MARTIN MARIETTA

National Security Program Office

**ENVIRONMENTAL MONITORING
FOR DETECTION OF URANIUM
ENRICHMENT OPERATIONS:
COMPARISON OF LEU AND
HEU FACILITIES**

D. M. Hembree, Jr.
J. A. Carter
H. H. Ross

March 1995

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DEPARTMENT OF ENERGY

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H. H. Ross**

**Prepared by the
National Security Program Office
Oak Ridge Y-12 Plant
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EXECUTIVE SUMMARY

In 1994, the International Atomic Energy Agency (IAEA) initiated an ambitious program of worldwide field trials to evaluate the utility of environmental monitoring for safeguards (Task 3 of Programme 93+2). Part of this program, conducted during the week of May 16-20, 1994, involved two extensive United States field trials conducted at the large uranium enrichment facilities at Paducah, Kentucky, and Portsmouth, Ohio. The Paducah operation involves a large low-enriched uranium (LEU) gaseous diffusion plant that has never exceeded 2.1% enrichment while the Portsmouth facilities include a large gaseous diffusion plant that has produced both LEU and high-enriched uranium (HEU) (up to 97.5% ^{235}U) as well as an LEU centrifuge facility. As a result of the Energy Policy Act of 1992, management of the uranium enrichment operations at both of these sites was assumed by the U.S. Enrichment Corporation (USEC). The facilities are leased by USEC from the U.S. Department of Energy (DOE) and operated under contract by Martin Marietta Utility Services. Martin Marietta Energy Systems manages the environmental restoration and waste management programs at Portsmouth and Paducah for DOE.

These field trials were conducted by personnel from the Oak Ridge National Laboratory (ORNL) and the Savannah River Technology Center. IAEA inspectors were not involved in the trials. Samples included swipes from inside and outside process buildings, vegetation and soil samples taken from locations up to 8 km from main sites, and hydrologic samples taken on the sites and at varying distances from the sites. The hydrologic data will be covered in a separate report.

Most of the analytical results from bulk analysis were obtained using high abundance sensitivity thermal ionization mass spectrometers (TIMS) located at various laboratories in the DOE Network of Analytical Laboratories (NWAL).^{*} Samples were prepared for analysis by TIMS using either leaching or total dissolution methods, depending on the analytical methodology in place at a given DOE laboratory. Some of the vegetation samples (pine needles) were subjected to delayed neutron analysis at the High Flux Isotope Reactor located at ORNL. Delayed neutron analysis provides a measure of the level of certain fissile isotopes in a given sample, and is particularly sensitive to ^{235}U . A complete set of swipes with controls and pine needle samples was also sent to the Air Force Technical Applications Center (AFTAC) for particulate analysis.

Uranium isotopics altered from the normal background percentages were found for all the sample types listed above, even on vegetation 5 km from one of the enrichment facilities. The results from these field trials demonstrate that dilution by natural background uranium does not remove from environmental samples the distinctive signatures that are characteristic of enrichment operations. Data from swipe samples taken within the enrichment facilities were particularly revealing. In the Portsmouth Gaseous Diffusion Plant, which has produced 97.5% ^{235}U with tails less than 0.4%, bulk analysis of a swipe near the top end of the cascade (but not at the final product area) gave a ^{235}U value of 88.88%, while two swipes from the tails area gave 0.3006% and 0.2966% ^{235}U . Particulate analysis of these swipes provided a detailed "history" of both facilities, including the assays of the end product and tails for both facilities. These field trials demonstrate conclusively that directed sampling with swipes within nuclear facilities gives clear evidence of the nature of the processes occurring there.

^{*}The DOE NWAL is composed of Savannah River Technology Center, Oak Ridge National Laboratory, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Pacific Northwest Laboratories, and New Brunswick Laboratory.

BACKGROUND INFORMATION

The Paducah Gaseous Diffusion Plant is located in western Kentucky on the Ohio River near the border of Illinois (Fig. 1). The Ohio and Tennessee Rivers join approximately 24 km upstream from Paducah, while the Ohio River empties into the Mississippi River approximately 90 km below the site. The wind rose for the Paducah site shows the primary wind direction and speed is from the south/southwest at 2-4 m/s; however, the wind blows in most other directions with similar frequency. The plant started operations in 1952 supplying LEU for commercial reactors and military defense reactors and has enriched uranium no higher than 2.1%.

The Portsmouth facility is located approximately 43 km north of the city of Portsmouth on a 16.2 km² site in a sparsely populated part of southern Ohio (Fig. 2). The site is located approximately 1.6 km east of the Scioto River which joins the Ohio River ~45 km to the south. Wind rose information indicates that the wind blows predominantly from the south or south/southwest at 0-2 m/s. The Portsmouth facilities produced HEU until 1992 when HEU operations ceased. The plant continues to produce LEU by gaseous diffusion. The centrifuge facility at Portsmouth started operation in July 1983 and had a top enrichment of 3.2%. The plant was shutdown in July 1985.

Both the Portsmouth and Paducah sites have extensive environmental monitoring programs mandated by state and federal agencies. Detailed environmental reports covering external gamma radiation, ambient air, surface water, sediment, soil, vegetation, food crops, fish, wildlife, and groundwater are available for both facilities (ES/ESH-36, KY/E-164 and ES/ESH-50, POEF-3050).

SAMPLING AND ANALYSIS

To avoid any possibility of introducing HEU contamination from Portsmouth, the field trial began with the LEU facilities at Paducah. Contamination control was crucial because a set of samples from both facilities was sent to AFTAC for particulate analysis.

Swipe samples were collected using the same sampling procedure taught to IAEA inspectors at the March 1994, workshop in Oak Ridge, Tennessee. Briefly, swipe kits were prepared in advance (by AFTAC), and the collector/assistant procedure was used to ensure that no cross-contamination occurred. All sampling was performed from clean work areas (aluminum foil) and the samples were carefully double-bagged. Swipe sampling points were chosen to increase the likelihood that the sample would reflect the actual enrichment at given points in the process. Directed sampling at locations such as sampling stations, chemical traps, vents, product removal or transfer areas, and analytical laboratory equipment used to determine assay are all excellent areas to take swipe samples. Swipe samples were taken near the product and tails process areas as well as intermediate points along the cascades for both the Paducah and Portsmouth gaseous diffusion plants. In addition, swipe samples were taken in the analytical laboratory of the LEU centrifuge facility at Portsmouth (now shutdown). Samples could not be taken directly in the HEU product removal area of the Portsmouth plant because of safety concerns regarding high radiation levels in this area.

Vegetation samples were taken at 0, 1, 3, and 5 km from the Portsmouth site and at the same distances from the Paducah site, plus one more set of samples at 8 km. Although a range of samples were taken at each sampling point (e.g., pine needles, bark, grass, deciduous leaves, moss, lichen, and soil) only the high-priority pine needle samples were analyzed by TIMS, delayed neutron, and particulate analysis in this study. Sampling directions from each site were chosen along the predominant wind directions where possible.

At the conclusion of the field trial, all samples were transported directly to the ORNL off-site sample receiving and processing facility. The samples were distributed to the DOE NWAL and AFTAC in late May and early June 1994. Reporting of data from these samples was delayed because of the requirement for a review of the report by both facilities.

Fig. 1. Paducah Gaseous Diffusion Plant.

Fig. 2. Location of the Portsmouth site within the state of Ohio.

RESULTS AND DISCUSSION

Data from bulk and particulate analysis of environmental samples from both the Paducah and Portsmouth field trials are given in Appendixes 1 and 2, respectively (more detailed information for each sample, such as measurement standard deviations, is available through the official DOE and AFTAC electronic reporting systems). Appendixes 3-6 show graphical comparisons between the bulk and particulate results for each of the swipe and pine needle samples taken during both field trials. For each sample, ^{235}U vs ^{234}U and ^{235}U vs ^{236}U graphs are given. As expected, swipe samples taken inside process buildings provide detailed information on the nuclear operations occurring at a particular facility. In general, particulate results from swipes tend to show the overall "history" (i.e., data from particles originating from many points in an enrichment process) of the facility while bulk analysis tends to reflect the assay at the point where the sample was taken. For example, in the Portsmouth field trial, bulk analysis of samples taken in the 330 Building in an area that processed tails accurately measure the expected assay (0.3006 and 0.40514 atom % ^{235}U). The particulate data for this sample are clustered around 0.3-0.4 atom % ^{235}U , but also include particles above and below the expected assay. Examination of the swipe data in Appendixes 1, 2, 3, and 5 provide many more

examples of particulate data showing detailed "history" and bulk data measuring the assay at the sampling point. For both facilities, the assays of both the product and tails were established precisely by the particulate data. Surprisingly, bulk analysis also provided reasonable values from swipe samples taken in the product and tails areas. It was thought before this field trial that dilution effects from natural uranium and from uranium originating from other points in the cascade would dramatically skew the results of bulk analysis.

The results from analysis of vegetation samples (pine needles) by bulk and particulate analysis are given as raw data in Appendixes 1 and 2, and compared in graphical form in Appendixes 4 and 6. Particulate data from these samples provide very little information for either facility, except for the sample taken on-site at Portsmouth. Particulate data from pine needles collected off-site for both facilities is clustered around natural uranium (0.72 atom % ^{235}U). However, altered uranium isotopics can clearly be detected out to 5 km in the bulk data for the Portsmouth pine needles. Data from bulk analysis of the pine needles collected around the LEU facility at Paducah are similar to the particulate results—clustered around natural for most samples. The uranium concentrations reported in Appendix 1 for the pine needle samples are consistent with previously reported data in the annual environmental reports for each site.

Delayed neutron analysis was performed on pine needle samples taken at varying distances from both sites in these field trials. The purpose of using delayed neutron analysis was to investigate its utility as a screening tool to identify high-value samples that could then be subjected to more expensive detailed analysis. The concentrations reported were computed assuming that any uranium detected had natural background isotopic values (a high delayed neutron reading indicates the sample contains either a large quantity of natural uranium or contains a small quantity of uranium that has a large fraction of fissile ^{235}U). Figure 3 shows the results obtained around the LEU facility at Paducah, Kentucky. In most cases, the uranium concentration is well below 50 ppb and is in the range expected for normal background uranium on pine needles. [National Institute of Standards and Technology (NIST) standard reference material 1575, pine needles, was taken from pine trees in upper Michigan well away from nuclear operations, and contains 20 ± 4 ppb of natural uranium.] Figure 4 shows the results for pine needles collected around the Portsmouth facility. Even though HEU operations ceased 2 years prior to this field trial, the delayed neutron data shows clear evidence of altered uranium isotopics near the plant. The uranium concentration drops continuously with distance from the plant out to 5 km, where levels near background were found. Figure 5 is a simulation of delayed neutron results where the concentrations were computed from TIMS data taken from a study conducted when HEU was being produced. As can be seen in Fig. 5, the simulated delayed neutron signature (i.e., deviation from normal background concentration) is much more distinctive and can be detected at greater distances.

CONCLUSIONS

The results of these field trials (see Table 1) demonstrate, as expected, that particulate analysis of swipes obtained from inside nuclear facilities provides unmistakable signatures of the facility's past and present operations. This study also demonstrates that bulk analysis of swipe samples obtained by directed sampling (i.e., sampling in specific locations that are more likely to be exposed to process material) inside nuclear facilities provides very good estimates of the assay at that particular sampling location. In general, it was found that characteristic signatures of both LEU and HEU operations are easily detected from swipe samples analyzed by bulk analytical methods.

Delayed neutron analysis Paducah Field Trial

Fig. 3. Delayed neutron analysis of pine needles taken during the Paducah field trial. The y-scale is given in arbitrary units, but would be ppb if all the uranium in the sample had natural isotopic composition.

Delayed neutron analysis Portsmouth Field Trial

Fig. 4. Delayed neutron analysis of pine needles taken during the Portsmouth field trial. The y-scale is given in arbitrary units, but would be ppb if all the uranium in the sample had natural isotopic composition.

**Delayed neutron analysis
(Simulated from TMS data)
Portsmouth when producing HEU**

Fig. 5. Delayed neutron analysis of pine needles collected around Portsmouth when HEU was being produced. The y-scale is given in arbitrary units, but would be ppb if all the uranium in the sample had natural isotopic composition.

Bulk and particulate analysis of pine needle samples around the operating LEU facility at Paducah produced very little data indicating that nuclear operations existed in the facilities. The delayed neutron data also showed very little deviation from the normal uranium background. Conversely, even though HEU production ceased 2 years before the Portsmouth field trial, clear indications of altered isotopics out to 5 km were found in both the bulk analytical and delayed neutron data from pine needles. In this study, a rapid increase in the delayed neutron signal near the site coupled with evidence of altered isotopics from vegetation collected away from the facility provided strong evidence of HEU operations. Unexpectedly, the particulate data for the Portsmouth pine needles showed very little evidence of nuclear operations, except for the sample taken on-site.

Table 1. Conclusions from results obtained by each environmental monitoring technique employed to analyze samples from the Paducah and Portsmouth field trials

	Swipes	Pine needles
Bulk analysis	<p>Provides average assay of all material collected from a given sampling point.</p> <p>Tends to accurately measure the assay at a given point in the enrichment process.</p>	<p>Altered uranium isotopics well above background found up to 5 km away from HEU facility.</p> <p>Values near background found for all samples taken at LEU site.</p>
Delayed neutron analysis	Swipes were not analyzed by delayed neutron analysis.	<p>Clear rise in the apparent uranium concentration the closer the sampling point was to HEU facility.</p> <p>Samples from around LEU facility gave uranium concentrations near background levels.</p>
Particulate analysis	<p>Detailed information on past and present operations.</p> <p>Skewed to higher isotopics because of the way particles are selected.</p>	<p>Altered isotopics detected on-site.</p> <p>Very little evidence of HEU or LEU production detected off-site.</p>

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1. *Paducah Gaseous Diffusion Plant Environmental Report for 1992*, ES/ESH-36, KY/E-164, Martin Marietta Energy Systems, Inc., September 1993.
2. *Portsmouth Gaseous Diffusion Plant Annual Site Environmental Report for 1993*, ES/ESH-50, POEF-3050, Martin Marietta Energy Systems, Inc., November 1994.

ACRONYMS AND INITIALISMS

AFTAC	Air Force Technical Applications Center
DOE	Department of Energy
HEU	high-enriched uranium
IAEA	International Atomic Energy Agency
LEU	low-enriched uranium
NIST	National Institute of Standards and Technology
NWAL	Network of Analytical Laboratories
ORNL	Oak Ridge National Laboratory
TIMS	thermal ionization mass spectrometer
USEC	U.S. Enrichment Corporation

THE JAMES EARL RAY CASE

Ray, James Earl, 1924-1968

Ray, James Earl, 1924-1968. The James Earl Ray case. A study of the life and career of the assassin of Dr. Martin Luther King, Jr. Includes a bibliography and index.

Appendix 1

**DATA FROM BULK ANALYSIS OF ENVIRONMENTAL SAMPLES
(SWIPES AND PINE NEEDLES) TAKEN DURING THE
PADUCAH AND PORTSMOUTH FIELD TRIALS**

1901-1902

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**SWIPE SAMPLES
BULK ANALYSIS
PORTSMOUTH FIELD TRIAL**

<u>Facility (enrichment)</u>	<u>U-234</u>	<u>Atom% U-235</u>	<u>U-236</u>	<u>U-238</u>
330 Building (<0.4%)	0.001313 0.002330	0.3006 0.40514	0.000496 0	99.6976 99.59253
330 Building (2.5%)	0.0269 0.0133	2.938 1.814	0.00205 0.0010	97.033 98.171
344 Building (<5%)	0.01321 0.0139	1.8076 1.803	0.00352 0.00397	98.176 98.179
330 Building (5%)	0.03273 0.03266 0.02637	3.419 3.385 3.0308	0.002280 0.00218 0	96.546 96.580 96.9428
326 Building (25%)	0.3862 1.8204	26.76 88.8869	0.02224 0.0143	72.83 9.2784
326 Building (97%)	0.5170	34.949	0.02652	64.508
326 Building (97%)	0.33258 0.272	26.199 20.198	0.02547 0.020	73.44 79.501
PB1 (3001) Centrifuge (3-4%)	0.0084 0.0103	1.176 1.120	0.0058 0.0015	98.810 98.789

**PINE NEEDLE SAMPLES
BULK ANALYSIS
PORTSMOUTH FIELD TRIAL**

<u>Distance, km</u> <u>(ng/g)</u>	<u>U-234</u>	<u>Atom%</u> <u>U-235</u>	<u>U-236</u>	<u>U-238</u>
0 km (39.4823)	0.1083 0.041	10.0054 1.79	0 0.0282	89.8863 98.143
1 km (22.167, 0.147)	0.03011 0.014	3.1011 1.446	0.003048 0.0072	96.8658 98.533
3 km (17.7653)	0.00972 0.01291	1.01999 1.4454	0 0.00134	98.97029 98.540
5 km (15.547, 0.147)	0.01386 0.025	1.6290 1.920	0.00229 0.009	98.3549 98.046

**SWIPE SAMPLES
BULK ANALYSIS
PADUCAH FIELD TRIAL**

Facility (enrichment)	<u>U-234</u>	<u>Atom% U-235</u>	<u>U-236</u>	<u>U-238</u>
C315 Building (0.3%)	0.001579 0.00179 0.00182	0.3117 0.34619 0.3400	0.00248 0.00045 0	99.6843 99.6516 99.6580
C333A Building (0.72%)	0.00229 0.0047 0.0045	0.63503 0.683 0.6831	0 0 0	99.3627 99.31 99.31
C331 Building (1%)	0.00700 0.00391 0.0066	0.9377 0.63431 0.899	0.00086 0.00262 0.00204	99.0545 99.3592 99.092
C310 Building (1.8-2.1%)	0.00593 0.00843	0.8102 1.0085	0.000707 0	99.1831 98.9830
Railroad sign near C310	0.00405	0.6207	0.00246	99.3728

**PINE NEEDLE SAMPLES
BULK ANALYSIS
PADUCAH FIELD TRIAL**

<u>Distance. km</u> <u>(ng/g)</u>	<u>U-234</u>	<u>Atom%</u> <u>U-235</u>	<u>U-236</u>	<u>U-238</u>
0 km (13.742, 0.177)	0.00591 0.0013	0.7325 0.579	0.00160 0.0066	99.2600 99.413
1 km (53.6166)	0.00606 0.00536	0.72171 0.7139	0 0.00028	99.2722 99.280
3 km (15.946, 0.850)	0.005529 0.0061	0.73032 0.736	0.000301 0.017	99.26384 99.241
5 km (20.3767)	0.00640 0.0059 0.00540	0.79616 0.721 0.7207	0 0 0.00008	99.1974 99.27 99.274
8 km (30.396, 0.545)	0.00538 0.0054	0.7246 0.718	0 0.0017	99.2701 99.275

Appendix 2

**DATA FROM PARTICULATE ANALYSIS OF ENVIRONMENTAL SAMPLES
(SWIPES AND PINE NEEDLES) TAKEN DURING THE
PADUCAH AND PORTSMOUTH FIELD TRIALS**

1947

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500 FIFTH AVENUE
NEW YORK 17, N. Y.

AFTAC Portsmouth swipes

	Atom% U-234	Atom% U-235	Atom% U-236
0			
1	S010-01-02	Portsmouth	344 (<5%)
2	0.032900	3.9584	
3	0.020300	2.3136	0.0018000
4	0.0094000	1.1489	0.0017000
5	0.036900	3.9941	0.0022000
6	0.036600	4.0406	0.00040000
7	0.037100	3.9925	0.0020000
8	0.034600	3.8369	
9	0.035800	3.8567	0.0025000
10	0.029800	3.1917	0.0045000
11	0.038800	4.1827	0.0023000
12	0.040400	4.2767	0.0022000
13	0.034500	3.7501	0.00030000
14	0.030500	3.2888	0.010500
15	0.036300	3.8910	0.0013000
16	0.0077000	0.95830	0.00020000
17			
18	S010-02-02	Portsmouth	330 (5%)
19	0.069500	11.270	0.054300
20	0.0040000	0.66230	0.00030000
21	0.045800	6.0215	0.0071000
22	0.044900	7.5893	0.035500
23	0.12080	7.1155	0.0011000
24	0.12710	8.6528	0.0013000
25	0.84660	64.747	0.089400
26	0.017300	2.2717	0.011500
27	1.7584	93.269	0.014600
28	0.053400	5.5656	0.0080000
29	0.047500	5.1607	0.0025000
30	0.026200	3.0299	0.00080000
31	0.049100	4.8629	0.00070000
32	0.076400	5.7946	0.0011000
33	0.18840	10.979	0.00070000
34			
35	S010-03-02	Portsmouth	330 (2.5%)
36	0.015100	1.9634	0.00020000
37	0.013200	1.8336	1.0000e-04
38	0.0027000	0.52180	0.0000
39	0.016300	2.1748	0.0000
40	0.0065000	1.4508	0.013100
41	0.0095000	1.4758	0.0015000
42	0.0074000	1.2183	0.0039000
43	0.013200	1.8117	1.0000e-04
44	0.016900	2.8765	0.014300
45	0.013000	1.7028	1.0000e-04
46	0.0082000	1.4952	0.0091000

AFTAC Portsmouth swipes (cont.)

	Atom% U-234	Atom% U-235	Atom% U-236
47	0.0011000	0.30610	0.0027000
48	0.011200	1.7080	0.0039000
49	0.012100	1.7914	0.0039000
50	0.0027000	0.51660	0.0000
51			
52	S010-04-03	Portsmouth	330 (0.4%)
53	0.0025000	0.45410	0.0031000
54	0.00070000	0.21900	1.0000e-04
55	0.00070000	0.21740	0.0000
56	0.0014000	0.36330	0.0000
57	0.040000	4.1011	0.00020000
58		1.7145	
59	0.0012000	0.27710	0.00090000
60	0.00080000	0.22720	0.00020000
61	0.0021000	0.40160	0.0024000
62	0.00070000	0.21550	0.0000
63	0.0016000	0.36890	1.0000e-04
64	0.0012000	0.28570	0.00080000
65	0.00080000	0.23180	0.00090000
66	0.0016000	0.36860	1.0000e-04
67	0.036000	3.9346	0.00080000
68			
69	S010-05-02	Portsmouth	PB1/3001 (3-4%)
70	0.40180	47.234	0.036200
71	0.23840	19.225	0.0000
72	0.28010	38.025	0.028100
73	1.0610	92.423	0.14480
74	1.6556	92.315	0.016500
75	0.22230	29.527	0.027100
76	0.13750	12.832	0.0000
77	0.00060000	0.19290	0.0028000
78	0.41480	24.255	1.0000e-04
79	0.0045000	0.70670	0.0010000
80	0.0053000	0.75060	0.0048000
81	0.0055000	0.84500	0.0022000
82	0.17840	28.575	0.10720
83	0.16330	26.425	0.094800
84	0.17840	28.098	0.10020
85			
86	S010-06-02	Portsmouth	326 (97%)
87	0.26490	39.771	0.35190
88	1.0059	91.827	0.21850
89	1.2675	96.858	0.051600
90	1.1680	89.160	0.13470
91	0.25880	35.310	0.022400
92	0.87550	91.914	0.28510
93	0.045400	6.4717	0.032500

AFTAC Portsmouth swipes (cont.)

	Atom% U-234	Atom% U-235	Atom% U-236
94	0.15260	26.979	0.12720
95	0.19770	27.429	0.10270
96	0.23400	32.374	0.030400
97	0.34100	37.890	0.017600
98	1.7699	96.391	0.022200
99	2.2546	96.339	0.0093000
100	2.1955	95.114	0.041800
101	0.25790	23.141	0.025800
102	0.14260	16.583	0.0085000
103			
104	S010-07-02	Portsmouth	326 (25%)
105	0.80830	55.850	0.071200
106	0.19120	18.414	0.017600
107		14.417	
108	0.067300	6.3067	0.00080000
109	0.068200	6.2914	0.0018000
110	0.35510	36.992	0.022500
111	0.13200	11.458	0.0010000
112	0.22330	36.672	0.10150
113	0.24440	39.567	0.13050
114	0.23890	37.707	0.11440
115	0.45700	49.498	0.010600
116	0.46790	52.628	0.031000
117	0.14990	29.310	0.041800
118	0.22400	30.377	0.10440
119	1.5989	79.954	0.017500
120			
121	S010-08-02	Portsmouth	326 (97%)
122	0.60510	41.234	0.035500
123	0.99280	60.013	0.031000
124	0.23510	32.235	0.026100
125	0.11600	9.3042	0.0040000
126	0.065100	6.0430	0.00020000
127	0.12930	11.611	0.00070000
128	0.074300	6.7299	
129	1.2438	80.730	0.069600
130	1.7619	97.211	0.015100
131	1.7222	96.193	0.017400
132	0.88850	91.960	0.26080
133	2.0337	96.867	0.016300
134	0.22820	18.410	0.019700
135	0.098000	10.534	0.0079000
136	1.9784	95.653	0.012600
137	2.0806	96.703	0.015100
138	0.32310	28.933	0.0015000

AFTAC Portsmouth pine needles

	Atom% U-234	Atom% U-235	Atom% U-236
0			
1	V010-09-01	Portsmouth	Pine needle (5 km)
2	0.0057000	0.71020	0.0000
3	0.0029000	0.71400	0.0000
4	0.0054000	0.70090	0.00030000
5	0.0026000	0.52770	1.0000e-04
6			
7	V010-10-01	Portsmouth	Pine needle (3 km)
8	0.0061000	0.72830	0.0000
9	0.0046000	0.70920	0.0000
10	0.0031000	0.69510	0.0000
11	0.0042000	0.72250	0.00020000
12	0.0032000	0.72180	0.0000
13	0.0095000	0.73180	0.0000
14	0.0055000	0.71990	0.0000
15	0.0031000	0.70950	0.0000
16			
17	V010-11-01	Portsmouth	Pine needle (1 km)
18	0.0052000	0.71040	0.0000
19	0.0023000	0.71010	0.0000
20	0.0053000	0.70270	
21	0.0031000	0.73870	0.0000
22	0.0059000	0.72110	0.0000
23			
24	V010-12-01	Portsmouth	Pine needle (0 km)
25	0.035300	6.0350	0.046200
26	0.089400	7.3571	0.0051000
27	0.85490	53.631	
28	0.22030	23.025	0.072000
29	1.1722	75.150	0.068500
30	0.087600	7.0781	0.0059000
31	0.23360	17.483	0.033200
32	0.13580	11.470	0.014600
33	0.090400	7.1089	0.0056000
34	0.22670	24.676	0.024400
35	0.10000	7.4856	
36	0.96490	62.433	0.047800
37	0.16190	17.257	0.10710

AFTAC Paducah swipes

	Atom% U-234	Atom% U-235	Atom % U-236
0			
1	S009-01-01/Paducah	Building C315 (0.3%)	
2	0.0013000	0.29180	3.0000e-05
3	0.0015000	0.30380	0.0016200
4	0.0014000	0.29310	0.0029300
5	0.0042000	0.58440	1.0000e-05
6	0.0014000	0.30660	0.0013100
7	0.0026000	0.43280	0.0000
8	0.0063000	0.83460	0.00020000
9	0.0063000	0.83460	0.00020000
10	0.0014000	0.29940	2.0000e-05
11	0.0023000	0.40840	0.00028000
12		0.31020	0.0017300
13	0.0018000	0.34440	0.00025000
14	0.0013000	0.29050	0.0025500
15	0.0013000	0.28980	0.0025200
16	0.0042000	0.70680	0.0027100
17	0.0057000	0.85530	0.00044000
18	0.0079000	1.0772	8.0000e-05
19	0.0040000	0.61340	0.0024600
20	0.0056000	0.84950	0.0015900
21	0.0039000	0.59250	0.0048900
22	0.0052000	0.67990	0.0070600
23	0.0024000	0.50660	0.00026000
24	0.0038000	0.71800	
25	0.0048000	0.72940	0.0000
26	0.0054000	0.77820	0.0062800
27	0.0021000	0.38790	0.00082000
28	0.00070000	0.20200	0.0024700
29	0.0044000	0.67900	0.0034000
30	0.0065000	0.86070	
31	0.0065000	0.98570	0.00020000
32			
33	S009-02-01/ Paducah	RR sign near C310	
34	0.0053000	0.72510	0.0000
35	0.0055000	0.71840	4.0000e-05
36	0.0053000	0.72250	0.0018900
37	0.00070000	0.20340	0.0021800
38	0.0052000	0.71690	3.0000e-05
39	0.0054000	0.72180	0.0026600
40	0.0017000	0.30850	0.0037100
41	0.0052000	0.65910	0.012820
42	0.0053000	0.64160	0.012320
43	0.0054000	0.71600	0.0015300
44	0.0054000	0.71710	0.0014100
45			
46	S009-03-01/Paducah	Building C333A	Normal (0.72%)

AFTAC Paducah swipes (cont.)

	Atom% U-234	Atom% U-235	Atom % U-236
47	0.0038000	0.60140	0.0038000
48	0.0045000	0.57420	0.0033500
49	0.0024000	0.49680	
50	0.010200	1.2213	0.00015000
51	0.0016000	0.32520	0.00022000
52	0.0056000	0.65770	0.0087400
53	0.0040000	0.59820	0.0048600
54	0.0054000	0.71730	0.0000
55	0.0049000	0.70830	0.0000
56	0.0030000	0.51110	0.0023100
57	0.0016000	0.33700	3.0000e-05
58	0.0018000	0.33760	0.00049000
59	0.0024000	0.41340	0.00015000
60	0.0052000	0.71660	0.0000
61	0.012400	1.5156	0.00036000
62			
63	S009-04-01/Paducah	C331 (~1%)	
64	0.0016000	0.33280	0.00040000
65	0.0052000	0.64370	0.012570
66	0.0033000	0.50620	5.0000e-05
67	0.0024000	0.43610	1.0000e-05
68	0.0072000	0.96020	0.00037000
69	0.0048000	0.69270	0.00016000
70	0.0080000	1.0487	0.0044600
71	0.0014000	0.31100	0.0000
72	0.0021000	0.36680	0.00059000
73	0.0013000	0.29390	0.00085000
74	0.0041000	0.63270	0.00016000
75	0.0065000	0.90000	0.00067000
76	0.0030000	0.53820	0.00052000
77	0.0050000	0.74780	0.00028000
78	0.0057000	0.80400	0.00088000
79	0.0078000	1.0770	0.0018800
80	0.0052000	0.72680	0.0013500
81	0.0062000	0.86600	0.0012100
82	0.0040000	0.70070	0.00016000
83	0.0054000	0.76110	0.00087000
84	0.0062000	0.87840	0.0012000
85			
86	S009-05-01/Paducah	C310 (1.8-2.1%)	
87	0.016600	1.9136	0.0015300
88	0.0048000	0.78550	0.00022000
89	0.013900	1.6291	4.0000e-05
90	0.0047000	0.65880	0.00096000
91	0.0029000	0.45190	0.00021000
92	0.0045000	0.62430	0.0051100
93	0.015800	1.8565	2.0000e-05

AFTAC Paducah swipes (cont.)

	Atom% U-234	Atom% U-235	Atom % U-236
94	0.015600	1.7785	5.0000e-05
95	0.0058000	0.86980	0.0023900
96	0.016500	1.9001	3.0000e-05
97	0.016600	1.9232	0.0000
98	0.015300	1.7310	6.0000e-05
99	0.016500	1.9083	0.0000
100	0.016600	1.9195	1.0000e-05
101	0.016500	1.9194	0.0000
102	0.015700	1.8382	4.0000e-05
103	0.016600	1.9173	0.0000
104	0.015900	1.9102	2.0000e-05
105	0.0017000	0.33790	0.00033000

AFTAC Paducah pine needles

	Atom% U-234	Atom% U-235	Atom% U-236
0			
1	V009-06-01/Paducah	Pine needle (8 km)	
2	0.0053000	0.72080	0.0000
3	0.0044000	0.72310	0.0000
4	0.0048000	0.71120	0.00039000
5	0.0057000	0.73160	0.00013000
6	0.0057000	0.70640	0.0000
7	0.0040000	0.70360	
8	0.0061000	0.68840	0.0000
9	0.0042000	0.73020	0.00050000
10	0.0046000	0.71520	0.0000
11	0.0053000	0.71850	0.0000
12		0.72230	
13	0.0045000	0.71070	0.00013000
14			
15	V009-08-01/Paducah	Pine needle (3 km)	
16	0.0044000	0.72010	1.0000e-05
17	0.0055000	0.71780	5.0000e-05
18	0.0055000	0.72280	0.0000
19	0.0052000	0.71970	7.0000e-05
20	0.037500	4.0908	0.00075000
21	0.0055000	0.72110	0.0000
22	0.0056000	0.70830	0.0000
23	0.0050000	0.72470	0.00026000
24	0.0055000	0.72310	0.0000
25	0.014600	1.7110	0.00028000
26			
27	V009-09-01/Paducah	Pine needle (1 km)	
28	0.0056000	0.72790	0.0000
29	0.0049000	0.71530	0.0000
30	0.0053000	0.73080	0.0000
31	0.0038000	0.71220	0.0000
32	0.0054000	0.69920	0.00039000
33	0.0052000	0.72050	0.0000
34		0.71320	
35	0.0057000	0.71560	0.0000
36	0.0045000	0.71540	0.00015000
37	0.0045000	0.71920	
38	0.0055000	0.72950	
39	0.0045000	0.73230	0.0000
40	0.0060000	0.72640	0.00029000
41	0.0052000	0.71250	1.0000e-05
42	0.015600	1.7925	5.0000e-05
43			
44	V009-10-01/Paducah	Pine needle (0 km)	
45	0.0049000	0.72010	0.0000

Appendix 3

**COMPARISON OF BULK AND PARTICULATE DATA
FROM SWIPE SAMPLES TAKEN DURING
THE PORTSMOUTH FIELD TRIAL**

THE UNIVERSITY OF CHICAGO
LIBRARY
540 EAST 57TH STREET
CHICAGO, ILL. 60637

Portsmouth
330 Building (<0.4%)

Portsmouth
330 Building (2.5%)

Portsmouth
330 Building (2.5%)

Portsmouth
344 Building (<5%)

Portsmouth
330 Building (5%)

Portsmouth
326 Building (97%)

Portsmouth
326 Building (97%)

Portsmouth
PB1(3001)-Centrifuge
(3-4%)

Portsmouth
PB1(3001) Centrifuge
(3-4%)

Appendix 4

**COMPARISON OF BULK AND PARTICULATE DATA
FROM PINE NEEDLE SAMPLES TAKEN DURING
THE PORTSMOUTH FIELD TRIAL**

100

100

100

100

Appendix 5

**COMPARISON OF BULK AND PARTICULATE DATA
FROM SWIPE SAMPLES TAKEN DURING
THE PADUCAH FIELD TRIAL**

**Paducah
C315 Building (0.3%)**

Paducah
C333A Building (0.72%)

**Paducah
C333A Building (0.72%)**

Paducah
C310 Building (1.8-2.1%)

Paducah
RR Sign near C310

Paducah
RR Sign near C310

Appendix 6

**COMPARISON OF BULK AND PARTICULATE DATA
FROM PINE NEEDLE SAMPLES TAKEN DURING
THE PADUCAH FIELD TRIAL**

THE UNIVERSITY OF CHICAGO
LIBRARY
540 EAST 58TH STREET
CHICAGO, ILL. 60637

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