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Vegetation Concentration and Inventory of Metals and Radionuclides in the Old F-Area Seepage Basin, 904-49G (U)

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VEGETATION CONCENTRATION AND INVENTORY OF METALS AND RADIONUCLIDES IN THE OLD F-AREA SEEPAGE BASIN, 904-49G (U)

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Abstract

Measured concentrations of radionuclides and toxic metals are used to calculate the total inventory of in the vegetation growing on the Old F-Area Seepage Basin. Air concentrations and inhalation doses from exposure to smoke from burning the vegetation are calculated to evaluate the effect of open air burning. Radionuclide inventory is one order of magnitude (10 x) less than those necessary to produce a 1 mrem dose. Air concentrations of toxic metals are less than one third the permissible occupational dose.

INTRODUCTION

The objective of this task is to determine concentration and inventory of radionuclides and nonradioactive elements in vegetation growing at the Old F-Area Seepage Basin. One option for disposal of the vegetation is open-air burning in brush piles. Where applicable this option can result in considerable cost savings relative to other available options (Lorenz 1988). The inventory of metals and radionuclides determined through the measurements will be used as the potential source term for calculations of maximum smoke-inhalation dose from the burning the vegetation. The measured concentrations in the vegetation can also be used in developing the Ecological Risk Assessment for this site.

DISCUSSION

General Description and History

The Old F-Area Seepage Basin is located just northeast of the F-Area perimeter security fence and north of 221-F building. Midpoint coordinates of the basin are 33.17279^{o}N latitude and 81.404820^{o}W longitude. The rectangular basin, 59m long by 91m wide, has an area of approximately 5,370m^2. The area is surrounded by an exclusion fence which contains an area of approximately 8,960m^2. The basin was excavated in the native soil which was used to constuct a low dike around the basin. The excavation resulted in a narrow trench which runs in a east-west direction from the intake at the southwest corner of the basin. At the southeast corner of the basin this trench empties into a broader trench which flows westward to the outlet at the northwest corner (see Figure 1).

In 1986 uncontaminated soil from the surrounding area was used to construct four access roads into the basin (CORR-87-0117 1987). The roads were used to allow soil coring equipment into the basin without contaminating the equipment. The basin soils were sampled by drilling through the uncontaminated road bed to the basin soils below. Four locations, marked on Figure 1, were sampled.

At present, the Basin surface has been revegetated to a mixed forest of pine and various hardwood species. A small wet-weather pond, bordered with cat-tails and other emergent macrophytes has formed in the deepest part of the old seepage basin. The forest canopy has closed over most of the basin and the forest floor contains only a sparse understory of shrubs and herbs. A corridor of shrubs and herbs remains between the main entrance gate and the wet weather pond on the west end of the basin.

The Old F-Area Seepage Basin was the first basin constructed in this area and received between 35 and 52 million liters of waste water from November 1954 to mid-May 1955. The source of the waste water included evaporator overheads, laundry waste water, and other discharges of unknown constituent content. Since 1955, the basin has been used intermittently to divert rainfall runoff and process effluents from NPDES Outfall F-2. This includes between 14,000 to 21,000 liters of spent etching solution (6M HNO_3) used to etch depleted uranium during manufacturing of reactor targets. At the present time rainfall and process effluents are no longer diverted to the Old F-Area Seepage Basin.

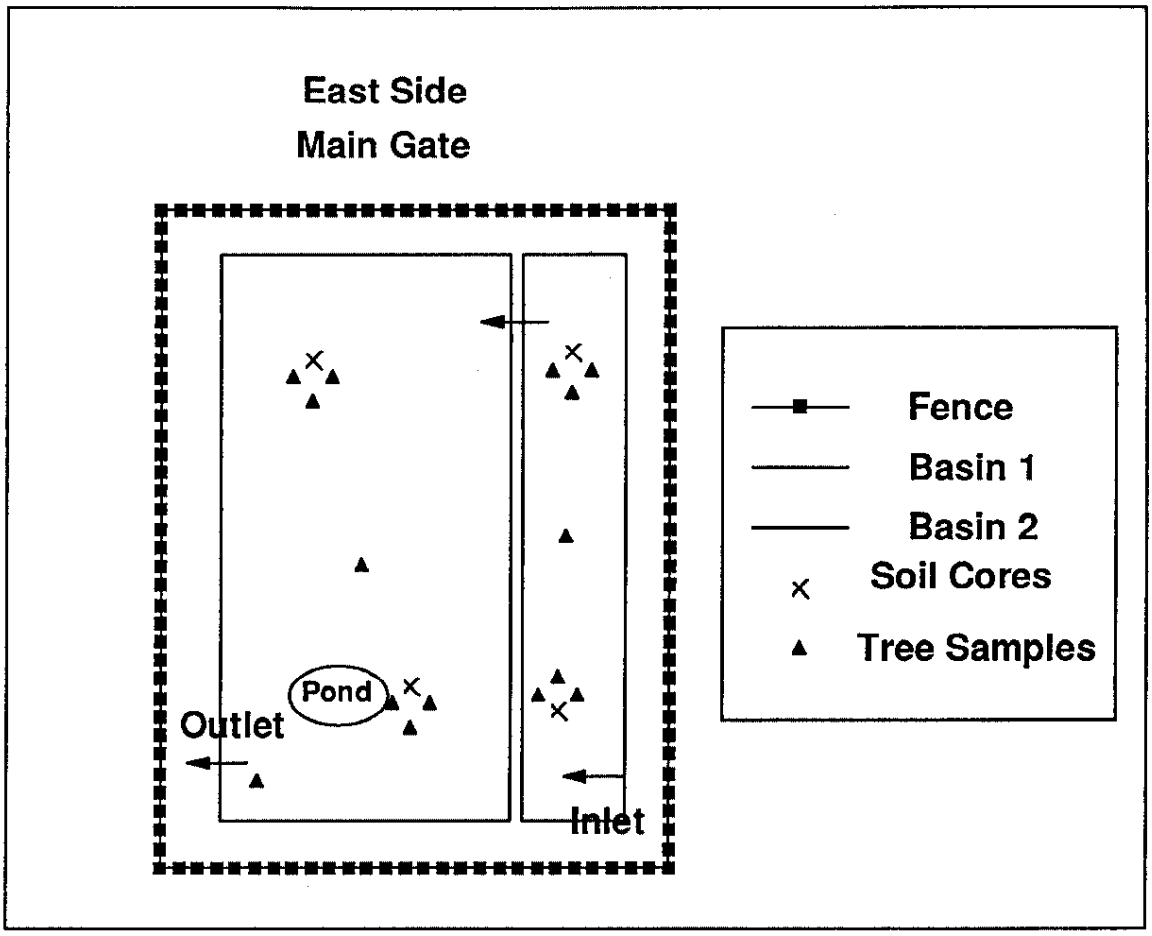

Figure 1. Diagram of Old F-Area Basin Showing the Approximate Location of the Basin and the Tree Samples

Identification of Contaminants of Concern

The choice of contaminants to be measured was based on the historical record of release and previous measurements of contaminants in basin soils and vegetation (CORR-87-0117 1987, DRAFT, WSRC-RP-90-731, Rev 2 1992, E.W. Rabon and D.I. Ross 1977, DPST-85-692 1985). One of three criteria were used for inclusion of a potential contaminant in the vegetation measurements. If the contaminant was found at elevated levels in the soil, based largely on the results found in CORR-87-0117 or DRAFT WSRC-RP-90-731, Rev 2, it was included. If the contaminant was found at elevated levels in the vegetation, based on E.W. Rabon and D.I. Ross (1977), it was included. If the contaminant was found to have been released to the basin, based on DPST-85-692, it was also included. Table 1 lists the contaminants to be measured and indicates the criteria used for inclusion on the list.

TABLE 1. Identification of Contaminants by Detection

	Detected In		
Contaminant	Releases	Soil	Vegetation
Cs-137		X	X
Pu-239,240	X	X	
U-238	X	X	
Sr-90	X	X	X
Ba	X		
Cr	X		
Pb	X		
Hg	X	X	X

Measurements were not made for some known contaminants. Contaminants, such as nitrate, which were released to the basin but are so mobile that none should remain in the surface soil and which were not measured at elevated levels in soil or trees were not included. Iodine-129 was known to be released to the basin and was detected in the soil but was not measured in the vegetation. This decision was based on the low level of I-129 found in the soil and the low uptake of iodine by vegetation. The combination of these factors suggested that any attempt to measure I-129 would be unlikely to be successful.

Measurement Requirements

The measurement requirements are set by the use of the measurements. The primary use of these measurements is the determination of a permissible dose from inhalation of the smoke from burning the vegetation. The International Commission on Radiation Protection considers a dose of less than 1.0 mrem to be insignificant to human health. The DOE dose guide for industrial exposure is 100 mrem/year. Limits for inhalation exposure to metal contaminants are set by the U.S. Environmental Protection Agency (CFR 29) and South Carolina Department of Health and Environmental Control (SCDHEC 61). The primary requirement of this task is to detect radionuclide and metal contaminants at concentrations in the vegetation that will allow evaluation relative to the regulatory standards for inhalation of smoke.

The required concentrations were calculated using the results of a Gaussian diffusion model tabulated in Turner (1967, page 29), the inhalation rate for the standard man (ICRP 1974), the DOE Dose Guide dose factors, and a burning scenario which assumes a 10 meter plume rise from the fire, neutral atmospheric dispersion conditions and a wind speed of 2 m/s. The maximum centerline plume concentration is used in the calculations. The steps in the calculation are shown in Table 2.

Table 2. Calculation of Permissible Source Strength of Radionuclides to Meet 1.0 mrem Standard.

Radionuclide	Regulatory Standard mrem	Dose Factor mrem/pCi	Equivalent Uptake pCi	Breathing Rate cu m/yr	Equivalent Air Exposure (pCi-day)/cu m	Xu/Q 1/sq m	Source Strength µCi
Cs-137	1	3.2E-05	31250	8000	1427	2.E-03	123000
Sr-90	1	0.0013	769	8000	35	2.E-03	3030
Pu-238 or 239	1	0.51	1.96	8000	0.09	2.E-03	8
U-238	1	0.12	8	8000	0.38	2.E-03	33

If the mass of vegetation to be burned is assumed to be 20 metric tons, based on estimates for similar waste sites, the necessary level of detection can also be estimated. For the radionuclides described in Table 2 the levels are Cs-137, 6.0 nCi/gm, Sr-90, 0.15 nCi/gm, Pu-238 or Pu-239,240, 0.39 pCi.gm and U-238, 1.6 pCi/gm. A similar set of calculations for the metals of interest is shown in Table 3.

Table 3. Calculation of Permissible Source Strength of Metals to Meet SCDHEC Standard.

Metal	Standard mg/cu m	Source Strength kg	Vegetation Concentration ppm
Barium	0.5	1.80	900
Chromium	0.05	1.80	90
Lead	0.15	5.40	270
Mercury	0.05	1.80	90

The results of the calculation summarized in Tables 2 and 3 indicate that the necessary levels of detection can be met by available measurement techniques. Analysis of the calculations indicate that they are not sensitive to the atmospheric stability assumed. The effect of distance that the plume reaches the surface is effectively offset by the spread of the plume leaving the surface maximum concentration nearly the same for all stability classes. The maximum concentrations are affected by the wind speed and plume rise values used in the calculations. The value of plume rise is based on the Southern Forestry Smoke Management Guide (1976).

A secondary use of the data could be its use for ecological risk assessment. The regulatory level of contaminants for protection of non-human biota is based on protecting the population of individual species. For this reason the target levels of detection are higher for radionuclides than the targets set for the protection of individual humans. While target levels for terrestrial animals have not been defined, a target level of 1.0 rad/day has been recommended for aquatic ecosystems. Calculation based on the 1.0 rad/day target lead to higher concentration limits than those indicated in Table 1 for inhalation of smoke. Therefore the source strength limitations and analytic detection limits derived for humans are adequate for evaluation of effects on other organisms. Target levels for metals are more difficult to set and are not necessarily the same as those for humans. Since the target levels are not easily determined for metals, the detection limits were determined by the best available method.

Vegetation Sampling

The sampling scheme was designed to allow comparison of the contaminant concentrations in the vegetation samples to contaminant concentration previously measured in the soil (CORR-87-0117 1987, DRAFT, WSRC-RP-90-731, Rev 2 1992). Three trees were sampled in the general vicinity of the four soil sampling cores taken in 1986 and 1988 . In addition three trees located between the core holes, and three located outside the fence were also measured. This brought the total number of trees sampled to eighteen and the total number of samples, leaves and wood for each tree, to thirty six.

An attempt was made to sample trees characteristic of the site in terms of species and size. However, because of accessibility of branch wood and leaves, hardwood species and smaller trees are over-represented in the sample. Branches were removed from the trees with cutting shears. The wood from the branch or stem of the trees was cut into 12 inch pieces and put into a plastic bag. The leaves were stripped from the same branches and put into a plastic bag. If additional leaves were needed they were taken from the same tree. One to two kilogram of material was collected.

Each bag was be labeled with the location (based on counting fence poles from the seepage basin fence entrance), date of collection, name of collector or supervisor. The information entered on the bag label was put in a numbered notebook along with additional information on the location and size of each sample. The bags were taken to the SRTC/ESS laboratories at Building 704B for storage and processing before analysis.

Vegetation Processing and Analysis

Leaves and wood were freeze dried. Leaves were processed before analysis by chopping in a food processor. The leaf material was ground until no fragment was greater than 0.25 cm in any dimension. Branches were ground in a Wiley Mill until they had the consistency of coarse sawdust. Branch material

included both the bark and wood. The ground material was delivered to SRTC/ADS for metals analysis. Moisture contents were determined for all samples so that concentrations could be expressed per unit dry weight.

Metal analysis was done by inductively coupled plasma spectroscopy (ICP). An aliquot of the ground sample was dissolved by microwave dissolution in acid solution. The results were reported in per cent of dry weight. Mercury was analyzed by cold vapor atomic absorption. The sample remaining after subsampling for metals analysis was transported to ESH&QA/EMS for radionuclide analysis.

The radionuclide analyses were done using procedures developed by EMS. Cs-137 analysis was done by gamma spectroscopy. The detection limit for Cs-137 was 1 pCi/g or less for all samples. Sr-90 analysis was done by beta counting after chemical separation of this isotope. A 5 gram aliquot was used for the strontium procedure, producing a detection limit of approximately 0.5 pCi/g. Pu-238, Pu-239/240, and U-238 were analyzed by alpha spectroscopy after chemical separation for each element.

RESULTS

Concentration of Metals

The complete results of the ICP analysis are shown in Table A.2. The results for the four contaminants identified as present in the seepage basin are summarized in Table 4.

Table 4. Summary of Analyses for Identified Contaminant Metal Concentrations (ppm-dry weight).

		Inside Basin				Outside Basin			
	Detection Limit ppm-dry	Number Above Detection	Mean ppm	Max ppm	Min ppm	Number Above Detection	Mean ppm	Max ppm	Min ppm
Pb	20	8	30	50	20	1	40	-	-
Ba	10	15	30	70	10	4	80	120	40
Cr	10	1	10	-	-	0	-	-	-
Hg	10	0	-	-	-	0	-	-	-

The metal contaminants are not detectable in a high percentage of the samples taken inside the seepage basin. The detected levels for all elements are always near the detection limits. Mercury is not detected in any sample and chromium in only one sample at the analytical detection limit. A comparison of these results with the limits derived in Table 3 indicates that the level of contaminants in the vegetation is too low to be of significance as a contaminant in the smoke from burning the vegetation.

Concentration of Radionuclides

The complete results of the radionuclide analyses are contained in Table A.3. The results were investigated graphically to look for consistency in the data and to determine if there were any patterns that would have an influence on the analysis of smoke inhalation dose.

The concentration of the two isotopes of plutonium were plotted against each other. Given the history of the basin it was suspected that the sources of the isotopes should be similar and their chemistry should be virtually the same. As indicated in Figure 2, there is good agreement in the concentration in the tree tissues for the two isotopes. The plot also points to the fact that out of the thirty-six samples, two have significantly higher levels of contamination. The two samples are leaf samples from different trees. The trees are both hardwood species that are growing in the low, moist area near the wet weather pond. This is an area that can be expected to collect sediment from the rest of the basin. These samples probably are from an area of higher than average contamination. As indicated by Figure 3, there does not seem to be a significant relationship for all of the radionuclides. The highest levels of Sr-90 and Cs-137 are not found in the same trees and high levels of either of these isotopes do not necessarily coincide with high levels of the plutonium or uranium isotopes.

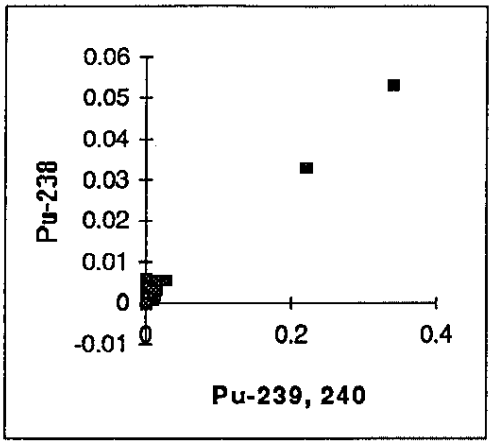

Figure 2. Pu-238 vs. Pu-239, 240 Concentration in the Same Sample.

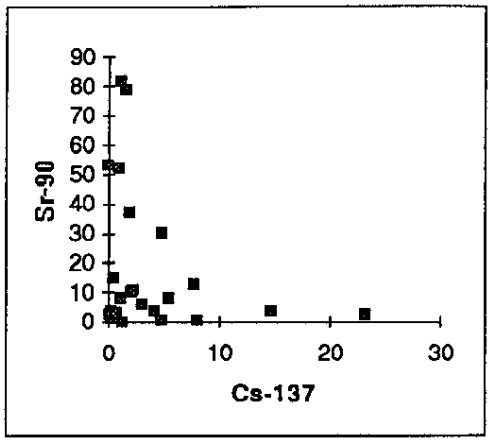

Figure 3. Sr-90 vs Cs-137 Concentration in the Same Sample

Another way of looking at the data is to plot the concentration in the wood versus the concentration in the leaves. While the ratio of leaf to wood concentration for these radionuclides should vary greatly between radionuclides, a tree growing in a more highly contaminated soil would be expected to have higher concentration in both leaves and wood than a tree growing in less contaminated soil. This expectation is confirmed for all of the radionuclides. Plots for Pu-239, 240 and Sr-90 are used as examples (Figures 3 & 5). Once again there are a relatively few tree with higher than average contamination. However, an inspection of the data shows that these are not the same trees for all of the isotopes. The tree with the highest Pu-239,240 concentration is not the same tree as the one having the highest Sr-90, Cs-137 or U-238 concentration. These tree do have on thing in common. They are all hardwood species which are more likely to have been growing in the low, moist areas of the basin.

From the above analysis it appears that the analytical results are consistent with what one would expect based on the behavior of the elements in the vegetation. This provides added confidence in applying the results. The analyses do suggest that the hardwood species have higher concentrations, than the pine trees, probably because of their location in the basins. Visual inspection of the basin indicates that the majority of the mass of vegetation is in pine trees. This means that the average concentration of radionuclides calculated from the samples may over-estimate the actual average concentration in all the vegetation. Ideally this could be corrected by weighting the average; however, the sample size is too small to make reliable separate estimates of average pine and hardwood concentrations.

Table 5 summarizes the results of measurements of the radionuclide concentration in the vegetation. The geometric mean value is higher in the leaves for all radionuclides; however, not significantly so for Sr-90. The concentrations measured in leaves inside the fence is higher than outside for all radionuclides. The same is not true for the wood samples. The concentrations of the wood are higher inside the fence only for Sr-90 and Cs-137. This is probably the result of the low concentration in wood both inside and outside the basin although the Pu-238 concentration in wood outside the fence is higher than the mean concentration in the leaves inside the fence.

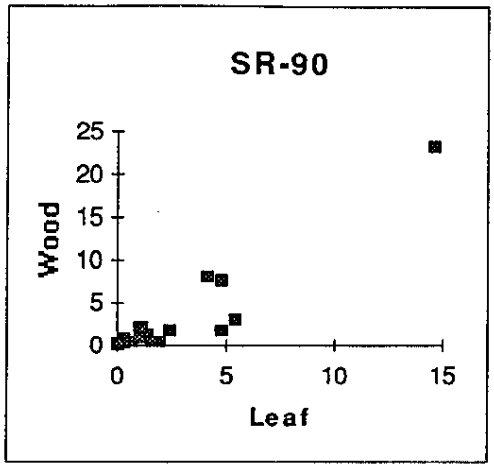

Figure 4. Comparison of Wood to Leaf Concertino of Sr-90.

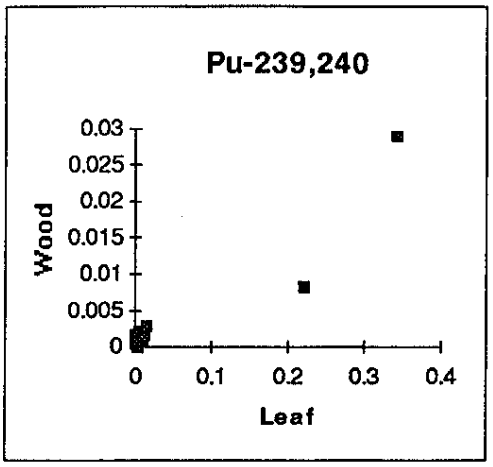

Figure 5. Comparison of Wood to Leaf Concentration of Pu-239, 240.

Table 5. Geometric Mean, 95% Confidence Limits of Tree Leaf and Wood Radionuclide Concentration inside Fence at the Old F-Area Seepage Basin and Mean Concentration of Samples from outside the Fenced Area (pCl/gm).

	Sr-90.	Cs-137	Pu 239, 240	Pu-238	U-238
Leaves					
Mean	0.95	11.1	0.0051	0.0018	0.158
Upper 95	2.83	26.6	0.0141	0.0043	0.411
Lower 95	0.32	4.67	0.0019	0.0007	0.061
Mean Outside Fence	0.58	2.8	0.0010	1.1E-05	0.043
Wood					
Mean	0.92	6.7	0.0007	0.0002	0.020
Upper 95	2.53	16.0	0.0047	0.0017	0.094
Lower 95	0.34	2.8	0.0001	1.4E-05	0.004
Mean Outside Fence	0.81	0.8	0.0008	0.0035	0.025

Calculation of Inventory of Metals and Radionuclides

An inventory of metals and radionuclide contaminants can be calculated by multiplying the concentrations measured in the vegetation by the mass of vegetation inside the basin enclosure. Since the concentrations in leaves and wood differ for some radionuclides, a better estimate will result from a separate estimate of the mass of leaves and wood.

The mass of wood inside the exclusion fence of the basin was estimated by taking a 100% tally of the trees by diameter class. The diameter class data was converted to mass of the entire tree with regressions based on a study of southern pine biomass by Metz and Wells (1965). The product of the basal area of the tree and the height was fit to the total mass of the trees. The adjusted R^2 for the regression was 0.99 The logarithm of the basal area-height product was regressed against the logarithm of the percentage of leaf mass. The R^2 of this regression was 0.95. The calculations are summarized in Table 6. An upper and lower 95% confidence level was computed for the estimates based on the 95% confidence limits of

the coefficients of the regression equations. The estimate for the lower 95% confidence limits computed leaf area percentage greater than the total mass of for the 2 and 4 inch classes. The values used in the calculation are linear extrapolations through zero of the values for 6 inch trees. This procedure does not significantly influence the volume estimates because the volume of the 2 and 4 inch diameter class trees do not make a large contribution to the total mass.

Table 6. Old F Basin Tree Mass Estimates (metric ton)

Diameter	Mean		Upper 95%		Lower 95%	
Class (in.)	Leaves	Wood	Leaves	Wood	Leaves	Wood
2	0.09	0.21	0.26	0.19	0.10	0.19
4	0.08	0.20	0.15	0.39	0.04	0.07
6	0.04	0.26	0.10	0.43	0.02	0.04
8	0.08	0.93	0.23	1.46	0.03	0.30
10	0.13	2.20	0.39	3.32	0.05	0.90
12	0.17	3.79	0.53	5.57	0.05	1.76
14	0.13	3.77	0.43	5.44	0.04	1.89
16	0.10	3.70	0.36	5.26	0.03	1.95
Sum	0.82	15.06	2.45	22.05	0.36	7.12

The inventory of contaminants can be calculated for each contaminant. Because of the low number of samples with metal concentration above the detention level, it is not possible to compute confidence levels for these contaminants. In most cases it is only possible to compute upper limits based on the level of detection. Confidence limits can be estimated for the radionuclides be combining the limits calculated for the mass of vegetation and the confidence levels for the mean concentrations. The results are shown in Tables 7 and 8.

Table 7. Total Inventory of Radionuclides in the Vegetation (μCi)

	Sr-90	Cs-137	Pu-239, 240	Pu-238	U-238	Total	Total α
Mean	14.4	108	0.015	0.0036	0.41	123	0.43
Lower 95	2.4	20	0.001	0.0003	0.04	23	0.04
Upper 95	61.5	408	0.133	0.0467	2.96	473	3.14
1 mrem Equivalent	3030	123000	8	8	33		

Table 8. Total Inventory of Metals in Vegetation (kg)

Element	Ba	Cr[1]	Hg[1]	Pb
Inventory	0.47	0.16	0.16	0.49
Regulatory Equivalent	1.8	1.8	1.8	5.4

1. No samples above detection limit; inventory calculated at the detection limit.

CONCLUSION

The results indicate that the measured inventories of radionuclides are at least one order of magnitude less than the inventory that would cause a 1 mrem dose to the hypothetical maximally exposed

individual. The margin is not as great for the metals but it must be remembered that the concentration used in these calculations do not include most of the samples which were too low to detect. The actual average concentrations are likely to be much lower than those used in the calculations. Furthermore, the limiting air concentrations and inventories are based on the assumption that all of the material will become airborne in the smoke, something that does not seem likely considering the large amount of ash left at burning sites.

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APPENDICES

Table A.1 Old F Area Seepage Basin Sample Scheme

Sample Number	Sample Type	Species	Location	Date Collected
1	Leaf	Cherry	outside	7/26/93
2	Wood	Cherry	outside	7/26/93
3	Wood	Long-Leaf Pine	outside	7/26/93
4	Leaf	Long-Leaf Pine	outside	7/26/93
5	Leaf	Sweetgum	outside	7/26/93
6	Wood	Sweetgum	outside	7/26/93
7	Leaf	Cherry	inside	7/27/93
8	Wood	Cherry	inside	7/27/93
9	Leaf	Sweetgum	inside	7/29/93
10	Wood	Sweetgum	inside	7/29/93
11	Leaf	Pine	inside	7/29/93
12	Wood	Pine	inside	7/29/93
13	Leaf	Oak	inside	7/29/93
14	Wood	Oak	inside	7/29/93
15	Leaf	Pine	inside	7/29/93
16	Wood	Pine	inside	7/29/93
17	Leaf	Pine	inside	7/29/93
18	Wood	Pine	inside	7/29/93
19	Leaf	Hickory	inside	7/29/93
20	Wood	Hickory	inside	7/29/93
21	Leaf	Pine	inside	7/29/93
22	Wood	Pine	inside	7/29/93
23	Leaf	Cherry	inside	7/29/93
24	Wood	Cherry	inside	7/29/93
25	Leaf	Willow	inside	7/29/93
26	Wood	Willow	inside	7/29/93
27	Leaf	Unknown	inside	7/29/93
28	Wood	Unknown	inside	7/29/93
29	Leaf	Sweet Gum	inside	7/29/93
30	Wood	Sweet Gum	inside	7/29/93
31	Leaf	Oak	inside	7/29/93
32	Wood	Oak	inside	7/29/93
33	Leaf	Pine	inside	7/29/93
34	Wood	Pine	inside	7/29/93
35	Leaf	Pine	inside	7/29/93
36	Wood	Pine	inside	7/29/93

Table A.3 Concentration of Metals in Trees (% dry weight)

No.	Ca	Cd	Co	Cu	Mg	Mn	Pb	Zn	Zr	Al	Ba	Fe
1	0.682				0.162	0.025		0.005			0.004	0.005
2	0.313				0.039	0.03		0.004			0.006	0.007
3	0.202				0.011	0.003		0.008				
4	0.293				0.08	0.043		0.015		0.007		0.008
5	1.097			0.001	0.277	0.093		0.009		0.046	0.009	0.01
6	1.094			0.001	0.074	0.026	0.004	0.004		0.007	0.012	0.006
7	0.944				0.282	0.057		0.006			0.006	0.005
8	0.163			0.001	0.03	0.004	0.003	0.004			0.002	0.004
9	0.843			0.001	0.229	0.07		0.007		0.053	0.004	0.014
10	1.09			0.001	0.043	0.016	0.002	0.005		0.006	0.006	0.005
11	0.264				0.085	0.044		0.011		0.038		0.007
12	0.302				0.055	0.013		0.01				0.004
13	1.553			0.001	0.182	0.008		0.01		0.006	0	0.016
14	0.202		0.001	0.002	0.017	0.003	0.005	0.005		0.009	0.001	0.0012
15	0.374				0.083	0.102		0.008		0.055		0.02
16	0.529				0.074	0.017		0.011		0.027		0.006
17	0.243				0.071	0.062		0.007		0.02		0.005
18	0.193				0.04	0.02		0.006		0.01		0.003
19	0.47				0.188	0.11		0.006			0.003	0.005
20	0.191				0.029	0.007		0.004				0.002
21	0.254				0.112	0.011		0.009		0.004		0.009
22	0.251				0.099	0.002		0.008				0.005
22	0.184				0.095	0.002		0.007				0.002
23	0.722				0.272	0.035	0.003	0.004			0.007	0.004
23	0.723				0.265	0.031		0.005			0.005	0.005
24	0.198			0.001	0.034	0.004	0.002	0.006			0.002	0.005
24	0.161			0.001	0.028	0.003		0.005		0.003	0.001	0.003
25	0.92				0.19	0.112		0.035				0.005
25	1.001				0.209	0.121		0.041				0.007
26	0.141				0.017	0.007		0.006				
27	0.993				0.134	0.005		0.004				
28	0.301				0.023	0.002		0.004				0.002
29	0.732			0.001	0.24	0.089	0.003	0.008		0.052	0.002	0.018
30	0.42			0.001	0.03	0.01	0.003	0.006		0.005	0.002	0.005
31	0.513			0.001	0.145	0.009	0.004	0.007		0.011	0.002	0.017
32	0.333			0.001	0.036	0.043		0.005		0.005	0.002	0.005
33	0.256				0.087	0.044		0.006		0.036		0.009
34	0.206				0.054	0.015		0.006				0.002
35	0.415				0.087	0.022		0.022		0.048		0.006
36	0.143				0.024	0.004		0.006				0.005

Table A.2 Concentration of Metals in Trees (% dry weight), Continued

No.	La	Li	Mo	Na	Ni	Sn	Sr	Ti	V	B	Cr	P	Si
1					0.001		0.002			0.002		0.137	0.011
2							0.002					0.026	
3												0.004	
4												0.051	0.027
5	0.001			0.003	0.001		0.005			0.003		0.091	0.084
6	0.001				0.001		0.007			0.001		0.028	0.072
7							0.003			0.003		0.162	0.005
8	0.001				0.001		0.001					0.024	
9	0.001				0.001		0.002			0.003		0.097	0.15
10				0.004	0.001		0.004			0.001		0.027	0.059
11										0.002		0.124	0.049
12												0.029	
13	0.001			0.338	0.001		0.001			0.003		0.066	0.014
14	0.002	0.001		0.086	0.002				0.001	0.001	0.001	0.046	0.004
15												0.087	0.073
16												0.043	
17												0.079	0.031
18												0.022	
19												0.097	0.006
20												0.021	
21												0.122	0.03
22												0.072	
22												0.077	
23					0.001		0.003			0.002		0.173	0.014
23					0.001		0.002			0.002		0.165	0.024
24	0.001				0.001		0.001					0.028	
24	0.001				0.001		0.001			0.001		0.024	
25							0.002					0.145	
25							0.002					0.15	
26												0.037	
27							0.001					0.107	0.007
28												0.02	
29	0.001				0.002		0.002			0.003		0.083	0.111
30	0.001			0.004	0.001		0.001			0.001		0.022	0.021
31	0.001			0.005	0.002		0.01			0.003		0.07	0.14
32	0.001			0.029	0.001		0.001			0.001		0.032	0.003
33												0.113	0.036
34												0.032	
35												0.099	0.031
36												0.014	

Note: Blank entries signify analyses that were below the analytical detection limit. For Cd, Co, Cu, Pb, Zn, Zr, Al, Ba, Fe, La, Li, Mo, Na, Ni, Sn, Sr, Ti, V, B, Cr, and Si the detection limit was 0.001 % dry weight. All other elements were detectable in all samples.

Table A.3 Concentration of Radionuclides in Vegetation Samples (pCi/gm-dry)

No.	Cs-137		Sr-90		Pu-238		Pu-239, 240	
	Activity	St. Dev.	Activity	St. Dev.	Activity	St. Dev.	Activity	St. Dev.
1	BD	BD	1.45E+00	1.55E-01	4.79E-04	5.87E-04	1.05E-02	1.76E-03
2	3.95E-01	1.35E-01	1.27E+00	1.50E-01	4.93E-03	7.67E-04	8.91E-04	3.16E-04
3	1.48E+00	1.22E-01	2.02E-01	1.08E-01	1.85E-03	4.50E-04	1.19E-03	3.60E-04
4	2.79E+00	1.97E-01	1.25E-01	1.00E-01	3.84E-09	2.32E-04	1.63E-04	1.63E-04
5	BD	BD	1.05E+00	1.38E-01	7.89E-04	3.13E-04	5.89E-04	2.41E-04
6	BD	BD	2.11E+00	1.78E-01	4.52E-03	7.03E-04	4.08E-04	2.04E-04
7	8.04E-01	2.19E-01	4.80E+00	2.49E-01	8.57E-04	3.17E-04	1.04E-03	3.44E-04
8	BD	BD	1.73E+00	1.58E-01	5.71E-03	6.79E-04	1.71E-03	4.28E-04
9	3.98E+00	3.42E-01	1.46E+01	4.15E-01	5.48E-03	1.00E-03	1.38E-02	1.58E-03
10	2.48E+00	2.31E-01	2.32E+01	5.19E-01	3.87E-03	7.61E-04	2.74E-03	6.46E-04
11	8.08E+00	3.43E-01	1.14E+00	1.52E-01	4.06E-04	5.74E-04	6.04E-04	4.52E-04
12	1.07E+01	3.33E-01	2.25E+00	1.80E-01	2.89E-04	2.05E-04	4.32E-04	2.03E-04
13	BD	BD	2.40E+00	1.86E-01	3.57E-03	6.91E-04	6.44E-03	9.30E-04
14	3.73E+01	7.98E-01	1.84E+00	1.67E-01	NM	NM	7.61E-04	3.28E-04
15	1.01E+01	4.92E-01	1.99E+00	1.77E-01	1.06E-03	4.32E-04	3.14E-03	7.45E-04
16	1.23E+00	2.16E-01	3.77E-01	1.18E-01	3.10E-04	2.69E-04	2.06E-09	2.18E-04
17	3.72E+00	2.67E-01	3.31E-01	1.25E-01	5.11E-04	3.07E-04	6.10E-04	3.81E-04
18	2.99E+00	1.94E-01	8.19E-01	1.40E-01	-1.15E-04	2.58E-04	1.15E-03	3.63E-04
19	4.02E+00	2.97E-01	4.10E+00	2.30E-01	3.06E-04	1.88E-04	1.98E-03	4.19E-04
20	7.63E-01	1.10E-01	7.95E+00	3.03E-01	4.82E-04	2.41E-04	1.20E-03	3.79E-04
21	BD	BD	5.14E-03	8.96E-02	1.72E-03	6.09E-04	4.48E-03	1.12E-03
22	BD	BD	1.48E-01	1.02E-01	5.03E-04	2.36E-04	2.13E-03	4.70E-04
23	BD	BD	6.90E-01	1.20E-01	1.27E-04	2.64E-04	1.73E-03	4.15E-04
24	BD	BD	4.94E-01	1.14E-01	4.37E-04	1.94E-04	1.72E-03	3.40E-04
25	7.85E+01	1.11E+00	1.60E+00	1.55E-01	5.32E-02	1.58E-03	3.42E-01	6.03E-03
26	1.53E+01	5.02E-01	4.04E-01	1.17E-01	5.41E-03	6.73E-04	2.89E-02	1.64E-03
27	BD	BD	3.25E-01	1.02E-01	1.29E-03	3.23E-04	6.65E-03	7.42E-04
28	BD	BD	2.09E-01	9.64E-02	1.05E-08	5.12E-04	8.31E-04	5.88E-04
29	3.01E+01	5.89E-01	4.82E+00	2.42E-01	3.27E-02	1.93E-03	2.22E-01	6.63E-03
30	1.30E+01	3.61E-01	7.66E+00	2.98E-01	1.96E-03	5.68E-04	8.30E-03	1.18E-03
31	8.12E+00	3.94E-01	5.37E+00	2.79E-01	1.84E-03	4.70E-04	1.22E-02	1.11E-03
32	6.32E+00	2.68E-01	3.01E+00	2.11E-01	1.19E-08	5.06E-04	1.59E-03	5.34E-04
33	8.17E+01	1.17E+00	1.06E+00	1.44E-01	3.16E-03	7.70E-04	1.37E-02	1.61E-03
34	5.26E+01	7.67E-01	8.66E-01	1.34E-01	7.52E-04	3.55E-04	2.74E-03	6.14E-04
35	5.36E+01	1.07E+00	1.75E-02	9.63E-02	-4.76E-04	2.75E-04	3.16E-04	3.87E-04
36	BD	BD	5.82E-03	8.95E-02	1.67E-04	2.05E-04	5.83E-04	3.00E-04

Table A.3 Concentration of Radionuclides in Vegetation Samples (pCi/gm-dry), Continued

No.	U-238 Activity	St. Dev.
1	NM	NM
2	-3.78E-05	8.85E-03
3	-8.69E-05	1.32E-02
4	4.27E-02	4.42E-02
5	NM	NM
6	2.47E-02	3.19E-02
7	1.69E-02	2.63E-02
8	7.16E-03	1.72E-02
9	6.10E-01	1.33E-01
10	1.52E-01	7.07E-02
11	-3.13E-04	2.29E-02
12	2.69E-02	3.85E-02
13	7.25E-02	5.29E-02
14	NM	NM
15	3.23E-01	1.00E-01
16	NM	NM
17	1.19E-01	6.73E-02
18	-5.03E-07	1.02E-03
19	2.16E-01	9.18E-02
20	NM	NM
21	-1.89E-04	1.92E-02
22	-2.95E-04	2.96E-02
23	-3.10E-05	8.15E-03
24	NM	NM
25	9.00E-02	5.75E-02
26	1.79E-03	1.38E-02
27	9.43E-03	2.21E-02
28	4.84E-03	1.58E-02
29	3.04E+00	3.24E-01
30	2.32E-01	9.69E-02
31	4.16E-01	1.24E-01
32	NM	NM
33	2.30E-01	9.72E-02
34	-1.34E-06	1.67E-03
35	-3.75E-04	3.11E-02
36	NM	NM

BD - Below the detection limit for sample weight and geometry of the individual sample.
NM - Not measured because of small quantity of sample.