INDEPENDENT CONFIRMATORY SURVEY SUMMARY AND RESULTS FOR THE HEMATITE DECOMMISSIONING PROJECT FESTUS, MISSOURI

Erika N. Bailey
and
Mark G. Jadick

Prepared for the
U.S. Nuclear Regulatory Commission

ORISE

Oak Ridge Institute for Science and Education

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Prepared by: Erika N. Bailey
E.N. Bailey, Project Leader
Independent Environmental Assessment and Verification

Date: 3/18/09

Reviewed by: T. J. Vitkus
T. J. Vitkus, Survey Projects Manager
Independent Environmental Assessment and Verification

Date: 3/18/09

Reviewed by: R. D. Condra
R. D. Condra, Laboratory Manager
Independent Environmental Assessment and Verification

Date: 3/18/09

Reviewed by: A. T. Payne
A. T. Payne, Quality Manager
Independent Environmental Assessment and Verification

Date: 3/18/09

Reviewed by: S. J. Roberts
S. J. Roberts, Associate Program Director
Independent Environmental Assessment and Verification

Date: 3/18/09

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Prepared by

Erika N. Bailey and Mark G. Jadick

Oak Ridge Institute for Science and Education
Oak Ridge, Tennessee 37831-0017

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FIELD STAFF

T. D. Herrera

LABORATORY STAFF

R. D. Condra

J. S. Cox

W. P. Ivey

W. F. Smith

CLERICAL STAFF

R. M. Fink

K. M. Moore

A. Ramsey

ILLUSTRATOR

J. A. Viars

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ABBREVIATIONS AND ACRONYMS

b_i	number of background counts in the interval
d'	index of sensitivity
ϵ_i	instrument efficiency
ϵ_s	surface efficiency
ϵ_{total}	total efficiency
Am-241	americium-241
BKG	background
cm	centimeter
cm ²	square centimeter
cpm	counts per minute
DCGL	derived concentration guideline level
DCGL _w	DCGL for average concentrations over a wide area, used with statistical tests
dpm/100 cm ²	disintegrations per minute per 100 square centimeters
FSS	final status survey
GPS	Global Position System
HDP	Hematite Decommissioning Project
HEPA	high-efficiency particulate air
IEAV	Independent Environmental Assessment and Verification Program
ITP	Intercomparison Testing Program
MAPEP	Mixed Analyte Performance Evaluation Program
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
MDCR	minimum detectable count rate
MeV	million electron volts
mg	milligram
min	minute
mm	millimeter
mrem/yr	millirem per year
NaI	sodium iodide
NIST	National Institute of Standards and Technology
Np-237	neptunium-237
NRC	U.S. Nuclear Regulatory Commission
NRIP	NIST Radiochemistry Intercomparison Program
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
pCi	picocuries
Pu-239/240	plutonium-239/240
s	second
Tc-99	technitium-99
Th-232	thorium-232
UF ₆	uranium hexafluoride
U-234	uranium-234
U-235	uranium-235
U-238	uranium-238
WEC	Westinghouse Electric Company

**INDEPENDENT CONFIRMATORY SURVEY SUMMARY
AND RESULTS FOR THE
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FESTUS, MISSOURI**

INTRODUCTION

The Westinghouse Electric Company, LLC (WEC) former fuel cycle facility near Festus, Missouri operated from 1956 to 2001 manufacturing uranium from natural and enriched uranium for use as nuclear fuel. The site ceased operational activities in September 2001 and is now proposing to decommission the facility which is now known as the Hematite Decommissioning Project (HDP). From its inception in 1956 through 1974, the facility was used primarily in support of government contracts that required production of highly enriched uranium products. From 1974 through the plant closure in 2001, the focus changed from government contracts to commercial fuel production. Specifically, operations included the conversion of uranium hexafluoride (UF₆) gas of various uranium enrichments to uranium oxide, uranium carbide, uranium dioxide pellets, and uranium metal. Secondary operations included research and development and uranium scrap recovery processes. The facility's central land area and the site creek were impacted by the fuel fabrication activities. Currently within permitted license activities, WEC has performed equipment decontamination and dismantlement and has shipped various equipment and material off site. WEC is also proposing to install a rail spur to allow direct loading of rail cars for offsite waste shipments.

The U.S. Nuclear Regulatory Commission (NRC) is responsible for oversight of permitted license activities that are currently being conducted at the HDP. The NRC has opted to perform independent (third party) confirmatory activities of various site activities. The purpose of confirmatory activities is to verify that any remedial actions have been effective in meeting site-specific guidelines and that documentation accurately and adequately describes the radiological conditions at the site. Oak Ridge Institute for Science and Education (ORISE) was designated as the organization responsible for this task at HPD. Specifically, ORISE was tasked to confirm the current radiological status of the roofs of Buildings 110 and 230, the high-efficiency particulate air (HEPA) room of Building 230, and the land area impacted by the proposed rail spur, and to observe ongoing site soil characterization core boring activities. The following descriptions of the buildings were taken from the Hematite Decommissioning Plan (WEC 2005).

Building 110 is the Pedestrian Entrance/Office Building. This building was built in 1970 and serves as the pedestrian entrance into the plant. The building currently has a security station at the entrance, several offices, a conference room, and a kitchen. No work with radioactive or chemical compounds is known to have occurred in this building and prior licensee surveys have shown no building surfaces that exhibit levels of radioactive contamination above the proposed levels for unrestricted use.

Building 230 is the Rod Loading Building. It was built in 1992 to receive finished pellets (i.e., standard, erbium, and gadolinium) which were then loaded into fuel rods and assemblies for shipment off site. No appreciable amounts of chemicals were used in this building and contact with fuel pellets was limited to two small areas. The building is currently being used as office space. The building surfaces have no known levels of radioactive contamination above the proposed levels for unrestricted use. During the period of mid-2003 to mid-2004, this building underwent radiological remediation in preparation for its current use as the Decommissioning Project office. A *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) “final status survey” (FSS) was conducted by the project in order to remove radiological controls on the building. While extensive, these surveys were not intended to serve as justification for the final radiological status.

SITE DESCRIPTION

The Hematite facility is located in Jefferson County Missouri less than 4 miles west of the town of Festus, Missouri and 35 miles south of the city of St. Louis. The site is surrounded by forest and agricultural lands and low density residential housing. The entire site consists of approximately 228 acres; however, the impacted portion of the site, referred to as the central tract, only includes approximately 19 acres. The central tract of the site is bounded by State Road P to the north, the northeast site creek to the east, Union-Pacific railroad tracks to the south, and the site creek/pond to the west.

OBJECTIVES

The objectives of the confirmatory surveys were to provide independent contractor field data reviews and to generate independent radiological data for use by the NRC in evaluating the adequacy and accuracy of the licensee’s procedures and survey results.

DOCUMENT REVIEW

Prior to onsite activities, ORISE reviewed limited documentation including revision 2 of the Hematite Decommissioning Plan (WEC 2005). The NRC did not approve revision 2; however, ORISE primarily used it for historical site information. In addition, the site provided ORISE with the proposed site-specific derived concentration guideline levels (DCGLs); however, the DCGL derivation document was in draft form, had not undergone internal WEC review and comment, nor had it been approved by the NRC (WEC 2008). Therefore, the proposed DCGLs are currently only considered as preliminary, working values. While on site, the site contact provided ORISE with survey and sample data for the subject areas from previous characterization activities. All documents and data were reviewed for adequacy and appropriateness taking into account the MARSSIM guidance (NRC 2000).

PROCEDURES

A survey team from ORISE visited the HDP from June 24 through 26, 2008 to perform visual inspections and measurement and sampling activities. Confirmatory survey activities were conducted in accordance with a site-specific survey plan, the ORISE/IEAV Survey Procedures Manual and the Quality Program Manual (ORISE 2008a, 2008b and ORAU 2007). Figure 1 shows an aerial photo of the areas involved in the confirmatory activities as discussed below.

WEC has subdivided the site into survey units; survey units are classified based on contamination potential, as either Class 1, 2, or 3 in accordance with MARSSIM (NRC 2000). A description of each is as follows:

- Class 1: Buildings or land areas that have a significant potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiological surveys) that exceeds the *proposed* derived concentration guideline value (DCGL_w).
- Class 2: Buildings or land areas, often contiguous to Class 1 areas that have a potential for radioactive contamination but at levels less than the *proposed* DCGL_w.

Class 3: Remaining impacted buildings and land areas that are not expected to contain residual contamination, or are expected to contain levels of residual contamination at a small fraction of the *proposed* $DCGL_{W}$.

The ORISE survey activities were conducted to confirm the current radiological status of the roofs of Buildings 110 and 230, including the roof of the HEPA room of Building 230 (all are Class 3s), the land area impacted by the proposed rail spur, and to observe ongoing site characterization core boring activities.

REFERENCE SYSTEM

All scans were performed outdoors; therefore, all gamma scan data were referenced to global positioning systems (GPS) coordinates. Measurement/sampling locations were documented on a survey map provided by the licensee.

SURFACE SCANS

Gamma and alpha plus beta surface scans of the building roofs were performed as well as gamma surface scans over the proposed rail spur area. Medium to high density scans were performed over these areas. On the roofs, particular attention was given to surfaces where material may have accumulated such as in cracks and joints, ledges, and other horizontal surfaces. ORISE was asked to stay at least 15 feet from the edges of the roofs if there was not a fall protection barrier in place. Scans were performed using sodium iodide (NaI) scintillation detectors for direct gamma radiation and gas proportional detectors for direct alpha plus beta radiation. Both types of detectors were coupled to ratemeter-scalers with audible indicators. The NaI detectors were also coupled to GPS systems that enabled real-time gamma count rate and position data capture.

SURFACE ACTIVITY MEASUREMENTS

Based on the radiation levels observed on the roofs during surface scans (background levels), ORISE opted not to perform extensive direct measurements. One direct measurement was performed on the roof of Building 110 (in a gutter) from the location exhibiting the highest alpha plus beta radiation level identified by ORISE. The direct measurement was made using a gas proportional detector coupled to a ratemeter-scaler. One smear sample was also collected at this

location to determine the removable gross alpha and gross beta activity levels. The measurement location is illustrated on Figure 2.

INTERLABORATORY COMPARISON

At the request of NRC Region III, ORISE was tasked with conducting an interlaboratory comparison to evaluate the quality of the licensee's radioanalytical data. The NRC selected 26 soil samples, collected by the licensee, for interlaboratory comparison analyses. These samples were collected within the boundary of the proposed rail spur area. For the gamma spectroscopy comparative analysis, ORISE requested and received the same sample analyzed by the licensee's contract laboratory, Test America. In order to perform liquid scintillation analyses for technetium-99 (Tc-99), ORISE requested an additional unprocessed (wet) portion be collected and sent.

SAMPLE ANALYSIS AND DATA INTERPRETATION

The one smear sample collected on site was returned to the ORISE laboratory in Oak Ridge, Tennessee for analysis and interpretation. The soil samples were shipped to the ORISE laboratory from Test America. Sample analyses were performed in accordance with the ORISE Laboratory Procedures Manual (ORISE 2008c). The smear sample collected for the quantification of gross alpha/beta activity was analyzed using a low-background proportional counter. The smear sample and direct measurement results are reported in units of disintegrations per minute per one-hundred square centimeters (dpm/100 cm²). Soil samples were analyzed by gamma spectroscopy for the main gamma-emitting contaminants of concern: thorium-228 (Th-228), thorium-232 (Th-232), uranium-235 (U-235), and uranium-238 (U-238). Wet chemistry extraction followed by liquid scintillation analysis was used to quantify Tc-99. The soil samples were also analyzed for U-233/ U-234, U-235, and U-238 via alpha spectroscopy. Soil sample results were reported in units of picocuries per gram (pCi/g).

APPLICABLE SITE GUIDELINES

Based on past site investigations, the primary contaminants of concern at the HDP are Tc-99, Th-232, U-234, U-235, and U-238. Secondary radiological contaminants include the transuranic radionuclides of americium-241 (Am-241), neptunium-237 (Np-237), and plutonium-239/240 (Pu-239/240) because they are likely to be present only in trace concentrations (WEC 2005).

The proposed surface soil derived concentration guideline levels (DCGLs) for the site have not yet been approved by the NRC so they are not included at this time. However, the soil DCGL values will be used for FSS samples to determine compliance with the 25 mrem/yr criterion.

Likewise, the proposed DCGL values for building surfaces have not been approved. The DCGL values will be the surface activity levels in dpm/100 cm² that will be used to evaluate measurements to determine compliance with the 25 mrem/yr criterion.

The laboratory analyses and surface activity measurement data collected by ORISE are provided and can be compared to the site-specific DCGL values once they have been approved.

FINDINGS AND RESULTS

SURFACE SCANS

Surface scans of the roofs did not identify radiation levels greater than background levels, with the exception of generally elevated alpha plus beta radiation associated with the gutters. Although not confirmed via sampling during this survey, these elevated radiation levels are commonly found with gutters. Prior experience has determined the origin to be either radon progeny electrostatically bound to the metal or results from short-term build-up of beryllium-7 in sediments that collect in low points. The gamma scans of the proposed rail spur area did identify elevated gamma radiation levels; however, the identified areas of contamination were consistent with the licensee's findings. Refer to Figures 2 through 5 for the gamma scan results.

SURFACE ACTIVITY MEASUREMENTS

One direct measurement was performed on the roof of Building 110 at the location exhibiting the highest alpha plus beta radiation level identified by ORISE (Figure 2). The surface activity value of 5,500 dpm/100 cm² represents the gross surface activity level that has not been corrected for background contributions. Corrected for background the surface activity is 3,900 dpm/100 cm² and is most likely the result of naturally occurring radiation. Removable activity at this location was 0 dpm/100 cm² for gross alpha and 2 dpm/100 cm² for gross beta.

INTERLABORATORY COMPARISON

The WEC soil sample data were provided by the licensee in a report requested by the NRC (WEC 2008). Refer to Tables 1 through 3 for comparison data. With the exception of one sample—ORISE sample number 1768S0011—the WEC contract laboratory gamma spectroscopy analyses were consistent and in agreement with the ORISE analytical results. However, a large fraction of the alpha spectroscopy and the Tc-99 analyses were not in agreement within the expected statistical uncertainties. The most likely explanation for the Tc-99 differences is that ORISE analyzed an unprocessed (wet) portion of the sample (the recommended methodology for Tc-99 analysis). The WEC contract laboratory analyzed a dry portion of each sample for Tc-99. As Tc-99 is considered somewhat volatile, an unknown portion of the Tc-99 may have been released from the sample during the drying process performed at the WEC contract laboratory. Without knowing the exact extraction procedure used by the WEC contract laboratory, it is difficult for ORISE to address the differences in the alpha spectroscopy data.

COMPARISON OF RESULTS WITH GUIDELINES

The laboratory analyses and surface activity measurement data collected by ORISE is provided and can be compared to the site-specific DCGL values once they have been approved.

SUMMARY

At the request of the U.S. Nuclear Regulatory Commission, the Oak Ridge Institute for Science and Education conducted confirmatory surveys at the Hematite Decommissioning Project during the period of June 24 through 26, 2008. The survey activities included visual inspections and measurement and sampling activities.

The confirmatory surface scans of the roofs of Buildings 110 and 230, including the HEPA room of Building 230, did not identify radiation levels greater than background levels. The gamma scans of the proposed rail spur area did identify elevated radiation levels; however, the identified areas of contamination were consistent with the licensee's findings.

The one smear collected did not indicate removable activity. ORISE's radiological survey data confirm that the radiological conditions of the areas surveyed were commensurate with licensee's

findings. Confirmatory survey activities validated the licensee's conclusions regarding each area's classification, and radiological status.

The interlaboratory comparison of soil samples resulted in significant differences in the soil sample data analyzed by alpha spectroscopy and the Tc-99 analyses. The differences in the Tc-99 analyses are most likely due to the difference in procedures used (analyzing dry samples verses wet).

However, without knowing the exact alpha spectroscopy procedure used by the WEC laboratory it is difficult to address those differences. Therefore, ORISE requests additional information regarding the procedures used by the licensee's laboratory in order to further address the alpha spectroscopy differences. If it is determined that WEC laboratory procedures are not acceptable/approved analyses methods, the collection of additional samples may be warranted.

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APPENDIX A

FIGURES

FIGURE 1: PLOT PLAN OF THE HEMATITE DECOMMISSIONING PROJECT
BUILDINGS 230 & 110 HIGHLIGHTED

FIGURE 2: BUILDING 110 – GAMMA SCAN RESULTS AND SAMPLE LOCATION

FIGURE 3: BUILDING 230 – GAMMA SCAN RESULTS

FIGURE 4: BUILDING 230 HEPA ROOM – GAMMA SCAN RESULTS

FIGURE 5: PROPOSED RAIL SPUR AREA – GAMMA SCAN RESULTS

APPENDIX B

TABLES

**TABLE 1: CONCENTRATIONS AND COMPARISON OF RESULTS FOR
SELECTED GAMMA EMITTING RADIONUCLIDES IN SOIL SAMPLES
WESTINGHOUSE DECOMMISSIONING PROJECT
HEMATITE, MISSOURI**

Sample ID			Radionuclide ^a	Radionuclide Concentrations ^b (pCi/g)	
ORISE	WEC	NRC Region III		ORISE	WEC ^c
1768S0001	FS-19-1-SYS-12-SO-1	H-08-01	Th-228	0.98 ± 0.09, ^d 0.07	NR ^e
			Th-232	0.98 ± 0.16, 0.12	0.9
			Total Th ^f	1.96 ± 0.18	NR
			U-238	8.14 ± 0.82, 0.91	8.0
			U-235	2.46 ± 0.22, 0.23	2.1
			Total U ^g	64.0 ± 4.8	NR
1768S0002	FS-19-1-SYS-12-SO-2	H-08-02	Th-228	1.03 ± 0.10, 0.08	NR
			Th-232	1.18 ± 0.19, 0.13	1.2
			Total Th	2.21 ± 0.21	NR
			U-238	1.65 ± 0.42, 1.03	2.3
			U-235	0.22 ± 0.09, 0.23	0.3
			Total U	6.6 ± 2.0	NR
1768S0003	FS-19-1-SYS-12-SO-3	H-08-03	Th-228	1.11 ± 0.10, 0.06	NR
			Th-232	1.18 ± 0.18, 0.13	1.1
			Total Th	2.29 ± 0.21	NR
			U-238	1.59 ± 0.40, 0.72	2.0
			U-235	0.14 ± 0.08, 0.16	0.1
			Total U	4.8 ± 1.8	NR
1768S0004	FS-19-1-SYS-13-SO-1	H-08-04	Th-228	0.86 ± 0.08, 0.05	NR
			Th-232	0.83 ± 0.15, 0.14	0.7
			Total Th	1.69 ± 0.17	NR
			U-238	6.57 ± 0.69, 0.92	5.8
			U-235	1.73 ± 0.17, 0.20	1.7
			Total U	45.8 ± 3.8	NR
1768S0005	FS-19-1-SYS-16-SO-1	H-08-05	Th-228	0.60 ± 0.06, 0.06	NR
			Th-232	0.62 ± 0.12, 0.12	0.5
			Total Th	1.22 ± 0.13	NR
			U-238	19.4 ± 1.5, 1.0	17.7
			U-235	6.10 ± 0.43, 0.25	5.5
			Total U	157.9 ± 9.5	NR

**TABLE 1: CONCENTRATIONS AND COMPARISON OF RESULTS FOR
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WESTINGHOUSE DECOMMISSIONING PROJECT
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Sample ID			Radionuclide ^a	Radionuclide Concentrations ^b (pCi/g)	
ORISE	WEC	NRC Region III		ORISE	WEC ^c
1768S0006	FS-19-1-SYS-16-SO-2	H-08-06	Th-228	1.01 ± 0.09, 0.07	NR
			Th-232	1.04 ± 0.17, 0.14	1.1
			Total Th	2.05 ± 0.19	NR
			U-238	3.52 ± 0.54, 1.02	2.8
			U-235	0.83 ± 0.13, 0.22	0.7
			Total U	22.4 ± 2.9	NR
1768S0007	FS-19-1-SYS-16-SO-3	H-08-07	Th-228	1.12 ± 0.10, 0.07	NR
			Th-232	1.25 ± 0.19, 0.13	1.1
			Total Th	2.37 ± 0.21	NR
			U-238	1.30 ± 0.40, 0.77	0.8
			U-235	0.11 ± 0.08, 0.19	0.1
			Total U	3.8 ± 1.8	NR
1768S0008	FS-19-1-SYS-19-SO-1	H-08-08	Th-228	0.33 ± 0.04, 0.03	NR
			Th-232	0.31 ± 0.07, 0.07	0.2
			Total Th	0.64 ± 0.08	NR
			U-238	2.21 ± 0.34, 0.54	1.8
			U-235	0.39 ± 0.07, 0.12	0.5
			Total U	11.1 ± 1.6	NR
1768S0009	FS-19-1-BIA-1-SO-1	H-08-09	Th-228	0.89 ± 0.09, 0.09	NR
			Th-232	0.99 ± 0.17, 0.16	1.0
			Total Th	1.88 ± 0.19	NR
			U-238	33.1 ± 2.4, 2.6	28.7
			U-235	8.57 ± 0.57, 0.38	7.5
			Total U	228 ± 13	NR
1768S0010	FS-19-1-BIA-2-SO-1	H-08-10	Th-228	0.87 ± 0.08, 0.07	NR
			Th-232	0.90 ± 0.16, 0.13	1.0
			Total Th	1.77 ± 0.18	NR
			U-238	21.6 ± 1.7, 1.5	18.5
			U-235	6.71 ± 0.46, 0.32	5.8
			Total U	170 ± 10	NR
1768S0011	FS-19-1-BIA-3-SO-1	H-08-11	Th-228	5.91 ± 0.57, 0.58	NR
			Th-232	7.2 ± 1.1, 0.7	5.6

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Sample ID			Radionuclide ^a	Radionuclide Concentrations ^b (pCi/g)	
ORISE	WEC	NRC Region III		ORISE	WEC ^c
			Total Th	13.1 ± 1.2	NR
			U-238	838 ± 54, 20	464.0
			U-235	340 ± 20, 5	213.0
			Total U	8560 ± 440	NR
1768S0012	FS-19-1-BIA-3-SO-2	H-08-12	Th-228	1.12 ± 0.09, 0.05	NR
			Th-232	1.14 ± 0.17, 0.10	0.9
			Total Th	2.26 ± 0.19	NR
			U-238	5.17 ± 0.57, 0.85	4.7
			U-235	1.13 ± 0.13, 0.18	1.0
			Total U	30.8 ± 2.9	NR
1768S0013	FS-19-1-BIA-3-SO-3	H-08-13	Th-228	1.11 ± 0.10, 0.06	NR
			Th-232	1.10 ± 0.17, 0.14	1.3
			Total Th	2.21 ± 0.20	NR
			U-238	2.40 ± 0.46, 0.75	2.7
			U-235	0.45 ± 0.11, 0.20	0.6
			Total U	12.6 ± 2.4	NR
1768S0014	FS-19-1-BIA-4-SO-1	H-08-14	Th-228	0.41 ± 0.05, 0.04	NR
			Th-232	0.48 ± 0.09, 0.09	0.5
			Total Th	0.89 ± 0.10	NR
			U-238	34.3 ± 2.4, 1.1	30.2
			U-235	8.01 ± 0.53, 0.25	7.1
			Total U	216 ± 12	NR
1768S0015	FS-19-1-BIA-5-SO-1	H-08-15	Th-228	3.55 ± 0.27, 0.12	NR
			Th-232	4.58 ± 0.53, 0.14	3.9
			Total Th	8.13 ± 0.59	NR
			U-238	83.1 ± 5.5, 2.6	66.0
			U-235	31.8 ± 1.8, 0.6	27.9
			Total U	805 ± 39	NR
1768S0016	FS-19-1-BIA-5-SO-2	H-08-16	Th-228	1.11 ± 0.09, 0.05	NR
			Th-232	1.09 ± 0.16, 0.13	1.2
			Total Th	2.20 ± 0.18	NR
			U-238	5.75 ± 0.60, 0.83	4.6

**TABLE 1: CONCENTRATIONS AND COMPARISON OF RESULTS FOR
SELECTED GAMMA EMITTING RADIONUCLIDES IN SOIL SAMPLES
WESTINGHOUSE DECOMMISSIONING PROJECT
HEMATITE, MISSOURI**

Sample ID			Radionuclide ^a	Radionuclide Concentrations ^b (pCi/g)	
ORISE	WEC	NRC Region III		ORISE	WEC ^c
			U-235	1.31 ± 0.14, 0.18	1.2
			Total U	35.5 ± 3.1	NR
1768S0017	FS-19-1-BIA-5-SO-3	H-08-17	Th-228	1.08 ± 0.10, 0.06	NR
			Th-232	0.97 ± 0.16, 0.14	1.2
			Total Th	2.05 ± 0.19	NR
			U-238	1.33 ± 0.38, 0.71	0.8
			U-235	0.12 ± 0.09, 0.18	0.1
			Total U	4.1 ± 2.0	NR
1768S0018	FS-19-2-SYS-02-SO-2	H-08-18	Th-228	1.12 ± 0.10, 0.07	NR
			Th-232	1.08 ± 0.17, 0.13	1.3
			Total Th	2.20 ± 0.20	NR
			U-238	1.14 ± 0.42, 1.00	1.0
			U-235	0.31 ± 0.26, 0.31	0.1
			Total U	8.2 ± 5.7	NR
1768S0019	FS-19-2-SYS-06-SO-3	H-08-19	Th-228	1.12 ± 0.10, 0.05	NR
			Th-232	1.12 ± 0.17, 0.19	1.0
			Total Th	2.24 ± 0.20	NR
			U-238	1.08 ± 0.37, 0.80	1.7
			U-235	-0.07 ± 0.16, 0.22	0.1
			Total U	-0.5 ± 3.5	NR
1768S0020	FS-19-2-SYS-10-SO-1	H-08-20	Th-228	0.96 ± 0.09, 0.05	NR
			Th-232	0.75 ± 0.14, 0.16	1.0
			Total Th	1.71 ± 0.17	NR
			U-238	1.35 ± 0.84, 1.03	1.6
			U-235	0.21 ± 0.09, 0.18	0.1
			Total U	6.1 ± 2.1	NR
1768S0021	FS-19-2-SYS-14-SO-1	H-08-21	Th-228	0.58 ± 0.06, 0.06	NR
			Th-232	0.60 ± 0.13, 0.14	0.7
			Total Th	1.18 ± 0.14	NR
			U-238	1.38 ± 0.42, 0.86	1.4
			U-235	0.09 ± 0.12, 0.21	0.2
			Total U	3.4 ± 2.6	NR

**TABLE 1: CONCENTRATIONS AND COMPARISON OF RESULTS FOR
SELECTED GAMMA EMITTING RADIONUCLIDES IN SOIL SAMPLES
WESTINGHOUSE DECOMMISSIONING PROJECT
HEMATITE, MISSOURI**

Sample ID			Radionuclide ^a	Radionuclide Concentrations ^b (pCi/g)	
ORISE	WEC	NRC Region III		ORISE	WEC ^c
1768S0022	FS-19-2-SYS-16-SO-1	H-08-22	Th-228	0.48 ± 0.05, 0.04	NR
			Th-232	0.67 ± 0.11, 0.08	0.4
			Total Th	1.15 ± 0.12	NR
			U-238	0.84 ± 0.25, 0.47	0.8
			U-235	0.15 ± 0.36, 0.13	0.2
			Total U	4.2 ± 7.8	NR
1768S0023	FS-19-2-SYS-16-SO-2	H-08-23	Th-228	0.95 ± 0.08, 0.06	NR
			Th-232	1.02 ± 0.16, 0.11	1.1
			Total Th	1.97 ± 0.18	NR
			U-238	1.64 ± 0.40, 0.83	1.5
			U-235	0.05 ± 0.25, 0.27	0.1
			Total U	2.8 ± 5.4	NR
1768S0024	FS-19-2-SYS-16-SO-3	H-08-24	Th-228	1.17 ± 0.10, 0.05	NR
			Th-232	1.09 ± 0.17, 0.13	1.4
			Total Th	2.26 ± 0.20	NR
			U-238	1.03 ± 0.37, 0.82	1.8
			U-235	0.14 ± 0.07, 0.15	0.1
			Total U	4.2 ± 1.6	NR
1768S0025	FS-19-2-SYS-19-SO-1	H-08-25	Th-228	0.86 ± 0.07, 0.05	NR
			Th-232	0.97 ± 0.14, 0.10	0.8
			Total Th	1.83 ± 0.16	NR
			U-238	2.55 ± 0.37, 0.56	1.6
			U-235	0.57 ± 0.09, 0.14	0.5
			Total U	15.5 ± 2.0	NR

TABLE 1: CONCENTRATIONS AND COMPARISON OF RESULTS FOR SELECTED GAMMA EMITTING RADIONUCLIDES IN SOIL SAMPLES WESTINGHOUSE DECOMMISSIONING PROJECT HEMATITE, MISSOURI					
Sample ID			Radionuclide ^a	Radionuclide Concentrations ^b (pCi/g)	
ORISE	WEC	NRC Region III		ORISE	WEC ^c
1768S0026	FS-19-2-SYS-21-SO-1	H-08-26	Th-228	0.92 ± 0.09, 0.08	NR
			Th-232	1.00 ± 0.18, 0.17	0.7
			Total Th	1.92 ± 0.20	NR
			U-238	2.2 ± 3.2, 0.9	1.5
			U-235	0.36 ± 0.10, 0.16	0.2
			Total U	10.4 ± 3.9	NR

^aFor the ORISE analyses; Th-228 by Pb-212; Th-232 by Ac-228; U-238 by Th-234.

^bThe MDC's are after the comma.

^cRadionuclide concentrations provided in a WEC report to the NRC (WEC 2008).

^dUncertainties represent the 95% confidence level, based on total propagated uncertainties.

^eNot reported.

^fTotal Th is the sum of concentrations of the Th-228 + Th-232.

^gThe equation for Total U is U-238 + U-235 + (21.7*U-235).

**TABLE 2: CONCENTRATIONS OF URANIUM ISOTOPES
IN SOIL SAMPLES BY ALPHA SPECTROSCOPY AP11,
REVISION 4; INTERIM CP2, REVISION 13
WESTINGHOUSE DECOMMISSIONING PROJECT
HEMATITE, MISSOURI**

Sample ID			Radionuclide Concentrations (pCi/g)			
ORISE	WEC	NRC Region III	WEC ^a	ORISE		
			U-234	U-233/234	U-235	U-238
1768S0001	FS-19-1-SYS-12-SO-1	H-08-01	NA ^b	53.2 ± 3.9 ^c , 0.0 ^{d,e}	2.31 ± 0.26, 0.01	7.27 ± 0.61, 0.03
1768S0002	FS-19-1-SYS-12-SO-2	H-08-02	NA	7.25 ± 0.58, 0.01	0.35 ± 0.06, 0.01	1.92 ± 0.18, 0.03
1768S0003	FS-19-1-SYS-12-SO-3	H-08-03	NA	1.28 ± 0.13, 0.01	0.06 ± 0.02, 0.01	1.05 ± 0.12, 0.02
1768S0004	FS-19-1-SYS-13-SO-1	H-08-04	NA	36.5 ± 3.9, 0.1	1.60 ± 0.37, 0.12	4.89 ± 0.72, 0.08
1768S0005	FS-19-1-SYS-16-SO-1	H-08-05	NA	124 ± 14, 0	4.9 ± 1.1, 0.2	20.2 ± 2.9, 0.2
1768S0006	FS-19-1-SYS-16-SO-2	H-08-06	NA	22.5 ± 2.4, 0.1	1.15 ± 0.25, 0.07	3.55 ± 0.50, 0.06
1768S0007	FS-19-1-SYS-16-SO-3	H-08-07	NA	1.55 ± 0.16, 0.03	0.07 ± 0.03, 0.01	1.15 ± 0.13, 0.01
1768S0008	FS-19-1-SYS-19-SO-1	H-08-08	15.1	15.4 ± 1.7, 0.0	0.81 ± 0.19, 0.03	3.08 ± 0.43, 0.05
1768S0009	FS-19-1-BIA-1-SO-1	H-08-09	193	159 ± 18, 1	6.4 ± 2.2, 0.5	27.2 ± 4.7, 0.9
1768S0010	FS-19-1-BIA-2-SO-1	H-08-10	67	148 ± 15, 0	5.6 ± 1.1, 0.1	21.8 ± 2.8, 0.2
1768S0011	FS-19-1-BIA-3-SO-1	H-08-11	4070	8940 ± 700, 10	340 ± 60, 7	561 ± 76, 26
1768S0012	FS-19-1-BIA-3-SO-2	H-08-12	42.6	32.3 ± 3.1, 0	1.3 ± 0.28, 0.04	6.36 ± 0.77, 0.07
1768S0013	FS-19-1-BIA-3-SO-3	H-08-13	8.1	7.06 ± 0.55, 0.02	0.28 ± 0.05, 0.01	2.11 ± 0.19, 0.03
1768S0014	FS-19-1-BIA-4-SO-1	H-08-14	230	190 ± 20, 0	8.0 ± 1.5, 0.1	37.6 ± 4.5, 0.3
1768S0015	FS-19-1-BIA-5-SO-1	H-08-15	1320	723 ± 57, 4	33.6 ± 6.0, 2.7	95 ± 11, 3
1768S0016	FS-19-1-BIA-5-SO-2	H-08-16	36.6	34.8 ± 3.4, 0.1	1.79 ± 0.36, 0.04	7.97 ± 0.95, 0.03
1768S0017	FS-19-1-BIA-5-SO-3	H-08-17	2.4	1.19 ± 0.13, 0.01	0.04 ± 0.02, 0.01	1.06 ± 0.12, 0.02
1768S0018	FS-19-2-SYS-02-SO-2	H-08-18	NA	1.08 ± 0.12, 0.02	0.03 ± 0.02, 0.03	1.02 ± 0.12, 0.02
1768S0019	FS-19-2-SYS-06-SO-3	H-08-19	NA	0.87 ± 0.11, 0.05	0.05 ± 0.03, 0.04	0.95 ± 0.11, 0.02
1768S0020	FS-19-2-SYS-10-SO-1	H-08-20	NA	3.33 ± 0.29, 0.04	0.13 ± 0.04, 0.03	1.19 ± 0.13, 0.03
1768S0021	FS-19-2-SYS-14-SO-1	H-08-21	NA	3.09 ± 0.29, 0.04	0.12 ± 0.04, 0.03	1.16 ± 0.14, 0.03
1768S0022	FS-19-2-SYS-16-SO-1	H-08-22	NA	4.30 ± 0.36, 0.01	0.17 ± 0.04, 0.01	1.01 ± 0.11, 0.01
1768S0023	FS-19-2-SYS-16-SO-2	H-08-23	NA	1.73 ± 0.18, 0.04	0.08 ± 0.03, 0.05	1.06 ± 0.13, 0.02
1768S0024	FS-19-2-SYS-16-SO-3	H-08-24	NA	1.14 ± 0.13, 0.02	0.07 ± 0.03, 0.03	1.07 ± 0.13, 0.01
1768S0025	FS-19-2-SYS-19-SO-1	H-08-25	NA	11.8 ± 1.0, 0.1	0.54 ± 0.12, 0.07	2.27 ± 0.27, 0.08
1768S0026	FS-19-2-SYS-21-SO-1	H-08-26	7.5	8.2 ± 0.66, 0.02	0.51 ± 0.08, 0.01	1.67 ± 0.17, 0.02

^aRadionuclide concentrations provided in a WEC report to the NRC (WEC 2008).

^bNA = Not analyzed by alpha spectroscopy.

^cUncertainties represent the 95% confidence level, based on total propagated uncertainties.

^dThe MDCs are after the comma..

^eZero values are due to rounding.

**TABLE 3: CONCENTRATIONS OF TECHNETIUM-99
IN SOIL SAMPLES
BY LIQUID SCINTILLATION ANALYSIS
AP5, REVISION 17; CP4, REVISION 3
WESTINGHOUSE DECOMMISSIONING PROJECT
HEMATITE, MISSOURI**

Sample ID			Radionuclide Concentrations (pCi/g)				
ORISE	WEC	NRC Region III ^a	ORISE	(wet)		WEC ^b	
1768S0001	FS-19-1-SYS-12-SO-1	H-08-01	43.1	± 5.0 ^c	, 0.3 ^d	27.0	
1768S0002	FS-19-1-SYS-12-SO-2	H-08-02	3.68	± 0.50	, 0.30	3.0	
1768S0003	FS-19-1-SYS-12-SO-3	H-08-03	1.68	± 0.26	, 0.23	49.5	
1768S0004	FS-19-1-SYS-13-SO-1	H-08-04	68.8	± 8.0	, 0.3	32.8	
1768S0005	FS-19-1-SYS-16-SO-1	H-08-05	41.3	± 4.8	, 0.3	21.2	
1768S0006	FS-19-1-SYS-16-SO-2	H-08-06	3.31	± 0.44	, 0.26	3.8	
1768S0007	FS-19-1-SYS-16-SO-3	H-08-07	1.13	± 0.23	, 0.29	0.4	
1768S0008	FS-19-1-SYS-19-SO-1	H-08-08	22.3	± 2.6	, 0.3	13.1	
1768S0009	FS-19-1-BIA-1-SO-1	H-08-09	60.1	± 7.0	, 0.3	34.6	
1768S0010	FS-19-1-BIA-2-SO-1	H-08-10	39.9	± 3.4	, 0.3	11.5	
1768S0012	FS-19-1-BIA-3-SO-2	H-08-12	3.98	± 0.41	, 0.27	0.9	
1768S0013	FS-19-1-BIA-3-SO-3	H-08-13	1.56	± 0.24	, 0.28	0.5	
1768S0015	FS-19-1-BIA-5-SO-1	H-08-15	141	± 12	, 0 ^e	31.7	
1768S0016	FS-19-1-BIA-5-SO-2	H-08-16	2.23	± 0.28	, 0.27	1.0	
1768S0017	FS-19-1-BIA-5-SO-3	H-08-17	2.78	± 0.13	, 0.24	1.2	
1768S0018	FS-19-2-SYS-02-SO-2	H-08-18	0.21	± 0.16	, 0.26	0.1	
1768S0019	FS-19-2-SYS-06-SO-3	H-08-19	0.29	± 0.16	, 0.25	-0.6	
1768S0020	FS-19-2-SYS-10-SO-1	H-08-20	0.62	± 0.18	, 0.26	0.0	
1768S0022	FS-19-2-SYS-16-SO-1	H-08-22	7.05	± 0.86	, 0.24	3.6	
1768S0023	FS-19-2-SYS-16-SO-2	H-08-23	0.90	± 0.20	, 0.25	0.5	
1768S0024	FS-19-2-SYS-16-SO-3	H-08-24	0.79	± 0.20	, 0.27	0.6	
1768S0025	FS-19-2-SYS-19-SO-1	H-08-25	22.7	± 2.7	, 0.3	10.4	
1768S0026	FS-19-2-SYS-21-SO-1	H-08-26	14.8	± 1.7	, 0.2	12.9	

^aThere was no wet portion available for ORISE for samples H-08-11, H-08-14, and H-08-21 for Tc-99 analysis.

^bRadionuclide concentrations provided in a WEC report to the NRC (WEC 2008); WEC dried sample prior to analysis.

^cUncertainties represent the 95% confidence level, based on total propagated uncertainties.

^dThe MDCs are after the comma.

^eZero value is due to rounding.

APPENDIX C
MAJOR INSTRUMENTATION

APPENDIX C

MAJOR INSTRUMENTATION

The display of a specific product is not to be construed as an endorsement of the product or its manufacturer by the author or her employer.

SCANNING INSTRUMENT/DETECTOR COMBINATIONS

Alpha plus Beta

Ludlum Floor Monitor Model 239-1
combined with
Ludlum Ratemeter-Scaler Model 2221
coupled to
Ludlum Gas Proportional Detector Model 43-37, Physical Area: 550 cm²
(Ludlum Measurements, Inc., Sweetwater, TX)

Ludlum Ratemeter-Scaler Model 2221
coupled to
Ludlum Gas Proportional Detector Model 43-68, Physical Area: 126 cm²
(Ludlum Measurements, Inc., Sweetwater, TX)

Gamma

Ludlum Pulse Ratemeter Model 12
(Ludlum Measurements, Inc., Sweetwater, TX)
coupled to
Victoreen NaI Scintillation Detector Model 489-55, Crystal: 3.2 cm x 3.8 cm
(Victoreen, Cleveland, OH)

DIRECT MEASUREMENT INSTRUMENT/DETECTOR COMBINATIONS

Alpha plus Beta

Ludlum Ratemeter-Scaler Model 2221
coupled to
Ludlum Gas Proportional Detector Model 43-68, Physical Area: 126 cm²
(Ludlum Measurements, Inc., Sweetwater, TX)

LABORATORY ANALYTICAL INSTRUMENTATION

Low-Background Gas Proportional Counter
Model LB-5100-W
(Tennelec/Canberra, Meriden, CT)

High Purity Extended Range Intrinsic Detector
CANBERRA/Tennelec Model No: ERVDS30-25195
(Canberra, Meriden, CT)
Used in conjunction with:
Lead Shield Model G-11
(Nuclear Lead, Oak Ridge, TN) and
Multichannel Analyzer
Dell Workstation
(Canberra, Meriden, CT)

High Purity Extended Range Intrinsic Detector
Model No. GMX-45200-5
(AMETEK/ORTEC, Oak Ridge, TN)
used in conjunction with:
Lead Shield Model SPG-16-K8
(Nuclear Data)
Multichannel Analyzer
Dell Workstation
(Canberra, Meriden, CT)

High-Purity Germanium Detector
Model GMX-30-P4, 30% Eff.
(AMETEK/ORTEC, Oak Ridge, TN)
Used in conjunction with:
Lead Shield Model G-16
(Gamma Products, Palos Hills, IL) and
Multichannel Analyzer
Dell Workstation
(Canberra, Meriden, CT)

Alpha Spectrometer
Model 7401 VR
(AMETEK/ORTEC, Oak Ridge, TN)
used in conjunction with
Dell Workstation
Canberra and Tennelec Alpha Spectrometers
(Canberra, Meriden, CT)

Tri-Carb Liquid Scintillation Analyzer
Model 3100
(Packard Instrument Co., Meriden, CT)

APPENDIX D

SURVEY AND ANALYTICAL PROCEDURES

APPENDIX D

SURVEY AND ANALYTICAL PROCEDURES

PROJECT HEALTH AND SAFETY

The proposed survey and sampling procedures were evaluated to ensure that any hazards inherent to the procedures themselves were addressed in current job hazard analyses. Prior to onsite activities, a pre-job integrated safety management checklist was completed and discussed with field personnel. Additionally, upon arrival on site, a walk-down of the site was performed to identify hazards present. All survey and laboratory activities were conducted in accordance with ORISE health and safety and radiation protection procedures (April 2008 and September 2005).

QUALITY ASSURANCE

Analytical and field survey activities were conducted in accordance with procedures from the following documents:

- Survey Procedures Manual (May 1, 2008)
- Laboratory Procedures Manual (September 10, 2008)
- Quality Program Manual (November 1, 2007)

The procedures contained in these manuals were developed to meet the requirements of Department of Energy Order 414.1C and the U.S. Nuclear Regulatory Commission *Quality Assurance Manual for the Office of Nuclear Material Safety and Safeguards* and contain measures to assess processes during their performance.

Calibration of all field and laboratory instrumentation was based on standards/sources, traceable to NIST. Quality control procedures include:

- Daily instrument background and check-source measurements to confirm that equipment operation is within acceptable statistical fluctuations.
- Participation in MAPEP, NRIP, and ITP Laboratory Quality Assurance Programs.
- Training and certification of all individuals performing procedures.
- Periodic internal and external audits.

CALIBRATION PROCEDURES

Detectors used for assessing surface activity were calibrated in accordance with ISO-7503¹ recommendations. Total alpha plus beta efficiencies (ϵ_{total}) were determined for each instrument/detector combination and consisted of the product of the 2π instrument efficiency (ϵ_i) and surface efficiency (ϵ_s): $\epsilon_{\text{total}} = \epsilon_i \times \epsilon_s$.

Tc-99 was selected as the beta calibration source. The 2π beta instrument efficiency (ϵ_i) factor for the gas proportional detector used to collect direct measurements was 0.40. ISO-7503 recommends an ϵ_s of 0.25 for Tc-99. The total beta efficiency was 0.10.

SURVEY PROCEDURES

Surface Scans

Structural surface scans were performed by passing the detectors slowly over the surface while the distance between the detector and the surface was maintained at a minimum. A large surface area (550 cm²) gas proportional floor monitor with a 0.8 mg/cm² window was used to scan the building roofs. A NaI scintillation detector was also used. Vents/HEPA surfaces were scanned using small area (126 cm²) hand-held detectors with a 0.8 mg/cm² window. Identification of elevated radiation levels were based on increases in the audible signal from the recording and/or indicating instrument.

Beta surface scan minimum detectable concentrations (MDCs) were estimated using the calculational approach described in NUREG-1507.² The scan MDC is a function of many variables, including the background level. Additional parameters selected for the calculation of scan MDCs included a two-second observation interval, a specified level of performance at the first scanning stage of 95% true positive rate and 25% false positive rate, which yields a d' value of 2.32 (NUREG-1507, Table 6.1), and a surveyor efficiency of 0.5. The beta total efficiency was 0.10.

To illustrate an example for a hand-held gas proportional detector using the instrument background of 372 cpm, the minimum detectable count rate (MDCR) and scan MDC can be calculated as follows:

¹International Standard. ISO 7503-1, Evaluation of Surface Contamination - Part 1: Beta-emitters (maximum beta energy greater than 0.15 MeV) and alpha-emitters. August 1, 1988.

²NUREG-1507. Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions. US Nuclear Regulatory Commission. Washington, DC; June 1998.

$$b_i = (372 \text{ cpm})(2 \text{ s})(1 \text{ min}/60 \text{ s}) = 12.4 \text{ counts}$$

$$\text{MDCR} = (2.32)(12.4 \text{ counts})^{1/2} [(60 \text{ s/min})/(2 \text{ s})] = 245 \text{ cpm}$$

$$\text{MDCR}_{\text{surveyor}} = 245/(0.5)^{1/2} = 347 \text{ cpm}$$

The scan MDC is calculated using the beta total efficiency of 0.10.

$$\text{ScanMDC} = \frac{\text{MDCR}_{\text{surveyor}}}{(\epsilon_s)(\epsilon_i)} \text{ dpm}/100 \text{ cm}^2$$

For the given background, the estimated scan MDC was 3,466 dpm/100 cm² for the hand-held gas proportional detector.

The identification of elevated radiation levels that could exceed the site criteria were determined based on an increase in the audible signal from the indicating instrument.

Specific scan MDCs for the NaI scintillation detector were not determined as the instrument was used solely as a qualitative means to identify elevated gamma radiation levels in excess of background.

Surface Activity Measurements

Measurements of total beta surface activity levels were performed using hand-held gas proportional detectors coupled to portable ratemeter-scalers. Count rates (cpm), which were integrated over one minute with the detector held in a static position, were converted to activity levels (dpm/100 cm²) by dividing the count rate by the total static efficiency ($\epsilon_i \times \epsilon_s$) and correcting for the physical area of the detector. ORISE did not determine construction material-specific background for each surface type encountered for determining net count rates. Instead, ORISE took a conservative approach and did not subtract material specific backgrounds in determining surface activity levels since the site specific DCGLs have not been approved.

The *a priori* MDC for surface activity measurements was calculated using the following equation:

$$MDC = \frac{3 + (4.65\sqrt{B})}{Tx\epsilon_{Total}xG}$$

Where:

B	=	background (total counts) in time interval, T
T	=	count time (min) used for field instruments
ϵ_{Total}	=	total efficiency = $\epsilon_i \times \epsilon_s$
ϵ_i	=	instrument efficiency
ϵ_s	=	source efficiency
G	=	geometry (physical detector area cm ² /100)

The *a priori* beta static MDC was approximately 736 dpm/100 cm² using the total efficiency of 0.10 instrument background of 372 cpm. The physical surface area assessed by the gas proportional detector used was 126 cm².

Removable Activity Measurements

Removable gross alpha and gross beta activity levels were determined using numbered filter paper disks, 47 mm in diameter. Moderate pressure was applied to the smear and approximately 100 cm² of the surface was wiped. Smears were placed in labeled envelopes with the location and other pertinent information recorded.

RADIOLOGICAL ANALYSIS

Gross Alpha/Beta

Smears were counted on a low-background gas proportional system for gross alpha and beta activity. The MDCs of the procedure were 9 dpm/100 cm² and 15 dpm/100 cm² for a 2-minute count time for gross alpha and gross beta, respectively.

Alpha Spectroscopy

Solid samples were crushed and homogenized. Soil samples were dissolved by potassium fluoride and pyrosulfate fusion and the elements of interest were precipitated with barium sulfate. Barium sulfate precipitate was redissolved and the specific element of interest—isotopic uranium was

individually separated by extraction chromatography using Eichrom resins and re-precipitated with a cerium fluoride carrier. The precipitate was then analyzed using ion implanted detectors (Canberra), alpha spectrometers (Tennelec and Canberra), and a multichannel analyzer (Nuclear Data). The typical MDC of the procedure for a 1000 minute count time is 0.02 pCi/g for solids.

Tc-99

Solid samples are leached with dilute nitric acid. The leachates are passed through an extraction chromatographic column containing a resin (TEVA resin) which is highly specific for technetium in pertechnatate form. The technetium is absorbed onto the extraction resin. The resin is added to a scintillation vial containing an appropriate cocktail and counted for 60 minutes using a liquid scintillation analyzer. All interfering beta emitting radionuclides are effectively removed (including C-14, P-32, S-35, Sr-90, Y-90, and Th234) using TEVA resin under the conditions in this procedure. Tritium may follow technetium due to the absorption of some tritium-labeled compounds by the resin. Possible tritium interferences are eliminated by setting the technetium counting window above the maximum energy for tritium beta particles. The typical MDC of the procedure is 2 pCi/g for a one gram aliquot.

DETECTION LIMITS

Detection limits, referred to as MDC, were based on 3 plus 4.65 times the standard deviation of the background count $[3 + (4.65(\text{BKG})^{1/2})]$. Because of variations in background levels, measurement efficiencies, and contributions from other radionuclides in samples, the detection limits differ from sample to sample and instrument to instrument.