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Contaminant Concentrations In Water and Bryophytes Found in Four Springs Along the Upper Rio Grande In New Mexico

Ralph Ford-Schmid, Michael Dale, Dave Englert, Kim Granzow

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New Mexico Environment Department
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Forward

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Abstract

In November of 2003, The RadioAcivist Campaign (TRAC) published a report identifying detectable cesiusm-137 in water and bryophytes (aquatic mosses) from spring 4A located below Los Alamos National Laboratory (LANL) near the Rio Grande in White Rock Canyon. The report stated that this cesium-137 was of LANL origin was the first confirmed detection of LANL radioactivity entering the Rio Grande from a groundwater pathway. In 2004, the New Mexico Environment Department DOE Oversight Bureau, collected and analyzed samples of bryophytes and water from Springs 4A and 4C (a nearby spring) and two springs (Big Spring and Hemingway Spring) located 70 km and 125 km upstream on the Rio Grande. Springs 4A and 4C show anthropogenic impact/influence such as elevated tritium, chloride, nitrate, and perchlorate. While this indicates that some portion of recharge to the springs is of a young age (<50 years) and possibly from past LANL discharges, we could not confirm the TRAC detections of cesium-137 in water or bryophytes at Springs 4C or 4A using the best analytical technology available to NMED.

Springs 4A and 4C discharges discharge from the upper portion of the regional aquifer or from deep perched intermediate zones beneath the Pajarito Plateau. As noted earlier, Springs 4A and 4C show anthropogenic impacts indicating some portion of recharge that is of a shallow/youthful source. The two upstream springs discharge from Rio Grande Basin sediments and are tritium-free indicating very old (>100 years), and are used here to represent background conditions.

Water samples from the four springs were analyzed for cesium-137, tritium, perchlorate, strontium-90, plutonium-238, plutonium-239, anions, cations, dissolved and total metals. Bryophytes were dried for perchlorate analysis, and reduced to ash for analysis for cesium-137 and other gamma emitting radionuclides, strontium-90, plutonium-238, plutonium-239, and total metals. Water samples were purged through a series of filters to determine if colloidal or dissolved cesium-137 was detectable in the spring waters. Approximately 100 liters of water were filtered through 0.45μ and 0.2μ cellulose filters followed by a 0.1μ 3M Empore ™ Cesium Rad Disk. The 0.2 μ filters were digested and analyzed to determine if detectable levels of greater than 0.2μ (and less than 0.45μ) colloidal bound cesium-137 were present in the water and the Cesium Rad Disks were used to extract any dissolved cesium or colloids <0.2μ but >0.1μ. These methods reduced cesium-137 detection limits by two orders of magnitude in both dissolved water and bryophytes.

Cesium-137 and strontium-90 were not detected in any of the spring waters or bryophytes. Perchlorate was not detected in any bryophyte samples but was detected in all four spring-water samples. The uranium isotopes 234, 235, 238 were detected in all bryophyte and spring water samples; with the exception that uranium-235 was not detected in Springs 4A and 4C water. Plutonium-239 was not detected in any spring waters but was detected in all bryophyte samples. Plutonium-238 may have been detected in both bryophyte and water samples at Spring 4C but was not detected in any other spring or bryophyte sample. Concentrations of gamma emitters detected in bryophytes were generally low and near detection limits. When concentrations of metals or radionuclides in both water and bryophyte tissue were greater than detection limits, bioconcentration factors were calculated.

Introduction

The New Mexico Environment Department (NMED) Department of Energy Oversight Bureau (DOE OB), and Los Alamos National Laboratory (LANL) have analyzed springs in White Rock Canyon for cesium-137 for many years and have never detected it in water. The detection limits in water reported by TRAC were three orders of magnitude more sensitive than those reported by LANL or NMED.

Many springs discharge ground water from the regional or drinking-water aquifer beneath the Pajarito Plateau to the Rio Grande in White Rock Canyon. LANL, as well as the Environmental Protection Agency, and NMED, have performed chemical testing on these springs over the past 20 years. One group of springs that occur in the vicinity of the junction of Pajarito Canyon and the Rio Grande is called the 4 series springs. The 4 series springs contain elevated or above background levels of the more pervasive contaminants such as chloride, nitrate, and sulfate compared to that of other regional-aquifer springs located to the north and south. The 4 series springs contain roughly twice as much perchlorate (0.4 to 0.6 ug/L or ppb) as do the springs to the north and south and a tritium anomaly exists at the 4 series springs. While this indicates a potential LANL impact to these springs, the presence of cesium-137 has not previously been documented in the 4 series springs.

TRAC sampled both unfiltered water and bryophytes found growing in the springs below LANL. There has been no previous work using bryophytes as a media for contaminant monitoring on the Pajarito Plateau though the U.S. Geological Survey has demonstrated that transplanted bryophytes can effectively bioconcentrate metals (Carter & Porter 1997, Nelson & others 2000, Mize & Deacon 2002). Aquatic bryophytes show potential for bioaccumulation studies and as bioindicator organisms (López & Carballeira 1993) and studies with transplanted bryophytes show significant differences in bryophyte trace-element concentrations can be found after as few as 10 days exposure to ambient conditions (Carter & Porter 1997, and Mize & Deacon 2002). Many radionuclides released by LANL or found in atmospheric fallout are metals and may also bioconcentrate in bryophyte tissue. Bryophytes are ubiquitous in nature and they exhibit a high resistance to pollution (López & Carballeira 1990), allowing for bioaccumulation over long-term exposure. Bryophyte samples from this study were classified to the lowest possible taxa to evaluate whether species-specific differences in bioconcentration exist.

This study compares contaminant concentrations in water and bryophytes found in two of the 4 series springs located down gradient from LANL and two springs located 80 km and 120 km upstream from LANL. All springs discharge into the Rio Grande from the west. Water and bryophytes were collected from spring 4A (the spring referenced in TRAC's report) and spring 4C (located approximately 0.4 km east-northeast from Spring 4A) in White Rock Canyon on the Rio Grande. Water and bryophytes were also collected from two springs located 80 km (Big Spring) and 120 km (Hemingway Spring) upstream from the White Rock Canyon springs for comparison purposes. A field duplicate of bryophytes and water from Big Spring, one of the upstream springs, was also collected. The study was expanded to include other analytes besides Cs-137 and includes tritium, perchlorate, strontium-90, plutonium-248, plutonium-239, metals, and gamma emitting radionuclides that may also be present if LANL waste disposal practices were the source of contamination.

Methods

Previous NMED and LANL analyses of Cs-137 in water provided detection limits several orders of magnitude higher than those reported by TRAC. To decrease the analytical detection limits for cesium-137 in water for this study we pumped approximately 100 liters of water through a series of filters, the last of which was a 3M Empore ™ Cesium Rad Disk. Empore Cesium Rad Disks combine an Empore ™ membrane with potassium cobalthexacyanoferrate crystals to selectively adsorb dissolved cesium in the presence of other common ions. Cesium-137 is then counted directly from the surface of the disk for an extended count time of 1000 minutes.

The presence of cesium-137 in water collected from the springs, if confirmed, could potentially be from several sources. Atmospherically deposited fallout from above ground nuclear weapons testing could be bound to particulate material present in the water sample. LANL has historically disposed of industrial radioactive waste by pumping sludge and liquids into unlined shafts or pits located on the Pajarito mesa. Liquid radioactive waste, both treated and untreated has been discharged directly into the canyon systems at LANL.

Radionuclides including strontium, cesium, and plutonium have traveled greater distances than expected from beneath leaking tanks at the DOE facility at Hanford, Washington. Colloid facilitated transport of contaminants is suspected to play a role in this enhanced mobility and solubility of the radionuclides in the subsurface (Auman, 2002). The detection of plutonium in groundwater some 3400 m downstream in Mortandad Canyon at LANL is cited widely as an example of colloid facilitated transport (Penrose et al., 1990). However, more recent review of these data suggests that Pu detected in downstream wells could not have entered through groundwater and thus the potential for Pu migration via colloidal transport may have been overstated (Marty et al., 1997).

To account for particulate or colloidal bound Cs-137 in samples of spring water, we pumped all samples through a 0.45 μ filter, then through a 0.2 μ filter prior to the Cesium Rad Disk. The pre-filters removed any particulate or colloidal material that could have plugged the 0.1 μ Cesium Rad Disk and assured that only dissolved cesium, or colloidal particles with a diameter less than 0.2μ and >0.1μ were collected by the Rad Disks. The 0.2 μ filters were also digested and analyzed separately to determine any colloid or particulate contribution to the concentration of Cs-137 in the spring waters. The 0.45 μ filters were archived and not analyzed for this study.

Low-level methods were also used for tritium, perchlorate, and plutonium in water. Washed bryophyte samples were reduced to ash (approximately a 100 to 3 reduction) and analyzed using larger sample sizes (10 grams) and longer count times (1000 minutes) to reduce detection limits for radionuclides. These methods reduced detection limits as far as practical using technology available to NMED.

Water Sampling Methods

Whole-water (unfiltered) samples were collected from springs and analyzed for total metals, perchlorate, isotopic plutonium, isotopic uranium, strontium-90 and low-level tritium. Samples for total plutonium, total uranium, total strontium, and total metals were preserved with nitric acid to a pH <2 and stored at 4 ^{o}C. Samples for tritium and perchlorate analyses were stored at 4 ^{o}C with no additional preservative.

- High-resolution alpha spectrometry methods were used to analyze total plutonium in water.
- High-resolution methodology was used for tritium analyses.
- High-resolution methods were used for dissolved metal analyses
- Perchlorate was analyzed using both high-resolution liquid chromatography MS/MS and low-resolution MS methods.
- Standard methods were used for the total strontium-90 and total uranium alpha spectrometry and total metal analysis.

Dissolved water samples (filtered through a 0.45μ filter) were analyzed for anions, cations, and dissolved metals. Field parameters such as temperature, conductivity, and pH were also collected at each spring.

Cesium-137 in Water

Figure 1. Collecting 10 liter sample for Cs-137 analysis from Spring 4C

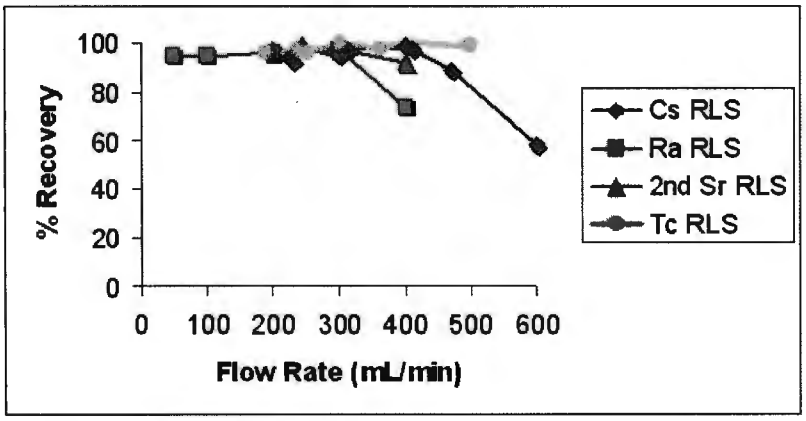
Researchers collected water for Cs-137 analysis by dipping a clean, rinsed container into the spring and filling a ten-liter container (Figure 1). The water was then pumped from the ten-liter container through three filters in series (Figure 2), repeating the process until at least 100 liters has been filtered. The first filter is a 0.45μ filter to remove particulate mater. The 0.45μ filters were changed as required and archived for future analyses if necessary. The next filter in series is a 0.2 μ celluloid filter. The 0.2 μ is intended to remove any colloid material less than 0.45 μ but greater than 0.2 μ to prevent the final 0.1 μ 3M Cesium Rad Disk™ from plugging. The 0.2 μ filters were changed as required and stored on ice for Cs-137 analyses. One sample from Hemingway Spring was collected using the3M Cesium Rad Disk filter only. The filter

plugged after 50 liters was passed through it. Results of the analyses of that disk showed non-detect for Cs-137.

Figure 2. Apparatus used to sample Cs-137 through a series of filters, 0.45μ filter, 0.2 μ filter and 3M Empore™, Cesium Rad Disk (blue - far right)

The final filter in series is a 3M Rapid Liquid Sampler™. The filter is a 3M Empore™, Cesium Rad Disk, contained in a plastic housing. It is intended for solid phase extraction of Cs-137 from water for analyses. The 3M Rapid Liquid Sampler™ is effective at > 95 percent Cs-137 removal efficiency if flow rates are kept below 400 ml/minute (Figure 3). All flow rates through the Cesium Rad Disks ranged from 100 to 300 ml/minute. All water passed through the filter array was captured in plastic buckets and measured using a graduated Erlenmeyer flask to determine total volume sampled. All cesium-137 results for the filters were converted from pCi/sample to pCi/L by dividing the analytical result by the volume of water passed through each filter.

Figure 3. Percent Recovery versus Flow Rates for Various 3M Rad Disks (graph provided by David Seely of 3M Filtration Products)



To determine the effectiveness of the 3M Empore™ Cesium Rad Disk at accurately measuring cesium-137 at low levels, a matrix spike sample was prepared by adding a known amount of cesium-137 to twenty liters of water collected from Big Spring, one of the upstream springs. The sample was processed with the same sampling procedures used in the field.

Bryophyte Preparation Procedure:

Figure 4. Washing bryophytes at Spring 4A

Bryophytes were sampled from each spring and analyzed for 23 trace metals, total perchlorate, total isotopic plutonium, total isotopic uranium, total strontium, gamma emitting radionuclides, and total Cs-137.

The bryophytes were washed in ambient spring water eight times to remove senescent material, aquatic insects, soils and sediment. Small samples of bryophytes were placed in five-gallon containers of water, broken into smaller pieces, agitated, and then transferred into another container with a small colander (screened scoop) and the process repeated eight times. The final step in the field processing of the bryophyte sample consists of packing the sample into a plastic mesh bag, which is then swung in a circular motion, using centrifugal force to remove excess moisture. The samples were spun till dry enough so that when squeezed in hands, they would not drip moisture. The samples were stored in labeled zip-lock bags and kept cool until further processing (drying, ashing). A small portion of the sample was set aside and stored in a labeled paper bag for identification to the lowest possible taxa by a trained bryologist.

Drying of the bryophytes is a two-step procedure. The bryophytes were placed in a tarred container, weighed (initial net weight of fresh bryophytes is recorded), and then air dried at 75 ^{o} C until no further weight loss was measured after continued drying time. The net dry weight was then recorded. Net dry weight divided by net fresh weight equals the dry/fresh ratio.

Ten grams of dried material was removed from the batch of dried bryophytes and placed in a labeled glass container for perchlorate analysis and stored in a freezer till shipped for analysis. In addition, approximately 35 grams of dried bryophytes from Hemingway Spring and Spring 4C was shipped to Norm Buske of TRAC for independent analyses using TRAC's methodology. Their results and conclusions can be seen at http://www.radioactivist.org/NMEDbryophytesresults.pdf.

Figure 5. Washed bryophytes sample ready for spin-drying

The container was again weighed and returned to the hood where it is dried at 400 ^{o} C, this temperature being sufficiently low to avoid the loss of volatile cesium-137 that can occur at 500 ^{o} C. The samples were dried till the samples were a white ash consistency and no further weight loss was noted. The net ash weight divided by the net dry weight is equal to the ash/dry ratio. All analytical results were reported as mg/kg ash weight (metals) or pCi/g ash weight (radiological). The concentration found in ash was multiplied by the ash/dry ratio to convert results to dry weight measurements for the purposes of this report. To convert the dry-weight values reported to fresh-weight concentrations, multiply the dry-weight values by the sample-specific fresh/dry factor found in Table 1.

After the first set of samples of bryophytes were dried, it became apparent that additional bryophyte material from each spring would need to be collected to complete all planned analyses. A second sampling of each spring was completed and the bryophyte samples were dried. Aliquots of dry bryophytes from each sampling trip (with different dry/fresh ratios) were combined prior to reducing to ash. The final dry/fresh ratios is weighted to account for the combination of varying weights of bryophytes at different dry/fresh ratios using the following formula:

$$\text{Final Dry/Fresh Factor} = \frac{(\text{Net Dry (A)} * \text{Dry/Fresh Factor (A)}) + (\text{Net Dry (B)} * \text{Dry/Fresh Factor (B)})}{\text{Total Dry (A+B)}}$$

Each sample has unique dry/fresh ratios and ash/dry ratios. These were used to convert each sample's ash weight results to dry weight results for reporting purposes. Table 1 lists each sample specific conversion factor determined from the drying/ashing process.

Table 1. Fresh to Dry, Dry to Ash, and Fresh to Ash reduction factors for bryophytes from Spring 4A, 4C, Hemingway Spring, and Big Spring

Sample ID	Fresh / Dry Factor	Dry / Ash Factor	Fresh / Ash Factor
Spring 4A - Moss	0.201	0.113	0.023
Spring 4C - Moss	0.206	0.136	0.028
Big Spring -Moss	0.258	0.114	0.029
Big Spring - Moss (Field Dup.)	0.239	0.117	0.028
Hemingway Spring - Moss	0.218	0.115	0.025
Average	0.224	0.119	0.027

Quality-Assessment Procedures

Quality assessment procedures were followed to ensure the consistency and accuracy of the data collection. Quality-control procedures for both the water-chemistry and bryophyte samples included analysis of one field-duplicate sample (25.0 percent of sample size). A field-duplicate is a sample that is used to determine the variability associated sample processing, handling, shipment, and analysis. A field-duplicate sample of water was obtained by collecting two samples, one immediately after the other. Water field-duplicate samples were collected for all water analyses except for dissolved metals. The Cs-137 in water field-duplicate was collected by setting up two pump and filter arrays which pumped water in parallel from the same 10 liter container into separate containers for volume measurement. Duplicate bryophytes samples were collected and processed as one sample and split into two samples of equal mass prior to shipment to the lab for drying and analysis. A matrix-spike sample was also prepared to evaluate the effectiveness of the 3M Cesium Rad Disk at capturing the Cs-137 in water using the same sampling equipment used in the field.

Precision is estimated by means of duplicate/replicate analyses. Duplicate/replicate samples should have analyte concentrations above the method detection limit (MDL) and may involve the use of matrix spikes (USEPA 1998). Precision is expressed as the relative percent difference (RPD) between field duplicate measurements, which is calculated as follows (USEPA 1998):

$$RPD = \left(\frac{X_1 - X_2}{(X_1 + X_2)/2} \right) \times 100$$

where,

RPD = Relative Percent Difference (%)
X1 and X2 = Duplicate measurements of the same sample

The smaller the RPD, the more precise are the measurements. The usability of duplicate measurements is assessed during data validation by comparing RPDs for field replicate measurements to established control limits (CLs). Because measurements near the MDL (defined as less than two times the MDL) are extremely imprecise, ± 200 % is considered to be the best possible level of precision in practice (U.S. Fish and Wildlife Service 2003). Therefore, for near-detection limit analyses (defined as less than two times the MDL), CLs for precision range from zero (no difference between duplicate control samples) to ± 200 %. When analyte concentrations are greater than two to 10 times the MDL, the CLs for precision range from zero to ±20%, and when the analyte concentrations are greater than 10 times the MDL, the CLs for precision are zero to ±10%. Data for these QC procedures are obtained by analyses of replicate, split and spiked samples, and blanks.

The field-duplicate results indicate that when total metal water concentrations were high (in the milligram per liter range) the differences between field-duplicate concentrations were generally within one percent. In metal analyses of ashed bryophyte samples, average difference between

field-duplicate concentrations was four percent with the exception of lead and cobalt, which had 9.4 and 35.6 percent differences respectively. Both lead and cobalt had detection and non-detection in either the field-duplicate or control sample. The average RPDs between laboratory duplicates and the original samples were 0.7 percent. The small differences in the field duplicates and laboratory duplicates indicate that sample processing and analysis did not introduce enough variation to affect interpretation of metals results in water or bryophytes.

One of the upstream sample locations, Big Spring, was use to collect the matrix spike sample. The matrix spike sample consisted of collecting 20 liters (20 percent of other Cs-137 sample size), adding a known concentration of Cs-137 and running it through the same filtering apparatus in series used for all other Cs-137 samples. The RPD between the sample result and the expected result was 4 percent (Table 8). The analytical laboratory also ran a duplicate analysis of the filters and obtained a 1 percent difference between the sample and expected result. The expected concentration was close to the method detection limit (approximately 2 times the detection limit) and demonstrated the filters effectively removed 96 to 99 percent of Cs-137 present in the sample. The duplicate error ratio (DER), explained below, between the Big Spring matrix spike (3M) filter and the lab duplicate was 0.114 indicating that the duplicate and the sample results are statistically equivalent.

In the comparison of radiochemistry results the total propagated uncertainty, which includes the random and systematic uncertainties involved, must be evaluated with the results to determine the validity of the duplicate measurement. This is accomplished by evaluating the DER, which is defined as:

$$DER = \left(\frac{/S - D/}{2 * \sqrt{\sigma_S^2 + \sigma_D^2}} \right)$$

Where:
/S – D/ = is the absolute value of the difference in the result from the sample minus the result of the duplicate

σ_S^2 = is the square of the sample's sigma

σ_D^2 = is the square of the duplicate's sigma

This number gives the degree to which the sample and duplicate are comparable, with respect to the associated uncertainties.

The DOE Oversight Bureau evaluates the DER at the 2σ confidence interval. A DER less than or equal to 1.42 indicates that the results, with their associated uncertainties, are statistically equivalent. A DER greater than 1.42 places the results in the 2σ "warning" range. A DER greater than 2.13 places the results outside the 3 σ control range.

DERs for field-duplicate radionuclide measurements in water were less than 0.18. DERs for filed-duplicate radionuclide measurements in ashed bryophyte samples from Big Spring were less than 0.23. DERs for laboratory-duplicate radionuclide measurements in ashed bryophyte samples from Hemingway Spring were less than 0.47. This indicates that the radiological duplicate results and sample results in both water and bryophytes are statistically equivalent.

Results

Contaminant Concentrations in Water

The following sections discusses the results of analyses for total and dissolved metals, dissolved anions and cations, total radionuclides, and perchlorate found in Spring 4A, 4C, Hemingway Spring, and Big Spring along the Rio Grande.

Major and Minor-Ion Chemistry of the Four Springs

Michael – details of assessment

Table 2 - Major and Minor-Ion Chemistry results for Spring 4A, 4C, Hemingway Spring, and Big Spring.

	Date Collected	Field pH (S.U.)	Field Temp °C	Field Specific Conductance (uS/cm)	Field TDS (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	SO4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)
Spring 4A	4/15/2004	7.38	21.1	190.5	91.1	20.0	12.7	2.30	4.64	5.39	0.41	4.50	0.04
Spring 4C	4/22/2004	7.29	16.9	212.0	101.3	21.8	13.5	2.66	4.33	9.83	0.45	6.39	0.06
Big Spring	5/29/2004	6.99	22.5	284.0	136.2	27.0	27.0	4.30	1.41	11.2	0.51	1.37	0.02
Hemingway Spring	5/5/2004	7.68	16.3	196.0	93.5	17.5	12.3	2.82	5.40	8.47	0.34	2.35	0.02
National Primary Drinking Water Standards											4		
National Secondary Drinking Water Standards		6.5 - 8.5			500					250	2	250	
NM WQCC Regulation										600	1.6	250	

Results for minor and major-ion element chemistry represent the dissolved fraction passing through a 0.45 micron filter prior to analyses - samples for cation analysis were preserved with nitric acid after filtration.

	Date Collected	Hard. (mg/L)	T-Alk (mg/L)	HCO3 Alk (mg/L)	CO3 Alk (mg/L)	NO3 as N (mg/L)	PO4-P (mg/L)	ClO3 (mg/L)	Oxalate (mg/L)	Perchlorate High Res (ug/L)	RL	MDL	Perchlorate Low Res (ug/L)	MDL
Spring 4A	4/15/2004	69.0	81	98.8	0.00	0.40	<0.01	<0.01	<0.01	0.45	0.20	0.05	<0.5	0.5
Spring 4C	4/22/2004	72.3	80.7	98.5	0.00	0.93	<0.01	<0.01	<0.01	0.56	0.20	0.05	<0.5	0.5
Big Spring	5/29/2004	73.3	129	137	10.10	0.77	<0.01	<0.01	<0.01	0.26 B	0.20	0.05	<0.5	0.5
field duplicate	5/29/2004	NA	NA	NA	NA	NA	NA	NA	NA	0.25 B	0.20	0.05	NA	-
re-analysis	5/29/2004	NA	NA	NA	NA	NA	NA	NA	NA	0.18 J	0.20	0.05	NA	-
Hemingway Spring	5/5/2004	65.9	85.2	104	0.00	0.58	0.02	<0.01	<0.01	0.074 J	0.20	0.05	<0.5	0.5
National Primary Drinking Water Standards						10								
National Secondary Drinking Water Standards														
NM WQCC Regulation						10								
										6 (CA State)			**6 (CA State)**	

B - The assoicated method blank contained the target analyte at a reportable level. Re-analysis suggest original value may be biased high.

J - Indicates an estimated value that is less than the reporting limit (quantitation limit) but greater than the method detection limit (MDL).

Results for minor and major-ion element chemistry (except perchlorate) represent the dissolved fraction passing through a 0.45 micron filter prior to analyses.

High-resolution perchlorate results were from a non-filtered sample.

Low-resolution perchlorate results were from a filtered (0.45 micron) sample.

Total Metals in Water

Total metals and dissolved metals were analyzed using different laboratories and the dissolved metal detection limits averaged one order of magnitude lower than the detection limits provided with the total metal values. The results for total metals (unfiltered) at each spring are provided in Table 3. All springs had detectable concentrations of total calcium, potassium, manganese, and sodium. Total barium was detected in Big Spring at near the detection limit and total vanadium was detected at the detection limit in Big Spring and Hemingway spring. All other metals were non-detectable as totals.

Table 3. - Trace Metals (Total, Unfiltered) results for Spring 4A, 4C, Hemingway Spring, and Big Spring:.

Sample Location	Date	Ag	Al	As	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Spring4A	15-Apr-04	< 0.01	< 0.2	< 0.01	< 0.1	< 0.005	18	< 0.005	< 0.01	< 0.01	< 0.01	< 0.1
Spring 4C	22-Apr-04	< 0.01	< 0.2	< 0.01	< 0.1	< 0.005	20	< 0.005	< 0.01	< 0.01	< 0.01	< 0.1
Big Spring	29-May-04	< 0.01	< 0.2	< 0.01	0.12	< 0.005	27	< 0.005	< 0.01	< 0.01	< 0.01	< 0.1
Big Spring (Field Dup.)	29-May-04	< 0.01	< 0.2	< 0.01	0.12	< 0.005	27	< 0.005	< 0.01	< 0.01	< 0.01	< 0.1
Hemingway Spring	5-May-04	< 0.01	< 0.2	< 0.01	< 0.1	< 0.005	17	< 0.005	< 0.01	< 0.01	< 0.01	< 0.1

Sample Location	Date	Hg	K	Mg	Na	Mn	Ni	Pb	Sb	Se	Tl	V	Zn
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Spring4A	15-Apr-04	< 0.0002	2.2	3.9	10	< 0.01	< 0.02	< 0.003	< 0.02	< 0.005	< 0.01	< 0.01	< 0.02
Spring 4C	22-Apr-04	< 0.0002	2.6	3.8	11	< 0.01	< 0.02	< 0.003	< 0.02	< 0.005	< 0.01	< 0.01	< 0.02
Big Spring	29-May-04	< 0.0002	4.5	1.3	23	< 0.01	< 0.02	< 0.003	< 0.02	< 0.005	< 0.01	0.01	< 0.02
Big Spring (Field Dup.)	29-May-04	< 0.0002	4.6	1.3	24	< 0.01	< 0.02	< 0.003	< 0.02	< 0.005	< 0.01	0.01	< 0.02
Hemingway Spring	5-May-04	< 0.0002	2.8	4.9	11	< 0.01	< 0.02	< 0.003	< 0.02	< 0.005	< 0.01	0.01	< 0.02

< = Less than

Dissolved Metals in Water

The dissolved metal data is used to compare to applicable ground water quality standards and Environmental Protection Agency maximum contaminant levels (MCLs) and to calculate bioconcentration factors for bryophyte tissue. Dissolved metals are most likely more biologically available for uptake and assimilation into bryophyte tissue. Dissolved metal concentrations in water are provided in Table 4. Dissolved metals were lower than the national primary and secondary water standards in all four springs. Dissolved metals were also lower than the New Mexico Water Quality Control Commission regulatory levels in all springs.

The highest levels of dissolved metals, including Ba, Cr, Fe, Li, Mo, Ni, Pb, Sr, U, and V were found in Big Spring. This may be due to the previously discussed differences in the chemical nature of Big Spring.

Table 4 - Trace Metals (Dissolved, Filtered) results for Spring 4A, 4C, Hemingway Spring, and Big Spring:.

	Date Collected	Ag (µg/L)	Al (µg/L)	As (µg/L)	B (µg/L)	Ba (µg/L)	Be (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cs (µg/L)	Cu (µg/L)	Fe (µg/L)	Hg (µg/L)	Li (µg/L)	Mn (µg/L)	Mo (µg/L)
Spring 4A	4/15/2004	<1	3	1.2	27	40	<1	<1	<1	3.8	<1	<1	70	0.07	30	<1	1.7
Spring 4C	4/22/2004	<1	<2	1.7	20	40	<1	<1	<1	3.5	<1	3.6	70	0.05	24	<1	1.3
Big Spring	5/29/2004	<1	<2	3.1	40	128	<1	<1	<1	4.4	<1	1.4	90	0.08	53	<1	2.6
Hemingway Spring	5/5/2004	<1	<2	3.2	26	18	<1	<1	<1	1.7	<1	2.3	60	<0.05	10	<1	1.4
National Primary Drinking Water Standards				10	2000		4	5		100		1300		2			
National Secondary Drinking Water Standards		100.0	50 - 200									1000	300			50	
NM WQCC Regulation		50.00	5000	100	750	1000		10	50	50			1000	2		200	1000

	Date Collected	Ni (µg/L)	Pb (µg/L)	Rb (µg/L)	Sb (µg/L)	Se (µg/L)	SiO2 (Cal) (µg/L)	Si (µg/L)	Sn (µg/L)	Sr (µg/L)	Th (µg/L)	Ti (µg/L)	Tl (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)
Spring 4A	4/15/2004	<1	1.6	3	<1	<1	71400	33400	<1	99	<1	<1	<1	1	7	13
Spring 4C	4/22/2004	<1	1.1	3	<1	1.1	53500	25000	<1	120	<1	<1	<1	1.3	8	9
Big Spring	5/29/2004	1.9	3.3	<1	<1	<1	33,000	15,400	<1	690	<1	<1	<1	1.8	14	9
Hemingway Spring	5/5/2004	<1	1.4	5	<1	<1	45,800	21,400	<1	150	<1	<1	<1	1.6	12	<1
National Primary Drinking Water Standards			15		6	50					2			30		
National Secondary Drinking Water Standards																5
NM WQCC Regulation		200	50			50								5000		10000

Samples filtered through a 0.45 micron filter prior to analysis and represent the dissolved fraction within the water. After filtration, samples were acidified with nitric acid to a pH < 2 S.U.

Stable Isotopes and Tritium in water

Michael please provide a short discussion of the stable isotope and tritium results.

Table 5 - Stable Isotopes and Tritium (non-filtered) results for Spring 4A, 4C, Hemingway Spring, and Big Spring.

	Date Collected	Approximate Elevation of Spring Source (ft asl)	δ D ‰	Estimated Recharge Elevation (ft)	$\delta^{18}O$ ‰	Estimated Recharge Elevation (ft)	Tritium (^3H) (pCi/L)	2 sig	MDA	Estimated Age (yrs)
Spring 4A	4/15/2004	5619	-73.96 [1]	7107 [1]	-10.86 [2]	7377 [2]	0.97	0.64	0.32	<100
Spring 4C	4/22/2004	5467	-83.82 [3]	8559 [3]	-10.83 [3]	7346 [3]	10.83	0.70	0.35	<50
Big Spring	5/29/2004	6160	-103.87	11512	-14.55	11177	-0.06	0.60	0.29	>100
Big Spring (Field Duplicate)	5/29/2004	6160					-0.03	0.60	0.29	>100
Hemingway Spring	5/5/2004	6997	-99.76	10907	-14.55	11177	0.39	0.60	0.29	>50
EPA National Primary Drinking Water Standards							20000 or 4 mrem/yr (Interim)			
EPA National Secondary Drinking Water Standards										
NM Drinking Water Regulations							20000 or 4 mrem/yr			
NM WQCC Regulation										

[1] - Average value from historical data collected by LANL and NMED (n = 8; 1 std = 5.01)
[2] - Average value from historical data collected by LANL and NMED (n = 10; 1 std = 0.32)
[3] - Result from a single sample collected on 1/28/02
Results obtained from samples that were not filtered and not preserved.

Recharge calculations derived from δ D and $\delta^{18}O$ using Vuataz and Goff, 1986 following the equations respectively:
Elevation (m) = -44.9 (δ D) - 1154 (r=-0.96)
Elevation (m) = -314 ($\delta^{18}O$) - 1161 (r=-0.97)
δ D 4% error calculated from 37 duplicate results from larger data set.
$\delta^{18}O$ 1 % error calculated from 37 duplicate results from larger data set.

Radionuclides in Water

In addition to the tritium analyses discussed in the previous section, unfiltered spring- water samples were analyzed for total Pu-238, Pu-239, Sr-90, U-234, U-235, and U-238 and results are provided in Table 6. Plutonium 239 and

Table 6. Total Pu-238, Pu-239, Sr-90, U-234, U-235, and U-238 results for Spring 4A, 4C, Hemingway Spring, and Big Spring

Sample ID	Date Collected	Media	Pu-238 pCi/L	Unc. pCi/L	MDC pCi/L		Pu-239 pCi/L	Unc. pCi/L	MDC pCi/L		Sr-90 pCi/L	Unc. pCi/L	MDC pCi/L		U-234 pCi/L	Unc. pCi/L	MDC pCi/L		U-235 pCi/L	Unc. pCi/L	MDC pCi/L		U-238 pCi/L	Unc. pCi/L	MDC pCi/L
Spring4A	15-Apr-04	W	< 0	0.01	0.006	U	< 0	0.01	0.006	U	< 0.11	0.17	0.29	U	0.8	0.2	0.07	<	-0.01	0.02	0.08	U	0.37	0.12	0.06
Spring 4A (Lab Dup)	15-Apr-04	W									< 0.1	0.16	0.27	U											
Spring 4C	22-Apr-04	W	0.008	0.01	0.006		< 0.002	0.01	0.010	U	< 0.01	0.15	0.27	U	0.77	0.19	0.04	<	0.03	0.03	0.04	U	0.33	0.11	0.04
Big Spring	29-May-04	W	< 0.002	0.01	0.010	U	< 0.005	0.01	0.006	U	< 0.06	0.14	0.25	U	1.69	0.36	0.05	<	0.03	0.04	0.05	U	0.8	0.21	0.06
Big Spring (Field Dup)	29-May-04	W	< 0.002	0.01	0.010	U	< 0	0.01	0.010	U	< 0	0.13	0.24	U	1.77	0.35	0.07		0.05	0.04	0.05		0.74	0.18	0.06
Hemingway Spring	5-May-04	W	< 0.003	0.01	0.007	U	< 0	0.01	0.007	U	< 0.21	0.16	0.26	U	1.36	0.29	0.04		0.04	0.03	0.02		0.74	0.19	0.04

W = Water sample
U = Result is less than sample specific MDC
< = Less Than
MDC = Minimum Detectable Concentration
Unc. = Uncertanty as two times the Total Propagated Uncertanty

Results for dissolved cesium-137 in water are provided in Table 7. Cesium-137 was not detected in the water or in particulate/colloidal material filtered out of 100 liters of water at any spring.

Table 7. Dissolved cesium-137 in water and particulate or colloid material for Spring 4A, 4C, Hemingway Spring, and Big Spring

Dissolved Cs-137 and Coloidal Bound (less than 0.2 microns)

Sample ID	Date	Filter Type		Cs-137	Unc.	MDC		Liters of water pumped through filters
				pCi/L	pCi/L	pCi/L		
Spring 4A	15-Apr-04	3M	<	-0.007	0.010	0.017	U	101.165
Spring 4C	22-Apr-04	3M	<	-0.010	0.011	0.019	U	100.3
Big Spring	29-May-04	3M	<	0.006	0.009	0.015	U	100.6
Big Spring (Field Dup.)	29-May-04	3M	<	0.001	0.015	0.026	U	100.4
Hemingway Spring	5-May-04	3M	<	-0.016	0.046	0.026	U	50 (3M filter only, no pre-filters)
Hemingway Spring	7-May-04	3M	<	0.001	0.020	0.012	U	101.6
Hemingway Spring (Lab Dup)	7-May-04	3M	<	0.00472	0.015	0.009	U	101.6

Cs-137 in particulate or colloid material less than 0.45 microns & greater than 0.2 microns

Sample ID	Date	Filter Type		Cs-137	Unc.	MDC		Liters of water pumped through filters
				pCi/L	pCi/L	pCi/L		
Big Spring	29-May-04	0.2 micron celulose	<	-0.005	0.015	0.027	U	100.6
Big Spring (Field Dup.)	29-May-04	0.2 micron celulose	<	-0.017	0.015	0.026	U	100.4
Spring4A	15-Apr-04	0.2 micron celulose	<	-0.012	0.015	0.027	U	101.165
Spring 4C	22-Apr-04	0.2 micron celulose	<	0.009	0.015	0.024	U	100.3
Spring 4C (Lab Dup)	22-Apr-04	0.2 micron celulose	<	-0.009	0.015	0.027	U	100.3
Hemingway Spring	7-May-04	0.2 micron celulose	<	-0.0197	0.028	0.016	U	101.6

Unc. = Uncertanty = 2 times the Total Propagated Uncertanty
U = Result is less than the sample specific minimum detectable concentration
MDC = Mimimimum Detectable Concentration

Table 8. Matrix spike results for 0.2 micron and 3M Rad Disk filters

Sample ID	Date	Filter Type		Cs-137 (Expected)	Cs-137 (Detected)	Unc.	MDC		RPD	Liters of water pumped through filters
				pCi/L	pCi/L	pCi/L	pCi/L		%	
Big Spring - Matrix Spike (3M filter)	18-Aug-04	3M		0.238	0.203	0.074	0.109		3.95	20.175
Big Spring - Matrix Spike (Paper filter)	18-Aug-04	0.2 micron celulose	<	0.000	-0.025	0.079	0.134	U		20.175
Big Spring - Matrix Spike (3M filter) (Lab Duplicate)	18-Aug-04	3M		0.238	0.228	0.079	0.134		1.08	20.175
Big Spring - Matrix Spike (Paper filter) (Lab Duplicate)	18-Aug-04	0.2 micron celulose	<	0.000	-0.030	0.074	0.129	U		20.175

RPD = Relative Percent Diference between Expected Result and Detected Result
MDC = Minimum Detectable Concentration
Unc. = 2 times the total propagated uncertanty

Contaminant Concentrations in Bryophytes

Mize and Deacon (2002) obtained bryophytes from Nate Creek in Colorado and transplanted them into streams in Colorado that were both impacted and non-impacted by mining. They generated two consecutive years of data on concentration of metals in Nate Creek bryophytes. This was the same location used by Carter and Porter (1997) for the bryophytes used in their study where bryophytes were transplanted into the Rio Grande and tributaries. Both dissolved metals in water and metals in bryophyte tissue data existed for non-mining sites was available. We used the average concentration of metals in bryophytes collected over two years in Nate Creek, Colorado by Mize and Deacon (2002) to compare with our results. Mize and Deacon (2002) also provided dissolved metal data for

Table 9. Concentration of total metals in native bryophytes from Spring 4A, 4C, Hemingway Spring, and Big Spring (mg/kg dry weight)

	Date	Media	Ag mg/kg DW	Al mg/kg DW	As mg/kg DW	Ba mg/kg DW	Be mg/kg DW	Ca mg/kg DW	Cd mg/kg DW	Co mg/kg DW	Cr mg/kg DW	Cu mg/kg DW	Fe mg/kg DW	Hg mg/kg DW
Spring 4A	2-Jul-04	Moss	< 0.113	192	0.43	204	0.32	24906	0.113	< 1.1 U	14.7	1.13	181	< 0.01
Spring 4C	2-Jul-04	Moss	< 0.136	232	0.69	120	0.55	21802	0.104	0.3	16.4	1.36	300	< 0.01
Big Spring	25-Jun-04	Moss	< 0.114	206	0.65	171	0.65 EN	25119	0.064 N	7.0 N	9.2 E	1.60	308	< 0.01
Big Spring (Lab Dup)	25-Jun-04	Moss	< 0.114	199	0.68	178	0.66	25119	0.069	7.2	9.2	1.58	272	< 0.01
Big Spring (Field Replicate)	25-Jun-04	Moss	< 0.117	187	0.79	187	0.61	28033	0.072	< 1.2 U	9.2	1.75	280	< 0.01
Hemingway Spring	25-Jun-04	Moss	< 0.115	139	0.39	82	0.31	25396	0.127	2.7	11.1	4.16	104	< 0.01

	Date	Media	K mg/kg DW	Mg mg/kg DW	Mn mg/kg DW	Na mg/kg DW	Ni mg/kg DW	Pb mg/kg DW	Sb mg/kg DW	Se mg/kg DW	Tl mg/kg DW	V mg/kg DW	Zn mg/kg DW
Spring 4A	2-Jul-04	Moss	5208	3283	26	317	1.4	< 0.34	< 0.23	1.70	< 0.11	10.3	17.0
Spring 4C	2-Jul-04	Moss	3952	2725	42	327	1.5	0.45	< 0.27	4.09	< 0.14	15.0	9.1
Big Spring	25-Jun-04	Moss	4796	1370 EN	78 E	502	2.6 EN	< 0.34	< 0.23	1.05	< 0.11	11.4 EN	10.5 EN
Big Spring (Lab Dup)	25-Jun-04	Moss	4887	1359	79	504	2.4	< 0.34	< 0.23	1.00	< 0.11	12.0	10.6
Big Spring (Field Replicate)	25-Jun-04	Moss	5139	1285	70	537	2.1	0.50	< 0.23	0.84	< 0.12	11.4	10.3
Hemingway Spring	25-Jun-04	Moss	3694	4271	15	266	3.8	0.35	< 0.23	0.59	< 0.12	13.9	7.6

E = Reported value is estimated because of the presence of interference.
N = Spike sample recovery not within control limits. Post spike is analyzed for all 6010B analyses when the matrix spike and/or spike duplicate fail and the native sample concentration is less than 4 times the spike added concentration.
< = Less than

Concentrations of Cs-137, Pu-238, Pu-239, Sr-90, U-234, U-235, and U-238 in bryophytes are shown in Table 8. Cesium-137 and strontium-90 were not detected in any of the bryophyte samples from the four springs sampled. Plutonium-238 was detected at the minimum detectable concentration at spring 4C only. Plutonium-239 was detected in bryophyte samples at all springs. Concentrations ranged from 0.0003 pCi/g at spring 4A to 0.0023 pCi/g at Hemingway Spring. A field duplicate was run on the Big Spring water sample and the calculated DER was 1.421. This just places this value in the 2σ "warning" range (1.42 – 2.13). This indicates that the two samples are not statistically similar and there is a 95% to 99% probability that the differences are real and not due to random chance. This could be due to the inhomogeneity of the sample or possible laboratory or processing error. A laboratory duplicate was also run on the Hemingway Spring bryophyte sample and the calculated DER was 1.88. This places this sample in the 2σ "warning" range and indicates that these values are also not statistically similar.

Uranium-234, -235, and -238 was detected in all bryophyte samples. Concentrations U-234 ranged from 3.859 pCi/g at Big Spring to 8.993 pCi/g at Spring 4C. Concentrations of U-235 ranged from 0.1016 pCi/g at Big Spring to 0.256 pCi/g at Spring 4C. Concentrations of U-238 ranged from 1.38 pCi/g at Big Spring to 4.88 pCi/g at Spring 4C. Both the Big Spring field duplicate and the Hemingway Spring laboratory duplicate DERs indicated that the sample results for Uranium-234, -235, and -238 are statistically similar. There have not been any previous studies of radionuclides in bryophytes in New Mexico to compare these results with but the LANL ecology group has measured radionuclide concentrations in produce and vegetation in northern New Mexico. They have generated regional statistical reference levels (RSRLs) for selected radionuclides in produce. These are the upper-limit background concentrations (mean + 2 std dev) based on data from 1994 to 2004.

Table 10. Concentrations of Cs-137, Pu-238, Pu-239, Sr-90, U-234, U-235, and U-238 in native bryophytes from Spring 4A, 4C, Hemingway Spring, and Big Spring (pCi/g dry weight)

Sample ID	Date	Media	Cs-137 pCi/g DW	Unc. pCi/g	MDC pCi/g	Pu-238 pCi/g DW	Unc. pCi/g	MDC pCi/g	Pu-239 pCi/g DW	Unc. pCi/g	MDC pCi/g	Sr-90 pCi/g DW	Unc. pCi/g	MDC pCi/g
Spring 4A -Moss	2-Jul-04	Moss	< 0.005	0.029	0.050	< 0.00000	0.00033	0.00062	0.0003	0.0003	0.0002	< 0.003	0.017	0.038
Spring 4C - Moss	2-Jul-04	Moss	< -0.016	0.037	0.063	0.00003	0.00005	0.00003	0.0006	0.0004	0.0002	< 0.004	0.019	0.044
Big Spring- Moss	25-Jun-04	Moss	< -0.017	0.026	0.047	< -0.00007	0.00032	0.00048	0.0008	0.0005	0.0005	< -0.006	0.017	0.042
Big Spring - Moss (Field Dup.)	25-Jun-04	Moss	< 0.001	0.029	0.049	< -0.00006	0.00032	0.00047	0.0005	0.0004	0.0002	< 0.004	0.020	0.046
Hemingway Spring - Moss	25-Jun-04	Moss	< 0.013	0.038	0.065	< 0.00028	0.00039	0.00065	0.0012	0.0008	0.0002	< 0.012	0.018	0.040
Hemingway Spring - Moss (Lab Dup)	25-Jun-04	Moss	< 0.000	0.030	0.051	< -0.00007	0.00035	0.00075	0.0023	0.0010	0.0006	< 0.002	0.017	0.039

Sample ID	Date	U-234 pCi/g DW	Unc. pCi/g	MDC pCi/g		U-235 pCi/g DW	Unc. pCi/g	MDC pCi/g		U-238 pCi/g DW	Unc. pCi/g	MDC pCi/g	
Spring 4A -Moss	2-Jul-04	5.230	0.985	0.001		0.1438	0.0294	0.0011		2.58	0.49	0.001	
Spring 4C - Moss	2-Jul-04	8.993	1.771	0.001	Y2	0.2562	0.0531	0.0027	Y2	4.88	0.95	0.001	Y2
Big Spring- Moss	25-Jun-04	3.859	0.651	0.001		0.1039	0.0183	0.0011		1.38	0.23	0.001	
Big Spring - Moss (Field Dup.)	25-Jun-04	3.890	0.654	0.001		0.1016	0.0187	0.0012		1.39	0.23	0.001	
Hemingway Spring - Moss	25-Jun-04	6.072	1.108	0.001		0.1397	0.0277	0.0012		2.98	0.54	0.001	
Hemingway Spring - Moss (Lab Dup)	25-Jun-04	5.345	0.970	0.001		0.1397	0.0277	0.0012		2.59	0.47	0.001	

Y2 = Chemical yield outside default limits
U = Result is less than sample specific MDC
< = Less Than
MDC = Minimum Detectable Concentration
Unc. = Uncertanty as two times the Total Propagated Uncertanty
LT = Value reported is less than client specified detection limit but greater than method detect limit

Table 11. Detections of gamma emitters in native bryophytes from Spring 4A, 4C, Hemingway Spring, and Big Spring (mg/kg dry weight)

Sample ID	Date	Ac-228 pCi/g Dry Weight	Unc.	MDC		Be-7 pCi/g Dry Weight	Unc.	MDC		Bi-212 pCi/g Dry Weight	Unc.	MDC		K-40 pCi/g Dry Weight	Unc.	MDC		Pa-234M pCi/g Dry Weight	Unc.	MDC
Big Spring - Moss	25-Jun-04					1.5	0.8	1.3						4.9	1.0	1.3				
Big Spring - Moss (Field Dup.)	25-Jun-04									0.7	0.4	0.7	TI	4.1	1.0	1.3				
Hemingway Spring - Moss	25-Jun-04	0.3	0.1	0.2	TI	2.2	1.1	1.7						3.0	1.2	1.7				
Hemingway Spring - Moss (Lab Dup)	25-Jun-04					1.3	0.7	1.1	NC					3.2	1.0	1.4	NC			
Spring 4A - Moss	2-Jul-04					1.1	0.7	1.1						5.5	1.2	1.6		18.9	9.8	15.1
Spring 4C - Moss	2-Jul-04					3.1	1.1	1.5						4.2	1.5	2.2				

Sample ID	Date	Sb-124 pCi/g Dry Weight	Unc.	MDC		Th-234 pCi/g Dry Weight	Unc.	MDC		Tl-208 pCi/g Dry Weight	Unc.	MDC		U-235 pCi/g Dry Weight	Unc.	MDC	
Big Spring - Moss	25-Jun-04	0.2	0.1	0.1	TI	1.4	0.8	1.4									
Big Spring - Moss (Field Dup.)	25-Jun-04					1.4	0.7	1.2									
Hemingway Spring - Moss	25-Jun-04					2.7	1.2	2.0		0.08	0.04	0.06	TI				
Hemingway Spring - Moss (Lab Dup)	25-Jun-04					2.3	0.8	1.3	NC	0.05	0.03	0.05	TINC	0.2	0.1	0.2	NC
Spring 4A - Moss	2-Jul-04																
Spring 4C - Moss	2-Jul-04					3.3	1.2	1.9						0.4	0.2	0.3	TI

MDC = Minimum Detectable Concentration
Unc. = Uncertanty = 2 Sigma
TI = Nuclide Identification is tentative
NC = RPD was not calculated

Bioaccumulation and Plant-Water Concentration Ratios

Bioaccumulation is largely governed by physical and chemical factors, by the concentration of metal in water and by the bioaccumulation factor of the bryophyte species (Lopez and Carballeria 1993).

Table 12. Metal bioconcentration factors (BCFs) for native bryophytes from Spring 4A, Spring 4C, Big Spring, and Hemingway Spring

	Trace Element BCFs[1]													
Sample Locations	**Al**	**As**	**Ba**	**Ca**	**Cr**	**Cu**	**Fe**	**K**	**Na**	**Ni**	**Pb**	**Se**	**V**	**Zn**
Spring 4A	64151	358	5094	1245	3873	--	2588	2264	25	--	--	--	1472	1306
Spring 4C	--	409	2998	1000	4672	379	4283	1486	24	--	409	3716	1874	1014
Big Spring	--	210	1338	930	2102	1142	3425	1115	19	1382	152	--	816	1167
Hemingway Spring	--	123	4553	1451	6519	1807	1732	1310	22	--	247	--	1154	--

[1] = concentration of trace element in native bryophyte tissue divided by dissolved concentration of trace element in water

-- = unable to determine because concentrations of trace elements in water or native bryophytes were below reporting level

Table 13. Radionuclide bioconcentration factors (BCFs) for native bryophytes native bryophytes from Spring 4A, Spring 4C, Big Spring, and Hemingway Spring

	Radionuclide BCFs [1]			
Sample Location	**Pu-238**	**U-234**	**U-235**	**U-238**
Spring 4A	--	6538	--	6976.03
Spring 4C	3.9	11680	--	14782.4
Big Spring	--	2284	--	1726.96
Big Spring (Field Dup)	--	2197	2032	1878
Hemingway Spring	--	4465	3492	4025

[1] = concentration of radionuclide in bryophyte tissue divided by (total) concentration of radiomuclide in water

-- = unable to determine because concentrations of trace elements in water or bryophytes were below reporting level

Table 12 Concentration of perchlorate in bryophyte samples from Spring 4A, 4C, Hemingway Spring, and Big Spring (mg/kg dry weight)

NEED Table or add results to another table

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