-226 left in the piles. Alpha radiation from radon decay products was not elevated in the sample trenches primarily due to the environmental dilution of the emanations in fresh air, but would be expected if enclosures such as tents were allowed on the spoils piles, or if access underground were permitted. In both of these cases, alpha radiation would be elevated due to restricted dilution with fresh air from outside.

The NPS and AMRP have closed these remote openings with nets made of ½-inch braided stainless steel cable, and posted radiation warning signs (Figure 2) within view just behind the closures. These signs display the international symbol for radiation hazards printed in the traditional magenta on yellow. Perhaps due to the remote setting and people’s fear of radiation, reinforced by the warning signs, the closures have not been compromised since they were installed in 1989. With the underground workings closed off, the threat of individuals encountering rock fall, elevated radiation, or other underground hazards is effectively mitigated. There is little likelihood of anyone spending enough time in the spoils areas outside the mines to receive a significant dose of gamma radiation. Spoil bank grades have not been reduced, but they are typical of natural colluvial slopes in the area. Due to the time-proven effectiveness of the closures and signage as well as the data gathered in this study, the NPS and AMRP maintain that the Lathrop Canyon Mines now pose minimal risk to human safety and health. A follow-up risk assessment will be performed to further substantiate this position.

Figure 2. Radiation warning sign.



The primary ecological receptors of concern are the mammals and birds [Herps?] residing in the area that may be exposed through ingestion of water in ephemeral down-gradient streams and pools, incidental ingestion of spoil material, and exposure to external gamma radiation from radium-226. There are no federally or state-listed threatened and endangered species in the area. Caddis fly larvae, indicative of good water quality, were found in the main drainage immediately below the mines. The small mammals in the area are not particularly dependent upon standing water in the drainage. They have highly effective metabolic systems that enable them to extract water from the fats stored in seeds and excrete high nitrogenous, high-solid, low-water urine. The larger mammals that use the area have large foraging ranges, which minimizes impacts from the spoil materials and ephemeral streams on these receptors. The same holds true for birds in the area, some of which are migratory, further diluting the impacts of these mine wastes. The bighorn sheep and mule deer fawns [why just fawns?] that frequent the area would be the receptors of major concern due to the societal and ecological value of standing water when it occurs in this ecosystem. After reviewing the water and spoil contaminant concentrations and noting the lack of vegetation on the spoils piles that might be ingested, it appears that the most likely route of toxicity would come from direct ingestion of water. Since the area is semi-arid, experiencing sporadic infrequent rains primarily in the months of April and May and again in the monsoon season of late July through early September, most streams in the area are ephemeral, supporting aquatic life only during these months of sporadic water flow. During the seasonal, infrequent, and often violent water flows in this drainage, most leachates out of these piles would be diluted.

In summary, it does not appear that ecological receptors are being adversely impacted at the populational level from the Lathrop Canyon Mine spoils piles due to: 1) dilution of leachates; 2) wide foraging range of large mammals and birds with choice of a variety of pools and water holes in the area; 3) short reproductive life [first mention of this... should discuss earlier if this is a summary] of aquatic species and small mammals; 4) adaptation to semi-desert environment; and

5) high toxicity levels of most of the metals to aquatic and ~~mammalian~~ terrestrial (?) species. This initial conclusion should be corroborated by natural resource inventories in the area. The NPS and AMRP appear to be justified in their decision to leave the spoils piles in-place.

This study looked at various methods that land management agencies might use to determine potential impacts from abandoned mines, waste piles, and subsequent leachates on human and ecological health. Many abandoned mine mitigation efforts are poorly funded and could not bear the cost of sampling events similar to the one used for this paper. However, it does appear that field instruments that measure soil pH and electrical conductivity are beneficial in trying to determine whether spoils material is leaching into ephemeral streams. It also appears that soil K_d measurements are valid in showing whether various minerals are leaching into the environment, but this measurement would require soil and water analytical analysis for confirmation. Soil sieving (at least to 8 mesh) is beneficial to analysis, as the resulting increase in soil surface area aids in the determination of leachable contaminants. At abandoned uranium and vanadium [first mention of this ... probably should mention earlier, perhaps in the intro] mines, radiation meters that indicate external dose readings from uranium decay products, and meters that can determine *in situ* radium concentrations may give a good indication of surface contamination and possibly reduce the number of samples necessary for site characterization. This would assist the land management agency in determining potential human health concerns and in deciding whether engineering controls were needed to prevent occasional recreational users from needless exposure to elevated radiation levels. However, these meters would yield no information on leachability of spoil materials or anticipated concentrations of contaminants in down-gradient, nor would they be useful in determining impacts at depth in the spoil piles due to the attenuating effect of overlying material. Stream pH and conductivity meters are useful in determining potential metal mobility or metal binding. Global positioning systems are beneficial in determining grid coordinates of sample locations and the spoils area, which, in turn, provides an estimate of spoil pile volumes and maps of variability in contaminant concentrations.

The data collected for this effort will be incorporated into a larger EPA study on uranium mine TENORM wastes. In areas less remote than Lathrop Canyon, accessible or inhabited by larger numbers of people, or in areas with threatened, endangered, and ecologically sensitive species, the conclusions on impacts or remediation described herein may not be applicable. Elsewhere certain abandoned uranium mines have been listed as EPA Superfund Sites under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). However, this particular field effort provides a snapshot of the fate and hazards of uranium mine TENORM in small and remote sites typical of the Colorado Plateau Region. The data sets presented are useful in understanding the radiochemical and heavy metals erosion and transport from unremediated sites.

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