Comparison of Radionuclide Levels in Soil, Sagebrush, Plant Litter, Cryptogams, and Small Mammals

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COMPARISON OF RADIONUCLIDE LEVELS IN SOILS, SAGEBRUSH, PLANT LITTER, CRYPTOGRAMS, AND SMALL MAMMALS

EXECUTIVE SUMMARY

Soil, sagebrush, plant litter, cryptogam, and small mammal samples were collected and analyzed for cesium-137, strontium-90, plutonium-238, plutonium 239/240, technetium-99, and iodine-129 from 1981 to 1986 at the U.S. Department of Energy Hanford Site in southeastern Washington State as part of site characterization and environmental monitoring activities. Samples were collected on the 200 Areas Plateau, downwind from ongoing waste management activities.

Plant litter, cryptogams, and small mammals are media that are not routinely utilized in monitoring or characterization efforts for determination of radionuclide concentrations. Studies at Hanford, other U.S. Department of Energy sites, and in eastern Europe have indicated that plant litter and cryptogams may serve as effective "natural" monitors of air quality. Plant litter in this study consists of fallen leaves from sagebrush and "cryptogams" describes that portion of the soil crust composed of mosses, lichens, algae, and fungi.

Comparisons of cesium-137 and strontium-90 concentrations in the soil, sagebrush, litter, and cryptogams revealed significantly higher ($p < 0.05$) levels in plant litter and cryptogams. Technetium-99 values were the highest in sagebrush and litter. Plutonium-238 and 239/40 and iodine-129 concentrations never exceeded 0.8 pCi/gm in all media. No evidence of any

significant amounts of any radionuclides being incorporated into the small mammal community was discovered.

The data indicate that plant litter and cryptogams may be better indicators of environmental quality than soil or vegetation samples. Augmenting a monitoring program with samples of litter and cryptogams may provide a more accurate representation of radionuclide environmental uptake and/or contamination levels in surrounding ecosystems. The results of this study may be applied directly to other radioecological monitoring conducted at other nuclear sites and to the monitoring of other pollutants.

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TERMS

DOE
ORNL
PUREX

U.S. Department of Energy
Oak Ridge National Laboratory
Plutonium-Uranium Extraction (Plant)

INTRODUCTION

The routine monitoring of soil, water, and vegetation at many nuclear facilities throughout the country for radionuclides and heavy metals is well documented (Hunter 1992, Cummins et al. 1989, Cirrincione and Costain 1990). At the U.S. Department of Energy (DOE) Hanford Site in southeastern Washington State (Figure 1), soil and vegetation samples are collected routinely to monitor radionuclide levels (Schmidt et al. 1993, Woodruff et al. 1993).

In support of special projects for the Plutonium-Uranium Extraction (PUREX) Plant and the Grout Treatment Facility from 1981 to 1986, soil, sagebrush leaves and twigs (*Artemisia tridentata*), plant litter, cryptogams, and small mammals were collected and analyzed for ^{137}Cs , ^{90}Sr , ^{238}P , $^{239/240}\text{P}$, ^{99}Tc , and ^{129}I . Plant litter, cryptogams, and small mammals are not routinely analyzed for radionuclide concentrations.

Plant litter was primarily composed of fallen leaves from sagebrush and was collected and analyzed to determine differences in the accumulations of radionuclides between this material and the live plant. Plant litter was collected at the Hanford Site in an earlier study (Vaughan 1978) and was analyzed for mineral content. That study indicated that leaf litter could be a useful ecological indicator for monitoring the effects of salt drift from cooling towers and gaseous and particulate airborne effluents from coal-fired steam-electric plants.

Small mammals also serve as indicators of environmental quality. Several studies at the Hanford Site (Vaughan 1978, Schmidt et al. 1992, and Landeen and Mitchell 1982) and other nuclear sites (Garten 1981, Hakonson and Gladney 1981, Arthur and Markham 1982) have shown that small mammals can take up radionuclides and other pollutants (Scanlon 1979 and Talmage and Walton 1991).

The term cryptogam describes a living soil crust composed of mosses, lichens, algae, and fungi. Data from other studies (Garner and Jenkins 1991, Sawidis and Heinrich 1992, Thomas et al. 1992, Mihok et al. 1989, and Richardson 1992) have indicated that lichens are effective natural monitors of air pollution, acting as sinks for the accumulation of airborne materials. Cesium-137 concentrations were four times higher in lichens and mushrooms collected on granite outcrops in Georgia than in the surrounding pine-hardwood forest (Garner and Jenkins 1991). Lichens and mosses have been analyzed for radionuclides in the Arctic (Thomas et al. 1992) and Alaska (Rickard et al. 1965) because many wildlife species depend on lichens as a primary food source. Hoffman et al. (1993) suggested that lichens are more suitable biological detectors for monitoring fallout radionuclides than soil samples.

Mosses also serve as efficient filters for trapping airborne particles (Mattsson and Liden 1975, Svoboda et al. 1986). They seem to be more efficient than lichens at taking up and accumulating heavy metals and are probably the plants used most frequently to monitor for metal pollutants in terrestrial habitats (Burton 1986). Studies in Canada (Glooschenko and Capobianco 1978 and Barclay-Estrup and Rinne 1978) and the northeastern United States (Groet 1976) have utilized sphagnum, feather, and other types of mosses to monitor concentrations of heavy metals.

Figure 1. Hanford Site in Southeastern Washington State.

The Hanford Site

In Sweden, Folkesson (1979) found that five mosses accumulated greater concentrations of heavy metals than the four lichen species used for comparison. Mosses were found to accumulate mercury by an order of magnitude greater than grasses and other vegetation around Oak Ridge, Tennessee (Huckabee 1973). Mosses on trees near a pulp mill at Lewiston, Idaho were sampled for sulfur gases (Hoffman, 1974) to assess ecological impacts. Wallin (1976) utilized mosses in Sweden to monitor the deposition of airborne mercury. Pilegaard (1979) showed a strong linear association between concentrations of metals in mosses near a Danish steelworks and Boileau et al. (1982) demonstrated that the mineral content of mosses accurately reflects urban emission patterns.

Richardson (1992), Papastefanou et al. (1989), and Elstner et al. (1987) document how lichens and mosses have been used successfully to monitor contamination by radioactive elements derived from atmospheric nuclear testing, orbital decay of nuclear-powered satellites, and accidents such as the one at the Chernobyl nuclear-powered electricity-generating station. Accumulation of ^{137}Cs and ^{90}Sr has been demonstrated and can be attributed to the relatively long half-lives of these isotopes and their chemical similarity to the essential macronutrients potassium and calcium, respectively.

Few radionuclide-uptake studies have been conducted on plant litter and mosses at North American nuclear sites. The purpose of this study was to make meaningful comparisons between the differential uptake of several radionuclides in soil, sagebrush, plant litter, cryptogams, and small mammals. Much of the data presented in this document on radionuclide uptake of ^{90}Sr , plutonium, ^{99}Tc , and ^{129}I by mosses and plant litter may be some of the first of its kind. Some of the data presented in this paper were previously reported in Westinghouse Hanford Company documents by Landeen et al. (1984, 1985), Swanson et al. (1988), and Johnson et al. (1991).

MATERIALS AND METHODS

Soil, sagebrush, plant litter, cryptogams, and small mammals were collected at 89 sample locations on the 200 East plateau area of the Hanford Site downwind from many ongoing waste management activities (Figures 2 and 3). Not all sample media were collected at each location and not all samples were analyzed for each radionuclide. Samples were collected from 1981 to 1986 to support site characterization and preoperational monitoring activities.

At each sample station, equivalent-volume soil plugs were collected at five points to make a composite sample. The five plugs were collected at a depth of from 0 to 2.5 cm. One sample was collected adjacent to the station marker post and one was collected in each of the four compass directions. Leaves and twigs were clipped from sagebrush growing within a 10-m radius of the station marker post. Plant litter was collected from underneath the canopies of the sampled sagebrush. Cryptogams were collected from within 10 m of each station marker post. Cryptogam species collected and analyzed in this study were identified by Dr. Larry St. Clair of Brigham Young University as a combination of two species of epigeic mosses, *Tortula ruralis* and *Bryum* sp., which are abundant in the Great Basin region of the western United States (Pearson and Rope 1987). Control samples for soil, sagebrush, litter, and cryptogams were collected several miles upwind and off the Hanford Site.

Figure 2. Locations and Sample Station Numbers of Radioecology Sampling Stations.

Figure 3. Locations and Sample Station Numbers of Radioecology Sampling Stations in Relation to the Wye Barricade.

Small mammals were collected from selected sample stations using "Museum Special" snaptraps. All but 4 of the 33 small mammals collected were identified as Great Basin pocket mice (*Perognathus parvus*). The other four species were deer mice (*Peromyscus maniculatus*).

Samples were submitted to U.S. Testing Company in Richland, Washington, for radionuclide analysis.

RESULTS

CRYPTOGAM ECOLOGY

The cryptogams,, collected and analyzed in this study were identified as terricolous (growing on soil) mosses (*Tortula ruralis* and *Bryum sp.*), which are relatively common on bare soil surfaces in western North American shrub-steppe environments.

RADIONUCLIDE RESULTS

Table 1 summarizes the average concentration values and other statistics for all the radionuclides in soil, sagebrush, plant litter, cryptogams, small mammals, and control samples. Tables A-1 through A-8 (Appendix A) contain all of the radionuclide values observed in all media during the study period.

Table 1. Average Radionuclide Concentrations in Various Environmental Media (pCi/gm).

Medium	¹³⁷ Cs	⁹⁰ Sr	⁹⁹ Tc	¹²⁹ I	²³⁸ Pu	^{238/239} Pu
Soil	2.30(86)a	0.41(59)a	0.99(12)a	-0.14(16)a	0.0001(29)a	0.014(53)a
Sagebrush	1.08(88)a	0.57(48)a	1.99(6)a	0.34(ab)	0.025(5)a	0.060(15)a
Litter	14.05(67)c	1.52(18)b	1.98(12)a	0.07(14)ab	0.002(3)a	0.047(3)a
Cryptogam	8.51(64)b	1.39(18)b	0.71(5)a	0.32(15)b	0.028(3)a	0.013(3)a

Note: Values are expressed as mean (number of samples). Values within a column followed by the same letter are not significantly different (p<0.05) (Tukey multiple comparison procedure).

Mean values of ¹³⁷Cs were 1.08 pCi/gm in sagebrush, 2.30 pCi/gm in soil, 14.05 pCi/gm in plant litter, and 8.51 pCi/gm in cryptogams. Mean values in small mammals were 0.14 pCi/gm for ¹³⁷Cs and 0.07 pCi/gm for ⁹⁰Sr. The highest ¹³⁷Cs value (900.0 pCi/gm) was found in a cryptogam and the highest ⁹⁰Sr value (5.72 pCi/gm) was detected in plant litter. Figure 4 shows the mean concentrations for ¹³⁷Cs and ⁹⁰Sr in all media. The highest mean values for ⁹⁹Tc were found, in descending order, in sagebrush, litter, soil, and mosses. Mean values for ²³⁸Pu, ^{239/240}Pu, and ¹²⁹I in all media did not exceed 0.35 pCi/gm. Mean concentration values for ¹²⁹I were negative in all media with the exception of sagebrush. Significant differences between radionuclide levels in all media are presented in Table 1.

Figure 4. Mean Concentrations of ^{137}Cs and ^{90}Sr in All Media. Table 2. Mean Concentration Ratios for ^{137}Cs and ^{90}Sr (pCi/gm sample media/pCi/gm soil).

	Sagebrush		Litter		Cryptogams	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Maximum	12.80	145.50	35.61	7.2	84.11	6.09
Minimum	0.00	0.02	0.48	0.19	0.73	0.91
Mean	0.85	4.56	8.40	2.74	6.41	2.67

Concentration ratios of sagebrush radionuclide levels to soil radionuclide concentrations were calculated for ^{99}Tc , ^{137}Cs , ^{90}Sr , and ^{129}I . Concentration ratios ranged from 0.65 to 13.31 for ^{99}Tc , 0.00 to 12.79 for ^{137}Cs , 0.02 to 145.50 for ^{90}Sr , and 0.01 to 5.22 for ^{129}I . The mean values for these concentration ratios in sagebrush are presented in Table 2 and shown graphically in Figure 5.

Figure 5. Mean Concentration Ratios of Selected Radionuclides in Sagebrush.

DISCUSSION

The radionuclide concentrations observed in this study were collected by May 2, 1986, before the nuclear reactor accident at Chernobyl in the Ukraine, which occurred on April 26, 1986. Approximately 81M Ci of radioactivity (primarily cesium) were released to the atmosphere as a result of the accident. The first indication of fallout in Washington State from the Chernobyl release was detected on May 5, 1986 (PNL 1987).

Two radioactive release incidents may have affected some of the samples, resulting in elevated values. The first consisted of releases of radioactive material from October to November of 1984 at the 207-A-42 Diversion Basin, which is proximal to a number of the sample locations. Most of the activity was attributed to short-lived radionuclides such as ^{106}Ru , ^{95}Zr , and ^{95}Nb . The second incident occurred at the 241-C-151 Diversion Box in January 1985. An estimated 1.4 Ci of ^{90}Sr and 0.02 Ci of ^{137}Cs were released over a rather widespread area downwind of the source term, which included a portion of the sampled area (Elder et al. 1986). Contamination attributable to these two incidents appeared to be detectable in the sample results.

SOIL

Concentration levels for all the radionuclides analyzed were lower in soil than all other media, which suggests that relying only on soil samples to monitor radionuclides and other pollutants might not give an accurate assessment of environmental conditions. This is particularly true when soil samples are collected from areas where air deposition is the only source of contamination. The highest mean concentration value observed in soil during this study was ^{137}Cs with a mean value of 2.3 pCi/gm.

SAGEBRUSH

Concentrations for all radionuclides with the exception of ^{99}Tc and ^{129}I were the lowest in sagebrush of all the media sampled. ^{99}Tc has a long half-life and a fission yield approximately equivalent to that of ^{90}Sr or ^{137}Cs (Wildung et al. 1979). The high fission yield and long half-life of ^{99}Tc ensure that it will be found at higher levels than ^{129}I because of worldwide nuclear testing. Studies at the Hanford Site (Routson and Cataldo 1977 and Wildung et al. 1974, 1976, and 1977) and elsewhere (Gast 1975) have shown technetium to be readily available for plant uptake. Cataldo et al. (1978) documented how plants effectively removed up to 90 percent of the technetium at soil concentrations of 0.1 $\mu\text{g/g}$.

Concentration ratios for ^{99}Tc in this study ranged from 0.65 to 13.31. In the studies mentioned earlier, concentration ratios for technetium ranged from 100 to 1000 (Cataldo 1979). ^{129}I concentration ratios ranged from 0.01 to 5.22. This is comparable to other Hanford Site studies (Cline and Klepper 1975) that showed concentration ratios for iodine ranging from 0.53 to 1.25 in agronomic plants grown in Ritzville soil. Iodine concentration ratios observed in Hanford Site studies of cheatgrass and tumbleweeds showed values ranging from 1.0 to 4.0 in cheatgrass and 6.0 to 13.0 in tumbleweeds (Cataldo 1979).

The ^{137}Cs concentration ratios in sagebrush reported here are somewhat higher than those found in trees (Landeem and Mitchell 1986) and cheatgrass and tumbleweeds (Cataldo et al. 1978 and Routson 1986) during previous radionuclide uptake studies conducted at the Hanford Site. In these Hanford Site studies, concentration ratios for ^{137}Cs never exceed 1.0. However, in a study by Garten et al. (1975) at Savannah River, concentration ratios for ^{137}Cs in roots, leaves, and twigs from wax myrtle and alder trees usually exceeded 1.0. In these Hanford Site studies, concentration ratios were higher for ^{90}Sr than for ^{137}Cs , which is the same trend observed in the present study.

LITTER

Mean concentration values in litter were higher than the corresponding soil values for all of the radionuclides and in most cases were higher than the sagebrush concentration values. ^{99}Tc concentrations in this study were the highest in sagebrush (2.25 pCi/gm) and litter (2.02 pCi/gm) compared to 0.87 pCi/gm in mosses. These results were similar to data published by Garten et al. (1985) from studies at DOE's Oak Ridge National Laboratory (ORNL) in Tennessee. Concentrations of ^{99}Tc in forest litter and surrounding vegetation were greater than concentrations found in the 0.5-cm zone of the soil.

Other studies conducted at ORNL [Witherspoon (1964) and Witkamp and Frank (1964)] analyzed tree litter concentrations of ^{137}Cs and ^{134}Cs . Both studies documented the rapid passage of cesium from the poplar and white oak trees to leaf litter and indicated that leaf fall doubled the amount of ^{137}Cs on the forest floor and increased the amount of ^{137}Cs in litter fifteen-fold.

SMALL MAMMALS

Levels of ^{137}Cs and ^{90}Sr did not exceed 0.70 pCi/gm in any small mammals collected in this study. Other studies at the Hanford Site (Paine et al. 1979, Landeem and Mitchell 1982, and Gano 1979) have documented elevated levels of radionuclides in pocket mice that reside on waste sites. Small burrowing mammals have also been documented with elevated radionuclide levels at other DOE sites (Arthur and Markham 1983, Arthur et al. 1986, Garten 1980, and Winsor and Whicker 1980). Mihok et al. (1989) observed elevated levels of ^{137}Cs in red-backed voles (*Clethrionomys gapperi*) in Canada following the Chernobyl accident. The elevated ^{137}Cs concentrations found in the voles was attributed to the consumption of fungi, which are a major part of their diet. Great Basin pocket mice are classified as granivores (seed eaters) and no documentation exists that would indicate that pocket mice consume lichens, mosses, or fungi. Kritzman (1974) indicated that vegetation and insects sometimes compose a small part of the diet of pocket mice at the Hanford Site. However, it does not appear that the higher levels of ^{137}Cs and ^{90}Sr found in litter and cryptogams is being incorporated into the small-mammal community.

CRYPTOGAMS (MOSESSES)

Mosses not only are good air pollution monitors, but in some ecosystems contribute a large part of the total biomass and productivity. Mosses grow in large carpets on the ground and have more surface area than other plants to intercept particulate deposition and rain (Manning and Feder 1980). Nutrient cycling in many ecosystems is dependent on mosses, which also occur in the

food chains of a great many invertebrate and vertebrate animals (Slack 1988). Mosses also play important roles as pioneer species in habitats that may have been severely disturbed.

Mosses absorb pollutants from the air and from precipitation. Nutrients are absorbed as particulates and in solution by interception of atmospheric deposition because the rhizoidal attachment to their substrate does not function as a root system. Mosses possess leaves and stems but the leaves are inserted on the stem in such a way that radial symmetry is created. Physiological activity in mosses depends on water content, which varies passively with environmental conditions. Under moderate to high temperatures and non-saturated atmospheric conditions, mosses become inactive. For example, species that grow in arid locations such as the Hanford Site can survive years of desiccation, whereas most aquatic species can only survive a few hours of desiccation (Nash and Egan 1988).

The ^{137}Cs , ^{90}Sr , and ^{238}Pu concentrations reported in this study, including control values, were generally higher in mosses than in the other media studied. These results are similar to lichen studies conducted at the Idaho National Engineering Laboratory in a shrub-steppe environment (Rope and Pearson 1990) and (Pearson and Rope 1987), which indicated that many trace elements were significantly higher in lichens than in soil, sagebrush, and grass. The authors concluded that lichens should be preferable to soil for monitoring the biologically available fraction of atmospheric sources of trace elements, especially those with a naturally high concentration in soil.

A review of the literature determined that most of the research about radionuclide uptake by mosses has been conducted in Great Britain, Scandinavia, and eastern Europe, utilizing sphagnum and feather mosses. Much of the published literature is from surveys of radioactive fall-out resulting from nuclear weapons tests.

Accumulation of ^{137}Cs and ^{90}Sr , in particular, has been demonstrated and can be attributed to their relatively long half-life and their chemical similarity to the essential macronutrients potassium and calcium. Because cesium is an analog for potassium, it may be taken up by plants as a surrogate using the same transport mechanisms (Tuominen and Jaakkola 1973). Sawidis and Heinrich (1992) and Papastefanou et al. (1992), in studies in northern Greece, reported ^{137}Cs levels in lichens and mosses, including the moss species *Tortula ruralis*, which was also collected in our study. Both lichens and mosses showed elevated levels of ^{137}Cs for two to five years after the Chernobyl accident. In their study, lichens showed consistently higher levels of ^{137}Cs than did the mosses collected in the same habitats. Mihok et al. (1989) collected and analyzed fungi (mushrooms), mosses, and lichens for ^{137}Cs in a spruce bog forest in Manitoba, Canada. They found that mushrooms had significantly higher levels of ^{137}Cs than lichens and mosses. Mosses (*Pseudoscleropodium purum* and *Hypnum cupressiforme*) were collected and analyzed for radionuclide content at various distances from the Sellafield nuclear processing plant in Great Britain. ^{137}Cs and ^{129}I concentrations in these mosses declined with distance from the plant (Sumerling 1984).

Bovard and Grauby (1967) advocated using sphagnum mosses to monitor radionuclides because of their demonstrated capacity to accumulate ^{137}Cs . Witkamp and Fränk (1967) supplied ^{137}Cs in simulated rain in a pine forest in Tennessee and showed that tussocks of the moss *Dicranum scoparium* retained 96 percent of the applied radioactivity compared with 72 percent retention by

rosettes of an angiosperm, *Potentilla canadensis*. Rickard's study in the Washington State (Rickard 1967) also found that mosses showed higher accumulations of ^{137}Cs than forest-floor litter or soil.

As previously stated, the high accumulation capacity and widespread distribution of mosses indicate their potential use as monitors of airborne sources of radionuclides. Mosses would not have much value in assessing the importance of soil contamination on, for example, uptake by food crops. Interspecies differences in uptake related to rooting depths and general morphology of other plants indicate that caution must be exercised in drawing conclusions about contamination based on vegetation samples. This problem appears to be less important for monitoring radionuclides in mosses, which have been shown to reflect temporal and spatial differences in deposition (Burton 1986).

SUMMARY

Soil, sagebrush, plant litter, cryptogams, and small mammals on the Hanford Site were analyzed for several radionuclides. The highest radionuclide concentrations observed were for ^{137}Cs , ^{90}Sr , and ^{99}Tc in litter and cryptogams. Radionuclide concentrations in soil, sagebrush, and small mammals were comparatively lower than in litter and cryptogams. This suggests that litter and cryptogams are probably better indicators of environmental quality related to airborne contamination than vegetation or soil samples for some radionuclides. Augmenting a sampling program at nuclear facilities with samples of litter and cryptogams may provide a more accurate representation of environmental uptake and/or contamination. Similar results might also be obtained in testing for levels of heavy metals or other pollutants. Studies need to be conducted at other nuclear facilities in North America to determine if cryptogams and plant litter should be sampled and analyzed for environmental contaminants.

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APPENDIX A
RADIONUCLIDE CONCENTRATION TABLES

Table A-1. Mean Concentration Levels (pCi/g) for all Media.

Radionuclide	Soil	Sage	Litter	Lichen	Mice
Cs-137	2.3	1.07	14.05	15.26	0.14
Range	0.17-55.0	0.04-33.1	0.47-96.3	0.82-900	-0.15-0.7
St. Dev.	6.11	3.52	16.67	111.1	0.2
# samples	86	88	67	65	32
Sr-90	0.41	0.75	1.78	1.3	0.07
Range	0.04-2.21	0.01-5.82	0.05-5.72	0.20-4.78	0.02-0.16
St. Dev.	0.36	1.04	1.51	0.98	0.05
# samples	59	57	31	28	9
Tc-99	1.3	2.25	2.02	0.87	
Range	0.13-9.44	0.34-7.22	-0.62-10.9	0.08-1.5	
St. Dev.	2.58	2.53	3.81	0.56	
# samples	12	6	13	6	
I-129	-0.13	0.34	-0.35	-0.16	
Range	-0.9-0.8	0.01-0.5	-1.84-0.59	-2.81-1.35	
St. Dev.	0.42	0.18	0.76	1	
# samples	18	6	16	17	
Pu-238	0.0001	0.04	0.003	0.05	
Range	-0.004-0.00	0.0-0.20	0.001-0.004	0.04-0.07	
St. Dev.	0.001	0.09	0.002	0.017	
# samples	29	5	3	3	
Pu-239/240	0.024	0.11	0.047	0.013	
Range	0.005-0.1	0.0-1.51	0.03-0.07	0.00-0.03	
St. Dev.	0.025	0.39	0.021	0.015	
# samples	53	15	3	3	
Control Cs-137	0.27	0.09	0.37	2.56	
Range	0.03-0.84	0.06-0.14	0.22-0.66	2.42-2.85	
St. Dev.	0.38	0.04	0.25	0.25	
# samples	4	3	3	3	
Control Sr-90	0.21	0.15	0.41	0.87	
Range	0.16-0.27	0.06-0.32	0.18-0.76	0.66-1.09	
St. Dev.	0.08	0.15	0.31	0.3	
# samples	2	3	3	2	
Control Pu-238	0.0008				
Range	0-0.002				
St. Dev.	0.0009				
# samples	5				
Control Pu-238/240	0.0218				
Range	0.002-0.05				
St. Dev.	0.027				
# samples	5				
Control I-129				-0.82	
Range					
St. Dev.					
# samples				1	

Table A-2. Radionuclide Values (pCi/g) in Litter.

ID #	Tc-99	I-129	Pu-238	Pu-239
A10			0.004	0.040
B10			0.004	0.070
C10			0.001	0.030
1	0.50	-1.69		
4	1.42	-1.84		
10		-0.002		
12		-0.78		
13	10.89	-0.85		
19	0.68	0.36		
22	-0.53	0.21		
23	-0.62	0.17		
25	10.06	-1.02		
35	1.61	0.59		
40	0.91	-0.27		
45	0.21	0.21		
47	0.43	-0.40		
50	0.01	-0.90		
51		0.50		
52	0.71	0.15		
Max	10.89	0.59	0.004	0.070
Min	-0.62	-1.84	0.001	0.030
Avg	2.02	-0.35	0.003	0.047
St. Devia	3.81	0.76	0.002	0.021
2St. Err	2.11	0.38	0.002	0.024
Total number	13	16	3	3

Table A-3. Radionuclide Values (pCi/g) for Cryptogams.

ID #	Tc-99	I-129	Pu-238	Pu-239
A10			0.0400	0.0100
B10			0.0700	0.0300
C10			0.0400	0.0000
1		-2.81		
2	0.08			
4		-1.77		
10		-0.09		
12		-0.68		
13		0.91		
19	0.60	0.01		
22		0.76		
23	1.23	0.43		
25		0.07		
27		-0.11		
35	1.33	0.22		
37		0.57		
39		-0.38		
45	0.48	1.35		
47		0.28		
51		-0.66		
52	1.50	-0.76		
Max	1.50	1.35	0.0700	0.0300
Min	0.08	-2.81	0.0400	0.0000
Avg	0.87	-0.16	0.0500	0.0133
St. Devia	0.56	1.00	0.0173	0.0153
2St. Err	0.46	0.49	0.0200	0.0176
Total number	6	17	3	3

Table A-4. Radionuclide Values (pCi/g) for Soil. (sheet 1 of 3)

ID #	Pu-238	Pu-239/240	Tc-99	I-129
A0	-0.003	0.010		
A2		0.010		
A3		0.010		
A4		0.020		
A5		0.030		
AX		0.010		
A6		0.010		
A7		0.030		
A8		0.020		
A9		0.010		
A10		0.010		
A14	-0.004	0.007		
B0				
B1		0.010		
B2				
B3		0.010		
B4				
B5		0.010		
B6				
B7		0.010		
B8				
B9				
B10		0.020		
B11	-0.004	0.010		
C0				
C1		0.010		
C2				
C3				
C4		0.010		
C5				
C6		0.010		
C7				

Table A-4. Radionuclide Values (pCi/g) for Soil. (sheet 2 of 3)

ID #	Pu-238	Pu-239/240	Tc-99	I-129
C8		0.010		
C9				
C10		0.010		
C11	0.0008	0.005		
1	0.0009	0.018	0.13	-0.210
2				
3				
4	0.0007	0.044	0.41	-0.060
5				
6	0.0002	0.016		
7	0.0005	0.031		
8				
9				
10			0.23	-0.040
11	0.0002	0.015		
12	0.0003	0.022		
13			0.53	-0.900
14				
15	0.0009	0.130		
16				
17	0.0005	0.019		
18			0.85	-0.300
19				0.800
20	0.0006	0.060		
21				
22	0.0003	0.013	0.95	0.400
23		0.010		0.090
24		0.011		
25			0.57	-0.070
26		0.014		
27				0.100
28		0.070		

Table A-4. Radionuclide Values (pCi/g) for Soil. (sheet 3 of 3)

ID #	Pu-238	Pu-239/240	Tc-99	I-129
29				
30	0.0008	0.1200		
31	0.0010	0.0700		
32	0.0009	0.0500		
33	0.0004	0.0300		
34	0.0004	0.0200		
35	0.0010	0.0400	0.42	-0.500
36	0.0003	0.0200		
37	0.0006	0.0380		
38	0.0004	0.0200		
39	0.0003	0.0100	0.49	-0.510
40			9.44	0.390
41	0.0004	0.0200		
42				
43	0.0005	0.0200		
44				
45	0.0001	0.0100	0.93	-0.480
46				
47	0.0003	0.0100		-0.430
48				
49	0.0003	0.0100		
50			0.60	-0.560
51				0.270
52				-0.340
Max	0.0010	0.1300	9.44	0.80
Min	-0.0040	0.0050	0.13	-0.90
Avg	0.0001	0.0238	1.30	-0.13
St. Dev	0.0013	0.0253	2.58	0.42
2St. Err	0.0005	0.0070	1.49	0.20
Total number	29	53	12	18

Table A-5. Radionuclide Values (pCi/g) for Sagebrush.

ID #	Pu-238	Pu-239/240	Tc-99	I-129
A0	0.0004	0.0020		
A2		0.0100		
A5		0.0100		
A6		0.0100		
A10		0.0100		
A14	0.2000	1.51		
B1		0.0100		
B3		0.0100		
B5		0.0100		
B10		0.0100		
B11	0.0009	0.005		
C0	0.0002	0.0030		
C6		0.0200		
C10		0.0100		
C11	0.0004	0.0030		
1			1.73	0.36
18			0.56	0.29
19			0.34	0.01
23			2.01	0.47
39			1.61	0.39
50			7.22	0.50
Max	0.20	1.51	7.22	0.50
Min	0.00	0.00	0.34	0.01
Avg	0.04	0.11	2.25	0.34
St. Dev	0.09	0.39	2.53	0.18
2St. Err	0.08	0.20	2.06	0.14
Total number	5	15	6	6

Table A-6. Cesium-137 and Strontium-90 Values for Small Mammals. (sheet 1 of 2)

ID #	Cs-137	Sr-90
A2	0.02	
A4	0.10	
A5	0.01	0.02
AX	0.06	
A6	0.01	0.05
A7	0.27	
A9	0.02	0.02
A10	0.08	
B1	0.70	
B2	0.05	0.07
B3	0.16	
B4	0.10	0.14
B5	0.29	
B7	0.01	
B9	0.64	0.05
B10	0.69	
C1	0.28	
C2	0.01	0.06
C4	0.05	
C6	0.06	
C7	0.09	0.16
C8	0.06	
C9	0.01	0.06
C10	0.28	
1	0.00	
2	0.11	
3	0.14	
11	0.05	
12	0.11	

Table A-6. Cesium-137 and Strontium-90 Values for Small Mammals. (sheet 2 of 2)

ID #	Cs-137	Sr-90
13	0.18	
42	-0.15	
43	-0.03	
Max	0.70	0.16
Min	-0.15	0.02
Avg	0.14	0.07
St. Dev	0.20	0.05
2St. Err	0.07	0.03
Total number	32	9

Table A-7. Strontium-90 Values for all Media. (sheet 1 of 3)

ID #	Soil	Sage	Litter	Cryptogams
A0	0.18	0.09		
A2	0.22	0.13	0.70	0.20
A3	0.17	1.60		
A4	0.18	0.78		
A5	0.57	0.31	0.80	0.60
AX	0.38	0.30		
A6	0.35	0.33		
A7	0.40	0.43		
A8	0.37	0.33		
A9	0.36	0.42		
A10	0.18	0.61	0.65	0.35
A11	0.34	0.50		
A12	0.41	0.01		
A13	0.12	0.03		
A14	0.19	0.01		
B0	0.23	0.04		
B1	0.19	0.34	0.16	0.22
B2	0.17	0.26		
B3	0.10	0.37		
B4	0.20	0.22		
B5	0.16	0.19		
B6	0.34	0.28		
B7	0.16	0.32	0.24	0.29
B8	0.30	0.43		
B9	0.04	5.82		
B10	0.23	0.25	1.65	1.21
B11	0.21	0.12		
C0	0.21	0.12		
C1	0.24	0.26	0.15	0.52
C2	0.20	0.87		
C3	0.24	0.23		
C4	0.26	0.15	0.05	0.56
C5	0.25	0.19		
C6	0.10	0.22		

Table A-7. Strontium-90 Values for all Media. (sheet 2 of 3)

ID #	Soil	Sage	Litter	Cryptogams
C7	0.13	0.36		
C8	0.18	0.26		
C9	0.20	0.25		
C10	0.23	0.24	0.39	1.40
C11	0.08	0.13		
1	2.21	2.48	5.72	4.78
2		2.48		
3			2.76	
4	0.46	1.56	1.98	2.44
5				
6		2.49	4.35	
7				
8				1.69
9			1.87	
10	0.23	0.34		
11		1.99	1.31	
12		1.27		
13	1.08		2.37	
14				
15		1.25		1.65
16				
17			0.61	
18	0.49		1.28	
19	0.71	0.69		
20				
21		1.14		1.60
22	0.65			
23				0.90
24			0.58	
25	0.42		1.78	
26			1.38	0.67
27		0.24	0.65	
28		4.10	5.25	0.41
29				

Table A-7. Strontium-90 Values for all Media. (sheet 3 of 3)

ID #	Soil	Sage	Litter	Cryptogams
30	1.1			
31	0.73		1.71	
32	0.83	0.99		
33	0.83			3.02
34	0.88			1.40
35	0.98	0.72	4.68	1.41
36	0.88			
37			1.88	
38	0.66			2.26
39	0.56	1.52	1.48	1.59
40				1.15
41		0.81	3.38	0.82
42				
43				1.54
44			2.66	
45	0.53	1.00		1.87
46				
47	0.54	0.12		0.84
48			1.18	
49				1.10
50	0.43	1.49		
51				
52				
Max	2.21	5.82	5.72	4.78
Min	0.04	0.01	0.05	0.20
Avg	0.41	0.75	1.78	1.30
St. Devia	0.36	1.04	1.51	0.98
2St. Err	0.09	0.28	0.54	0.37
Total number	59	57	31	28

Table A-8. Cesium-137 Values for all Media. (sheet 1 of 3)

ID #	Soil	Sage	Litter	Cryptogams
A0	0.63	0.16		
A2	0.46	0.28	6.38	2.04
A3	0.27	0.84		
A4	0.28	0.94	9.84	3.13
A5	0.86	0.20	7.68	2.29
AX	0.52	0.69		
A6	0.90	0.63	6.35	4.70
A7	0.95	0.85		
A8	1.09	0.43		
A9	1.06	1.33	10.20	5.40
A10	0.48	1.48	5.60	4.87
A11	0.49	0.27		
A12	1.84	0.12		
A13	0.81	0.37		
A14	0.77	0.13		
B0	0.74	0.11		
B1	0.48	0.21	0.82	1.43
B2	0.54	0.27		
B3	0.27	0.39	2.10	2.12
B4	0.24	0.46		
B5	0.87	0.35	3.17	2.83
B6	0.56	0.48	1.62	2.21
B7	0.71	1.21	3.09	1.53
B8	0.80	1.69		
B9	0.39	4.99		
B10	0.75	0.60	4.02	6.10
B11	0.71	0.43		
C0	0.62	0.31		
C1	0.65	0.17	1.74	1.68
C2	0.64	0.56		
C3	0.43	0.16	3.94	2.86
C4	0.48	0.41		
C5	0.41	0.43	0.47	4.54
C6	0.22	0.45	0.80	2.85

Table A-8. Cesium-137 Values for all Media. (sheet 2 of 3)

ID #	Soil	Sage	Litter	Cryptogams
C7	0.56	0.70		
C8	0.40	0.32	1.73	4.36
C9	0.40	0.37		
C10	0.59	0.79	1.73	2.79
C11	0.17	0.18		
1	55.00	33.10	36.40	68.20
2	1.94	0.97	62.90	49.40
3	1.99	0.80	70.80	18.50
4				900.00
4	10.70	1.62	20.90	36.00
5	8.21	1.51	96.30	12.10
6	5.15	1.24	23.90	27.70
7	4.02	0.64	15.40	7.70
8	3.05	0.43	27.00	9.90
9	2.53	0.46	18.40	5.40
10		0.31	6.38	3.44
11	2.12	1.07	8.32	3.10
12	1.80	0.73	28.20	5.84
13	0.60	0.04	4.69	7.71
14	2.01	1.17	0.97	
15	1.95	0.48	10.10	7.45
16	2.38	0.56	4.00	2.78
17	1.93	0.28	2.30	3.14
18	1.79	0.34	2.71	
19		0.66	17.40	4.38
20	2.10	0.51	22.00	17.70
21	1.25	0.43	10.10	5.40
22	0.55	0.34	2.71	4.20
23	0.76	0.34	8.14	
24	1.72	0.39	1.45	1.73
25	0.57	0.59	14.80	3.76
26	0.78	0.32	2.18	1.68
27	0.42	0.43	6.32	0.82
28	0.37	0.29	1.02	0.88

Table A-8. Cesium-137 Values for all Media. (sheet 3 of 3)

ID #	Soil	Sage	Litter	Cryptogams
29	13.40	0.26	22.70	9.77
30		0.47		
31	2.45	0.94	6.53	4.68
32	3.44	0.63	28.10	4.99
33	4.07	0.85	24.20	13.80
34	2.10	0.69	20.10	8.63
35	2.88	0.42	22.20	7.43
36	2.44	0.41	11.30	10.80
37	2.60	0.89	6.41	5.61
38	2.26	0.66	16.20	11.40
39	1.13	1.05	7.58	8.18
40	4.59	0.36	8.78	5.33
41	0.84	0.46	8.87	3.18
42	1.29	1.08	28.20	15.80
43	1.11	0.64	23.40	6.98
44	1.47	1.40	14.60	6.50
45	2.92	1.13	9.61	12.40
46	1.48	1.39	4.74	13.90
47	0.95	2.61	25.40	4.78
48	1.71	2.10	12.20	6.69
49	1.66		28.10	8.48
50	3.10	1.40	15.10	8.56
51				
52				
Max	55.00	33.10	96.30	900.00
Min	0.17	0.04	0.47	0.82
Avg	2.30	1.07	14.05	22.22
St. Devia	6.11	3.52	16.67	111.12
2St. Err	1.32	0.75	4.07	27.57
Total number	86	88	67	65

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