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TECHNICAL REPORT OF MEASUREMENT RESULTS FOR WASTE PITS 1, 2, AND 3 FOR FERNALD RADON-FLUX MEASUREMENT SURVEY, PHASE 1 FEBRUARY 1992

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Internal Technical Report

Fernald Environmental Management Project

Technical Report of Measurement Results for Waste Pits I, 2, and 3 for Fernald Radon-Flux Measurement Survey, Phase I

February 1992

Prepared for U.S. Department of Energy and
Westinghouse Environmental Management Project

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Geotech, Inc.

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EXECUTIVE SUMMARY

Radon-flux measurements were made on selected waste pits in the Waste Storage Area of the U.S. Department of Energy's Fernald Environmental Management Project, Fernald, Ohio by Chem-Nuclear Geotech, Inc., prime contractor for the U.S. Department of Energy, Grand Junction Projects Office. These measurements were made to provide a best estimate of the long-term average radon emissions from these waste pits. The sampling and analysis methodology of Standard Method 115 (40 CFR 61, Appendix B) was adopted for this purpose. This methodology uses Large Area Activated Charcoal Collectors (LAACCs) to absorb radon exhaling from the surface of the waste pit. The charcoal is analyzed using gamma spectroscopy, following the exposure to determine the amount of radon absorbed, from which the radon flux density is calculated.

This report describes the measurement methodologies, and results of measurements conducted on Waste Pits 1, 2, and 3. The measurements detailed in this report were conducted during the latter part of November, 1991. Although the weather was not ideal for these measurements, results were obtained that sufficiently characterize the average ^{222}Rn emissions from these waste pits.

It had been anticipated that elevated atmospheric radon levels, due to the presence of the K-65 Silos, would adversely affect the measurement results obtained from the LAACCs. To accommodate this possibility an attempt was made to determine an empirical correction factor that could be applied to the results from the LAACCs to correct for this measurement bias. Fortunately the atmospheric radon levels were at ambient outdoor background levels during the exposure periods, and no correction was necessary. The results from the LAACC measurements are reported as determined, with no correction applied.

As shown in Table I, the arithmetic mean of the measured radon-flux for each of the three pits is well below the National Emission Standards for Hazardous Air Pollutants (NESHAP) emission limit of 20 $pCi \cdot m^{-2} \cdot sec^{-1}$ for ^{222}Rn. It is also significant to note that the upper limit of the 99 percent confidence interval of the mean lies well below the NESHAP limit for all three pits.

Table I[a]
Summary of Standard LAACC Measurements

	Waste Pit 1	Waste Pit 2	Waste Pit 3
Number of Samples	99	98	100
Arithmetic Mean	9.1	6.4	2.6
Standard Deviation	13.4	13.4	6.2
Standard Error	1.4	1.4	0.6
Minimum	0.6	0.2	0.3
Maximum	75.2	81.0	48.0
99 Percent Confidence Interval of the Mean	5.6 - 12.7	2.9 - 9.9	1.0 - 4.2
Pit Area in m^2	7,430	4,460	22,300

[a]All values are given in units of $pCi \cdot m^{-2} \cdot sec^{-1}$ unless otherwise noted.

INTRODUCTION

Background

Uranium production operations began at the U.S. Department of Energy's Fernald Environmental Management Project (U.S. DOE-FEMP) in 1951 and continued until July 1989 when production was halted. Over that period, a number of different chemical and metallurgical processes were used at the FEMP, producing a variety of waste streams. A portion of the waste produced during operations was placed in the six waste pits on the western side of the production area. Figure 1 shows the Waste Storage Area. Some of the waste buried in these pits contained ^{226}Ra. Accurate records of the quantities of ^{226}Ra in the pits are not available. In 1987, a series of borings was made in the various waste pits. These borings were analyzed for ^{226}Ra along with other radionuclides. Greater than background ^{226}Ra concentrations were found in Pits 1, 2, 3, 4 and 5. ^{226}Ra was not detected in Pit 6 in concentrations above 20 pCi/g.

In the southwestern portion of the Waste Storage Area are four silos, also constructed in 1951 (Figure 1). The two southern most silos (also called the K-65 Silos) contain waste from the Manhattan Project, principally the residues from processing the radium-rich pitchblende ores from the Belgian Congo. These two silos contain several thousand curies of ^{226}Ra and are a source of elevated radon concentrations in the air of the Waste Storage Area. More detailed descriptions of the waste pits are found in "*Initial Screening of Alternatives for Operable Unit 1, Task 12 Report, Feed Materials Productions Center, Fernald, Ohio, Remedial Investigation and Feasibility Study*" (DOE, 1991).

Because the Waste Pits contain ^{226}Ra, distributed throughout the waste pits in an unknown manner, there is some question as to the ^{222}Rn emissions that can be expected from these waste pits. In an effort to more completely characterize the ^{222}Rn emissions, a project was developed to conduct radon-flux measurements on selected waste pits. The radon-flux measurements were conducted for the U.S. DOE-FEMP by Chem-Nuclear Geotech, Inc., the prime contractor for the U.S. Department of Energy's Grand Junction Projects Office (GJPO).

To provide technically defensible results, that would be comparable with measurements of similar radon sources (e.g., uranium mill tailings and phosphogypsum piles), the measurement methodology of 40 CFR, Part 61, Appendix B, Method 115 (U.S. EPA, 1990) was selected for use. Hereafter, this will be referred to as Method 115. Method 115 uses Large Area Activated Charcoal Collectors (LAACCs) for making radon-flux measurements based on the method described by Hartley and Freeman (1986).

Method 115 employs a LAACC to absorb radon exhaling from the surface at which the flux is to be measured. Following an exposure of approximately 24 hours, the charcoal is removed from the collector and analyzed using gamma-ray spectroscopy to determine the amount of radon retained by the charcoal and, hence, the radon-flux density.

Special Considerations

Information provided by FEMP technical personnel indicates that the atmospheric radon concentrations may be elevated to as much as 100 pCi/L in the vicinity of the waste pits during periods of temperature inversions. The K-65 Silos are the source for this elevated atmospheric radon. Because of this possibility, the GJPO Radon Laboratory undertook an evaluation of the effects of increased atmospheric radon concentration on radon-flux measurements using the LAACC. A series of experiments was performed on the

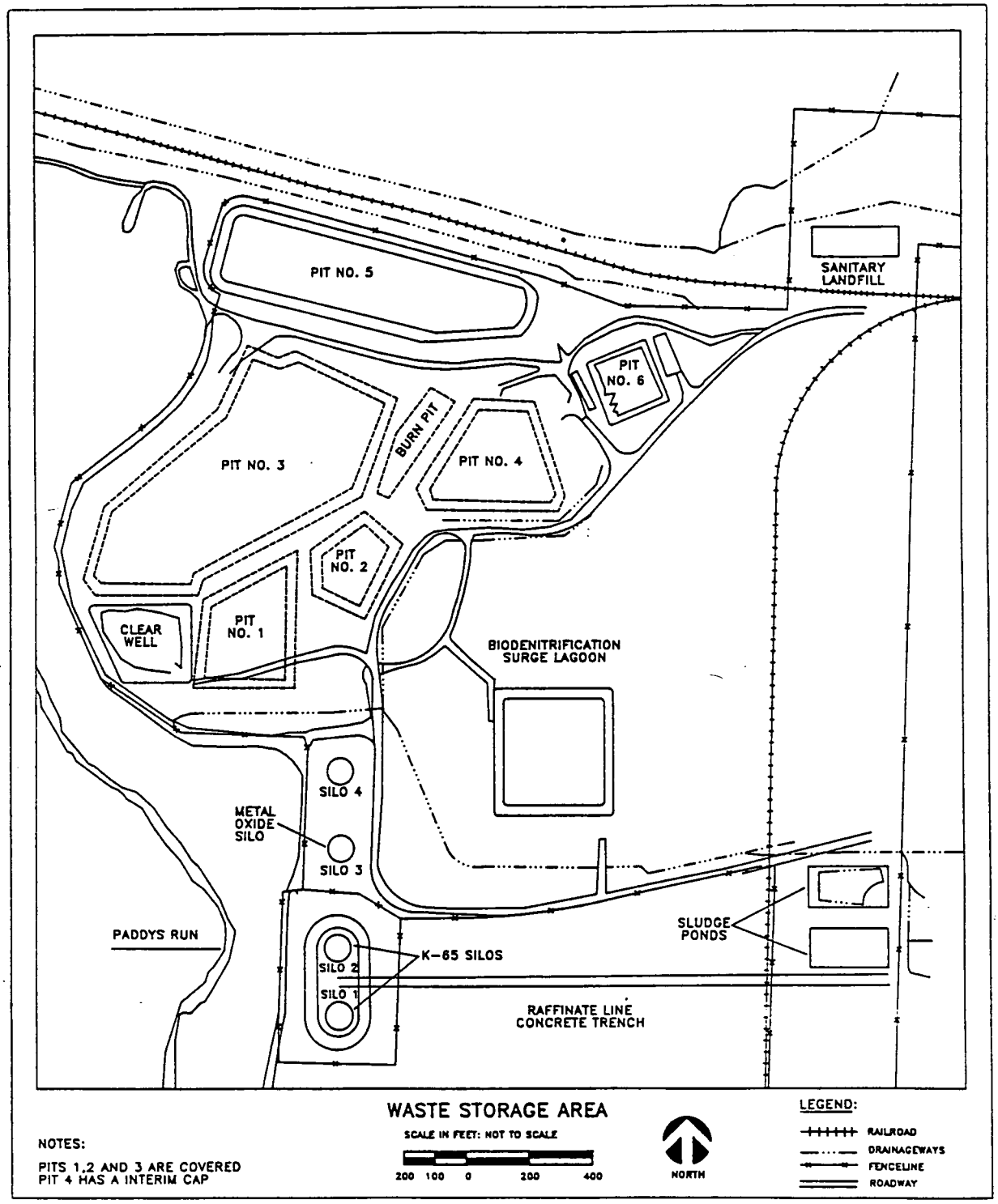

Figure 1. Generalized map of the Waste Storage Area.

GJPO Thin-Layer Radon-Flux Model to assess the impact on the measurement technique, and to evaluate mechanisms to compensate for any observed bias. The basic experimental design used a series of 24 hour exposures of replicate LAACC's on the flux model, with various atmospheric radon concentrations artificially maintained above the model. The atmospheric radon concentrations ranged from approximately 7 to 120 pCi/L. During one of these exposures two LAACCs were exposed with the bottom covered by aluminum foil. The foil cover prevented radon from entering the LAACC from the bottom, leaving only the 1/4 inch vent hole on the top of the device as an entry path. The following observations resulted from these investigations:

- For atmospheric radon concentrations up to approximately 120 pCi/L an increase in the device response of 0.015 ($pCi \cdot m^{-2} \cdot sec^{-1}$) per pCi/L of atmospheric radon was observed on the Thin-Layer Radon-Flux Model. The relationship between the LAACC measurement increase and the atmospheric radon concentration was reproducible and appeared linear.

- No more than 10 percent of this increase (0.0015 $pCi \cdot m^{-2} \cdot sec^{-1}$ per pCi/L of atmospheric radon) may be attributed to radon entering the device through the 1/4 inch vent hole on top of the LAACC.

It had been anticipated that the increase in the LAACC measurement observed on the Thin-Layer Radon-Flux Model might represent a maximum value, because of the high permeability of the tailings material used in the model. To test this hypothesis, a series of similar experiments was conducted at the GJPO, in Colorado. The basic experimental design was to measure radon-flux from normal uncontaminated soil with a pair of LAACC's for 24 hour periods, one under a make-shift radon chamber, and the second open to the atmosphere.

The results of these experiments demonstrated that, contrary to expectations, the increase in measured radon-flux per pCi/L of atmospheric radon was higher for the soils than for the tailings in the flux model. The average increase in measured radon-flux observed during these experiments was approximately 0.030 $pCi \cdot m^{-2} \cdot sec^{-1}$ per pCi/L of atmospheric radon.

These results do, however, confirm the direction of the bias resulting from increased atmospheric radon and provide a sense of the expected magnitude. Moreover these results demonstrate that the increase in LAACC response for a given atmospheric radon concentration is dependent on as yet unidentified parameters of the soil on which the flux measurements are made. Therefore, any empirical correction factor that might be developed on soils in Grand Junction would have questionable value if applied to measurements conducted elsewhere.

These factors contributed to the decision to attempt to determine an empirical site-specific correction factor for the LAACC measurements (Method 115) that were to be conducted on the FEMP waste pits. Because the magnitude of the measurement bias is dependent upon soil properties such as moisture, that change temporally, it was considered necessary to make the measurements from which the correction factor was to be determined at the same time that the LAACC measurements were made.

METHODS

A two-part measurement methodology was adopted for this project. The first part was to apply the measurement methodology of Method 115 to the waste pits without modification. Hereafter, these measurements will be referred to as the Standard LAACC Measurements. The second part was to conduct an additional series of measurements designed to determine an empirical correction factor to

compensate for elevated atmospheric radon levels. The correction factor would be applied to the results of the Standard LAACC Measurements in the event that significantly elevated atmospheric radon levels were encountered during the measurement period. These measurements will be collectively referred to as the Control Measurements.

Each of the waste pits was measured over a separate 24 hour period, resulting in three separate measurement sets. Because of the uncertain weather conditions, there was a high probability that it would not be possible to conduct measurements on all three waste pits. Waste Pit 3 was selected for the initial measurements because it was the largest of the three pits. Measurements were then made on Waste Pits 2 and 1 in that order.

Standard LAACC Measurements

A LAACC equivalent to that prescribed in Method 115 was used to collect the radon-on-charcoal samples for the Standard LAACC Measurements. Figure 2 shows a sketch of the collector used. The procedures used to collect the radon-on-charcoal samples and to perform the subsequent gamma-ray spectral analyses are given in the GJPO Radon Laboratory Technical Procedures "Calibration of a Computer Automated Gamma Counting System for Radon Flux Measurements" (RN-FLUX-C) and "Radon Flux Measurements Using the Large Area Activated Charcoal Collector Method" (RN-FLUX-U), (see Appendix A).

Diagram of a Large Area Activated Charcoal Collector (LAACC)

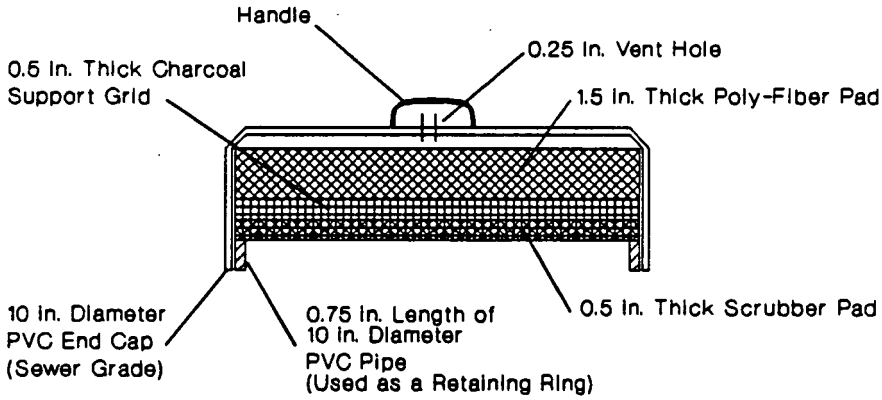

Figure 2 Diagram of a LAACC

As described in the procedure RN-FLUX-U, gamma analysis of a "Field Blank" is used to determine the appropriate background count rate for the LAACC sample analysis. Separate "Field Blanks" were prepared for each set of LAACC samples. The charcoal for the "Field Blank" was taken from the unexposed charcoal and canned at the same time that the LAACCs were being loaded for that measurement set. Each Waste Pit represents a separate measurement set.

Six additional blank charcoal samples, containing clean, dry, unexposed charcoal, were prepared and intermixed with the LAACC samples prior to

shipment to the GJPO Radon Laboratory for gamma analysis. These six blanks were used to verify the integrity of the sample handling and counting process. These blanks were labeled in a manner similar to the standard LAACC samples, except that a three-letter designator was used instead of the three-digit designator for the sample location.

Using Method 115 as guidance, a uniform rectangular grid of 100 sampling locations was developed for Waste Pits 2 and 3. A grid of 102 locations was used for Waste Pit 1. Figures 3, 4, and 5 show the locations of these sampling points for Waste Pits 1, 2, and 3 respectively.

Control Measurements

The Control Measurements consisted of coupled radon-flux and atmospheric radon measurements. The principle involved is to directly measure the effect of increasing the atmospheric radon level over one of a pair of LAACCs that would otherwise measure the same radon-flux density. The difference in measured radon-flux divided by the increase in atmospheric radon produces a correction factor of interest. The correction factor multiplied by the average atmospheric radon concentration provides an estimate of the measurement bias introduced by elevated atmospheric radon levels.

As discussed earlier, the actual magnitude of the measurement bias is dependent upon the local soil properties. These properties will vary spatially over a waste pit, so 10 Control Measurements were taken on each of the waste pits. An average correction factor was determined for each waste pit by computing the average of the measured correction factors for the ten randomly selected locations. The locations selected for Control Measurements are shown on Figures 3, 4, and 5.

The control flux measurements were made using the same type of LAACC as the Standard LAACC Measurements. Each of the control LAACC's was placed (topography permitting) about 6 ft (2 m) from the standard LAACC with which it was paired. A galvanized metal tub, approximately 0.2 m^2 in area, was inverted over each control LAACC. The inverted tub prevents radon exhaling from the ground from dispersing to the atmosphere, and thereby creates an elevated radon concentration in the air over and around the control LAACC: The tub serves as a radon accumulator.

The samples generated from the control LAACCs were treated the same as the samples from the Standard LAACCs so far as sample analysis is concerned. Only the field conditions under which the measurements were made differed from the Standard LAACC Measurements.

Diffusion barrier charcoal canisters (DBCCs) were used to measure the average radon concentrations in the air over the standard LAACC (open air) and in the air over the control LAACC (inside the tub). On the basis of experiments conducted at GJPO, it was expected that the radon concentration inside the tub would reach at least several tens of pCi/L above the outside air concentration. Procedures for usage and interpretation of data from DBCCs are contained in the GJPO Radon Laboratory Technical Procedure RN-DBCC-U found in Appendix A.

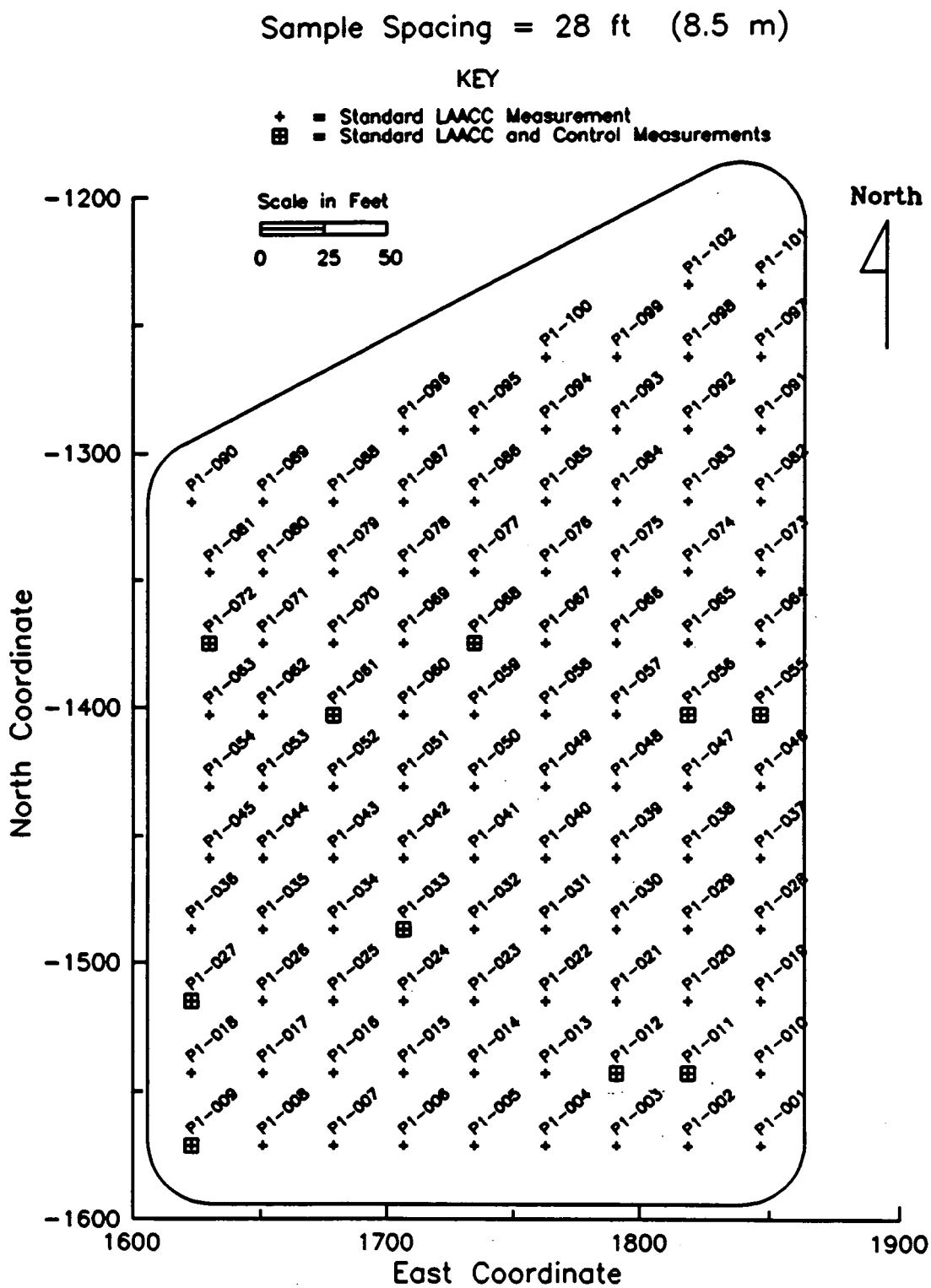

Figure 3. Sampling Grid for Waste Pit 1. Coordinates refer to the FEMP Site Coordinate System.

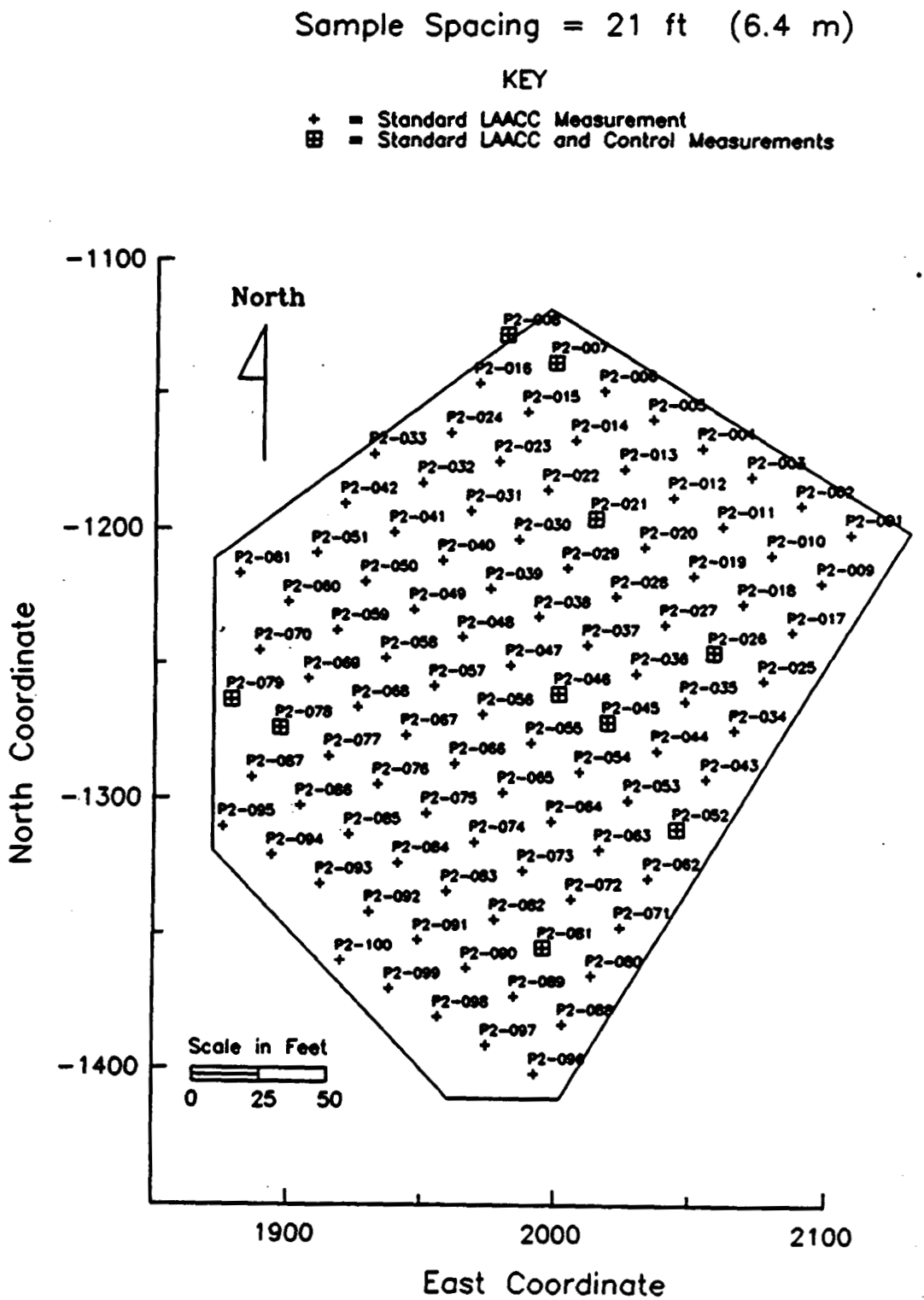

Figure 4. Sampling Grid for Waste Pit 2. Coordinates refer to the FEMP Site Coordinate System.

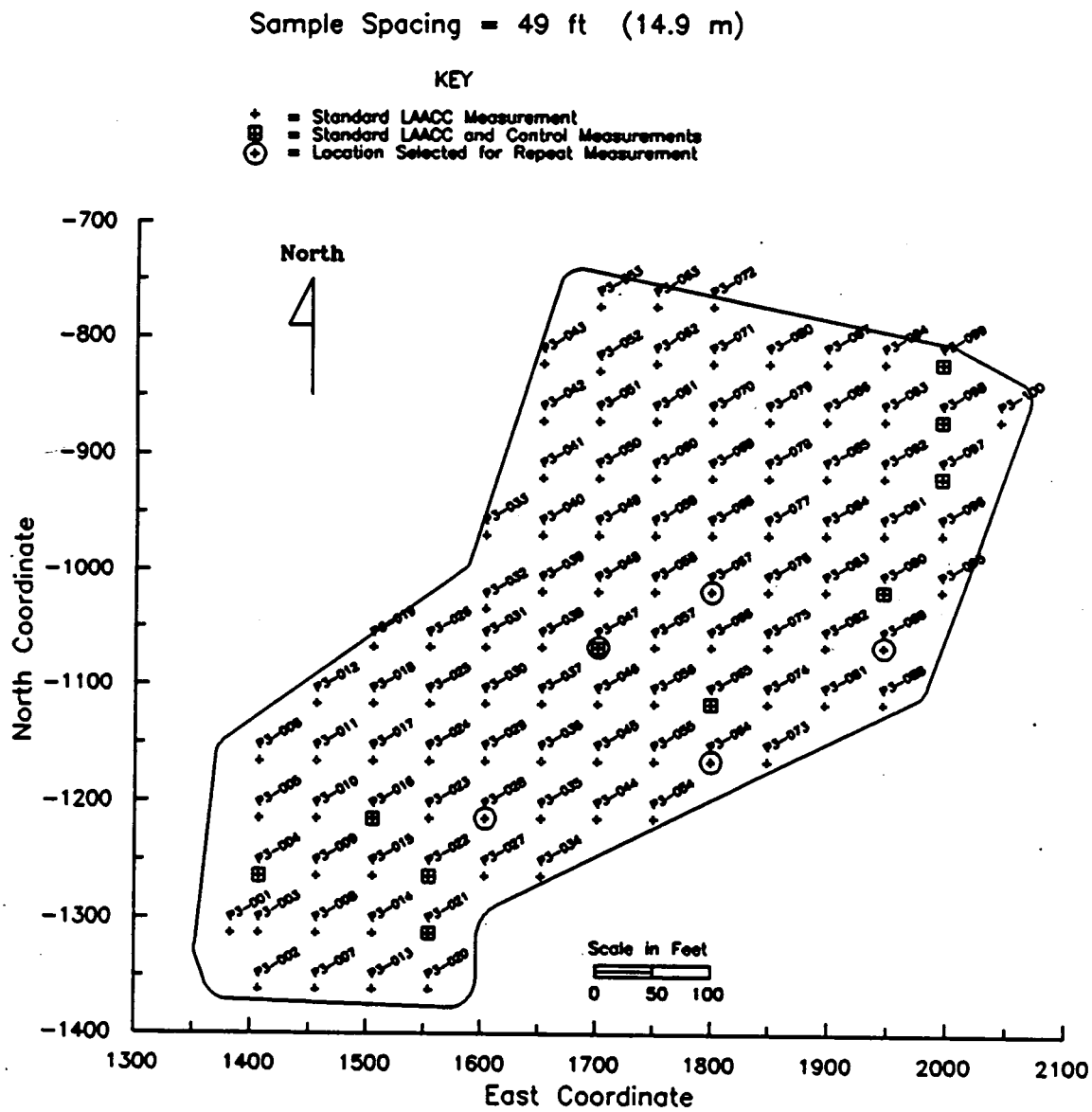

Figure 5. Sampling Grid for Waste Pit 3. Coordinates refer to the FEMP Site Coordinate System.

It was assumed that due to the engineered nature of the soils covering the waste pits, the flux measured by the Control LAACC would have been about the same as the flux measured by the Standard LAACC with which it was paired, if the radon accumulator tub were not present. If this assumption holds, the flux values (Standard and Control LAACCs) and the two atmospheric radon concentrations (outside and inside the accumulator tub) can be used to determine the empirical correction factor, using the following formula:

$$F = \frac{(J_A - J_S)}{(C_A - C_S)}$$

Where :

F = *Empirical Correction Factor* $[(pCi \cdot m^{-2} \cdot sec^{-1})/(pCi/L)]$
J_A = *Measured Flux Under Accumulator* $[pCi \cdot m^{-2} \cdot sec^{-1}]$
J_S = *Measured Flux of the Standard Measurement* $[pCi \cdot m^{-2} \cdot sec^{-1}]$
C_A = *Average Atmospheric Radon Concentration in the Accumulator* $[pCi/L]$
C_S = *Average Atmospheric Radon Concentration for the Standard Measurement* $[pCi/L]$

Repeat Measurement Locations

Because each waste pit was sampled over a separate 24 hour period, a resampling scheme was implemented to assess the short term temporal variations in radon-flux. Five percent (five locations) from the first pit sampled (Waste Pit 3) were resampled during the measurement period of each of the other two pits. The locations for repeat measurements were selected to provide a broad spatial distribution across Waste Pit 3, and were, therefore, not randomly selected.

Location and Preparation of Sampling Points

The sampling grids shown in Figures 3, 4, and 5 were located relative to the waste pit boundaries, as marked by FEMP personnel, by the use of a compass and chain. The estimated uncertainty in the location of the actual sampling points is approximately 5 ft (1.5 m).

Each of the sampling locations for a given waste pit was assigned a number ranging from 1 through 100, (1 to 102 in the case of pit 1). Each sampling point was marked with a pin flag bearing the sample location number.

Because all three of these waste pits have been covered for some time, each pit supports a well developed plant community of predominantly grasses and other low lying ground cover. To form a seal between the collector lip and the soil, the vegetation was removed using a weed-eater type grass trimmer. The vegetation was removed down to a stubble approximately 1/2 to 1 inch (1 to 3 cm) high. Care was exercised to avoid disturbing the soil during this process. The seal between the soil and the collectors was improved by forming a collar of concrete grade sand, approximately 1 to 2 in. (3 to 5 cm) around the edge of each collector.

Sample Identification

Each LAACC sample was assigned a unique Sample I.D. number. This number served to both uniquely identify the sample and to provide information concerning the waste pit number, the location on the waste pit, and the date the LAACC was placed. The following is an example of an I.D. number.

P3-056-111491 Where:

"P3"	indicates Waste Pit 3
"056"	indicates sample location 56
"111491"	indicates the month, day, and year of placement (November 14, 1991)

The suffix "-A" was appended to the sample location to denote samples collected under an accumulator. For example, the Control LAACC sample paired with the Standard LAACC at location 21 on Waste Pit 3 bears the sample number "P3-021-A-111491."

The same labeling scheme used for the flux measurement samples was employed with the DBCC samples, except that a "-D" suffix was added to each sample number. In the example above the DBCC placed in the accumulator bears the following sample number: "P3-021-A-111491-D."

Sample Handling

Special containers were used to store and transport the LAACCs. These containers were constructed from 12 in. diameter polyvinyl chloride (PVC) pipe, approximately 4 ft long. Each end of the pipe was fitted with a PVC end cap, one fixed in place and the other removable. Each container held ten LAACCs separated by spacers. This proved to be a reasonably convenient means of transporting and handling the LAACCs.

The LAACCs were loaded with freshly baked activated charcoal within a 3 hour time span before the start of the exposure. The LAACCs were loaded into the containers as they were filled with charcoal. An empty sample can was used as a volumetric gage to deliver the required amount of activated charcoal. The charcoal had been baked in a drying oven at 105 °C overnight. The actual mass of charcoal for each sample was approximately 185 ± 5 grams.

Each LAACC was labeled sequentially 1 through 120. The LAACCs were always handled in numerical order to limit the possibility of misidentifying a sample. Whenever possible the LAACCs were placed at the sampling location with the corresponding number. For example LAACC numbers 1 through 102 were placed at sample locations P1-001 through P1-102 on Waste Pit 1.

The exposed LAACCs were inspected before collection to determine if the sand used for a seal had been breached, or the LAACC had been disturbed in any way. Any LAACC that had been disturbed was considered an invalid sample. Only one sample (P2-062-111891) was invalidated because the LAACC had been bumped. This was apparently done by a team of technicians conducting ground water sampling on the waste pit during the exposure period. This sample was processed, but the results were not used in computing the average radon-flux density of the waste pit.

To prevent the transfer of potentially contaminated soil, each LAACC was cleaned immediately following its recovery from the sample point. This was accomplished by wiping the exterior surfaces of the LAACC with a clean rag. Following recovery from the sampling point the LAACCs were collected in the containers and transported to the staging area, located away from the Waste Pits.

The staging area was a "Sea-Land" container in which tables were set up to provide a clean, dry, work area, to transfer the charcoal from the LAACCs into sample cans. Special 4 in. diameter by 2 in. high, hermetically sealed sample cans were used to hold the charcoal for transport and subsequent gamma analysis. The sample number, date and time of placement, date and time of retrieval, and the initials of the person handling the can were written on a label affixed to the can. Because the samples would be analyzed in the GJPO Radon Laboratory, all times were recorded as Mountain Standard Time, rather than the local Eastern Standard Time, to avoid any confusion regarding time changes.

The DBCC's, Field Blank, and blank charcoal samples were packaged with the LAACC samples for overnight shipping. "Chain-of-custody seals" were placed on the shipping containers to provide assurance of sample integrity during shipment. Chain-of-custody paperwork accompanied the samples back to the laboratory.

Meteorological Parameters

To be consistent with the requirements given in Method 115, the measurements should only be conducted under certain weather conditions. Specifically, Method 115 places the following restrictions on making radon flux measurements:

- Measurements shall not be initiated within 24 hours of a rainfall.
- If a rainfall event occurs during the exposure period the measurement is invalidated if the seal around the LAACC is washed away, or if the LAACC is surrounded by standing water.
- Measurements shall not be performed if the ambient temperature is below 35 °F, or if the ground is frozen.

The weather during the latter part of November can best be characterized as predominantly overcast with continuous light to moderate breezes, and frequent drizzling rain. Because of the high probability of encountering rain during those periods when the temperatures were warm enough to meet the measurement criteria given in Method 115, technical representatives from the U.S. Environmental Protection Agency, Region V, were consulted regarding this measurement situation. Their recommendation, which was adopted, was to proceed with measurements if the total rainfall was 0.05 in. or less in the 24 hour period preceding the exposure. Light to moderate rain during the exposure period was considered less of a problem, because the ground under the LAACC is covered by the body of the LAACC itself.

The rainfall data were obtained from the FEMP Site Meteorological Station. Temperature data were obtained from both the FEMP Site Meteorological Station and from a Metrosonics DL-714 data logger situated on the waste pits. The temperature sensor on the Site Meteorological Station is situated at a height of 10 meters (33 ft) above ground level.

Both the ambient air temperature and the ground temperature were monitored to ensure that the measurements were conducted within the guidelines of Method 115. The Metrosonics data logger was configured to record 4 channels of type T thermocouple input for temperature measurement. Two channels were used to monitor the ambient air temperature at a height of approximately 10 cm (~4 in.) above ground and the two remaining channels were used to monitor the soil temperature at a depth of 2 cm (0.8 in.). These temperature measurements were conducted at two sample locations on each waste pit (P1-029 and P1-038 on Waste Pit 1; P2-028 and P2-038 on Waste Pit 2; and P3-076 and P3-077 on Waste Pit 3).

Laboratory Analysis

Detailed procedures are discussed in the GJPO Radon Laboratory Technical Procedure "Radon Flux Measurements Using the Large Area Activated Charcoal Collector Method" (RN-FLUX-U), see Appendix A. Following its receipt by the GJPO Radon Laboratory, each charcoal sample was counted for 300 seconds on a 3 in. x 3 in. NaI gamma detector. The detector was connected to a multi-channel analyzer (MCA) card within a personal computer. A series BASIC programs were used to control operation of the MCA. The various dates and times necessary for the computation of radon-flux density were entered into the computer at the time of counting. Once a spectrum was acquired for the sample, it was processed to recover the net counts for three regions of interest (ROI's), and a result in $pCi \cdot m^{-2} \cdot sec^{-1}$ was computed.

The background count rate for the analysis was determined by a 20 minute count of the appropriate Field Blank at the start of each day's counting. Performance of the system was verified by counting two standards both at the beginning and end of each day's counting. In addition, the six blank charcoal samples were counted with the samples from each measurement set to verify performance of the analytical system. The data quality objectives stated at the outset of the project were to produce analytical results for the LAACC measurements with a precision of 10 percent, an accuracy of ± 10 percent and completeness of 85 percent for all measurement results of 1 $pCi \cdot m^{-2} \cdot sec^{-1}$ or greater.

The procedure used to reduce the data from the DBCC's is the GJPO Radon Laboratory Technical Procedure "Measuring Radon Concentrations with Diffusion Barrier Charcoal Canisters" RN-DBCC-U, in Appendix A. This procedure is similar to that used to analyze the LAACC samples. Each charcoal canister was counted for 20 minutes and the resulting spectrum was processed to recover the net counts for two spectral ROI's. These data were used in conjunction with calibration constants derived from exposures conducted at the GJPO Radon Laboratory to determine the average radon concentration to which the canister was exposed.

RESULTS AND DISCUSSION

Standard LAACC Measurements

Tables 1, 2, and 3 show the results of the Standard LAACC Measurements. No correction for atmospheric radon has been applied to these results because the atmospheric radon was at normal outdoor background levels during the exposure periods; the basis for this conclusion is discussed under the section entitled Control Measurements, page 32, using data from Table 11. The value provided for the measured radon-flux density is the average of the results computed for three different gamma spectral regions. For those samples that were recounted, the average of the two count results is shown.

The coordinates shown in the tables (North and East Coordinate) refer to the FEMP Site Coordinate System. The North Coordinate is the distance in feet that the point lies in a northerly direction from the coordinate system origin. Correspondingly the East Coordinate is the distance in feet that the point lies in an easterly direction from the origin. The coordinate system origin lies approximately 1250 ft north and 2000 ft west of the center of Waste Pit 2, hence the negative values for the North Coordinates.

Table 1
Standard LAACC Measurement Results for Waste Pit 1

Sample ID	Sample Location	East Coordinate (ft.)	North Coordinate (ft.)	Radon-Flux Density ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P1-001-112191	P1-001	1847	-1571	8.0
P1-002-112191	P1-002	1819	-1571	3.9
P1-003-112191	P1-003	1791	-1571	2.1
P1-004-112191	P1-004	1763	-1571	1.3
P1-005-112191	P1-005	1735	-1571	2.6
P1-006-112191	P1-006	1707	-1571	1.6
P1-007-112191	P1-007	1679	-1571	1.4
P1-008-112191	P1-008	1651	-1571	4.8
P1-009-112191	P1-009	1623	-1571	2.7
P1-010-112191	P1-010	1847	-1543	2.3
P1-011-112191	P1-011	1819	-1543	2.2
P1-012-112191	P1-012	1791	-1543	34.3
P1-013-112191	P1-013	1763	-1543	2.5
P1-014-112191	P1-014	1735	-1543	0.2[a]
P1-015-112191	P1-015	1707	-1543	0.2[a]
P1-016-112191	P1-016	1679	-1543	0.7
P1-017-112191	P1-017	1651	-1543	1.3
P1-018-112191	P1-018	1623	-1543	4.4
P1-019-112191	P1-019	1847	-1515	2.4
P1-020-112191	P1-020	1819	-1515	0.4[a]
P1-021-112191	P1-021	1791	-1515	1.0
P1-022-112191	P1-022	1763	-1515	32.4
P1-023-112191	P1-023	1735	-1515	5.2
P1-024-112191	P1-024	1707	-1515	64.4
P1-025-112191	P1-025	1679	-1515	1.3
P1-026-112191	P1-026	1651	-1515	3.1
P1-027-112191	P1-027	1623	-1515	11.0
P1-028-112191	P1-028	1847	-1487	14.2
P1-029-112191	P1-029	1819	-1487	2.8
P1-030-112191	P1-030	1791	-1487	0.8
P1-031-112191	P1-031	1763	-1487	2.8
P1-032-112191	P1-032	1735	-1487	2.3
P1-033-112191	P1-033	1707	-1487	7.2
P1-034-112191	P1-034	1679	-1487	3.5
P1-035-112191	P1-035	1651	-1487	5.2
P1-036-112191	P1-036	1623	-1487	53.0
P1-037-112191	P1-037	1847	-1459	2.9
P1-038-112191	P1-038	1819	-1459	3.2
P1-039-112191	P1-039	1791	-1459	2.8
P1-040-112190	P1-040	1763	-1459	1.4
P1-041-112191	P1-041	1735	-1459	13.9
P1-042-112191	P1-042	1707	-1459	6.7
P1-043-112191	P1-043	1679	-1459	8.8
P1-044-112191	P1-044	1651	-1459	18.2
P1-045-112191	P1-045	1630	-1459	29.6
P1-046-112191	P1-046	1847	-1431	1.6
P1-047-112191	P1-047	1819	-1431	1.9
P1-048-112191	P1-048	1791	-1431	0.6
P1-049-112191	P1-049	1763	-1431	1.5
P1-050-112191	P1-050	1735	-1431	3.1

[a]Measurements conducted on paved portion of waste pit.

Table 1 (continued)
Standard LAACC Measurement Results
for Waste Pit 1

Sample ID	Sample Location	East Coordinate (ft.)	North Coordinate (ft.)	Radon-Flux Density ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P1-051-112191	P1-051	1707	-1431	2.8
P1-052-112191	P1-052	1679	-1431	5.6
P1-053-112191	P1-053	1651	-1431	3.3
P1-054-112191	P1-054	1630	-1431	75.2
P1-055-112191	P1-055	1847	-1403	12.1
P1-056-112191	P1-056	1819	-1403	2.9
P1-057-112191	P1-057	1791	-1403	0.7
P1-058-112191	P1-058	1763	-1403	1.8
P1-059-112191	P1-059	1735	-1403	1.7
P1-060-112191	P1-060	1707	-1403	2.4
P1-061-112191	P1-061	1679	-1403	5.5
P1-062-112191	P1-062	1651	-1403	3.2
P1-063-112191	P1-063	1630	-1403	32.9
P1-064-112191	P1-064	1847	-1375	6.2
P1-065-112191	P1-065	1819	-1375	12.1
P1-066-112191	P1-066	1791	-1375	4.9
P1-067-112191	P1-067	1763	-1375	1.2
P1-068-112191	P1-068	1735	-1375	0.8
P1-069-112191	P1-069	1707	-1375	2.0
P1-070-112191	P1-070	1679	-1375	2.3
P1-071-112191	P1-071	1651	-1375	2.0
P1-072-112191	P1-072	1630	-1375	4.4
P1-073-112191	P1-073	1847	-1347	19.7
P1-074-112191	P1-074	1819	-1347	10.0
P1-075-112191	P1-075	1791	-1347	5.9
P1-076-112191	P1-076	1763	-1347	5.8
P1-077-112191	P1-077	1735	-1347	10.8
P1-078-112191	P1-078	1707	-1347	8.8
P1-079-112191	P1-079	1679	-1347	1.4
P1-080-112191	P1-080	1651	-1347	0.9
P1-081-112191	P1-081	1630	-1347	1.3
P1-082-112191	P1-082	1847	-1319	10.4
P1-083-112191	P1-083	1819	-1319	8.3
P1-084-112191	P1-084	1791	-1319	4.7
P1-085-112191	P1-085	1763	-1319	12.6
P1-086-112191	P1-086	1735	-1319	11.9
P1-087-112191	P1-087	1707	-1319	8.6
P1-088-112191	P1-088	1679	-1319	3.3
P1-089-112191	P1-089	1651	-1319	1.4
P1-090-112191	P1-090	1623	-1319	0.7
P1-091-112191	P1-091	1847	-1291	3.2
P1-092-112191	P1-092	1819	-1291	8.6
P1-093-112191	P1-093	1791	-1291	18.0
P1-094-112191	P1-094	1763	-1291	17.2
P1-095-112191	P1-095	1735	-1291	32.6
P1-096-112191	P1-096	1707	-1291	2.0
P1-097-112191	P1-097	1847	-1263	4.0
P1-098-112191	P1-098	1819	-1263	35.3
P1-099-112191	P1-099	1791	-1263	23.7
P1-100-112191	P1-100	1763	-1263	47.0
P1-101-112191	P1-101	1847	-1235	1.9
P1-102-112191	P1-102	1819	-1235	10.4

Table 2
Standard LAACC Measurement Results for Waste Pit 2

Sample ID	Sample Location	East Coordinate (ft.)	North Coordinate (ft.)	Radon-Flux Density ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P2-001-111891	P2-001	2108	-1202	0.7
P2-002-111891	P2-002	2090	-1191	0.4
P2-003-111891	P2-003	2072	-1181	0.2
P2-004-111891	P2-004	2053	-1170	0.3
P2-005-111891	P2-005	2035	-1160	0.2
P2-006-111891	P2-006	2017	-1149	0.5
P2-007-111891	P2-007	1999	-1139	0.4
P2-008-111891	P2-008	1981	-1128	0.8[a]
P2-009-111891	P2-009	2098	-1220	0.3
P2-010-111891	P2-010	2079	-1210	0.3
P2-011-111891	P2-011	2061	-1199	0.5
P2-012-111891	P2-012	2043	-1189	0.3
P2-013-111891	P2-013	2025	-1178	0.2
P2-014-111891	P2-014	2007	-1168	0.8
P2-015-111891	P2-015	1988	-1157	0.8
P2-016-111891	P2-016	1970	-1147	0.8
P2-017-111891	P2-017	2087	-1238	0.4
P2-018-111891	P2-018	2069	-1228	0.8
P2-019-111891	P2-019	2051	-1217	1.2
P2-020-111891	P2-020	2032	-1207	0.9
P2-021-111891	P2-021	2014	-1196	0.6
P2-022-111891	P2-022	1996	-1186	1.0
P2-023-111891	P2-023	1978	-1175	3.3
P2-024-111891	P2-024	1960	-1165	6.1
P2-025-111891	P2-025	2077	-1256	1.2
P2-026-111891	P2-026	2058	-1246	2.8
P2-027-111891	P2-027	2040	-1235	3.8
P2-028-111891	P2-028	2022	-1225	0.5
P2-029-111891	P2-029	2004	-1214	0.6
P2-030-111891	P2-030	1986	-1204	1.3
P2-031-111891	P2-031	1967	-1193	0.9
P2-032-111891	P2-032	1949	-1183	5.5
P2-033-111891	P2-033	1931	-1172	3.2
P2-034-111891	P2-034	2066	-1275	1.1
P2-035-111891	P2-035	2048	-1264	0.8
P2-036-111891	P2-036	2030	-1254	1.7
P2-037-111891	P2-037	2011	-1243	1.0
P2-038-111891	P2-038	1993	-1233	0.9
P2-039-111891	P2-039	1975	-1222	0.3
P2-040-111891	P2-040	1957	-1212	0.4
P2-041-111891	P2-041	1939	-1201	2.1
P2-042-111891	P2-042	1921	-1191	2.3
P2-043-111891	P2-043	2056	-1293	0.7
P2-044-111891	P2-044	2037	-1282	0.5
P2-045-111891	P2-045	2019	-1272	1.2
P2-046-111891	P2-046	2001	-1261	2.0
P2-047-111891	P2-047	1983	-1251	0.3
P2-048-111891	P2-048	1965	-1240	0.6
P2-049-111891	P2-049	1946	-1230	2.9
P2-050-111891	P2-050	1928	-1219	0.6

[a]Measurement conducted outside waste pit boundary.

Table 2 (continued)
Standard LAACC Measurement Results
for Waste Pit 2

Sample ID	Sample Location	East Coordinate (ft.)	North Coordinate (ft.)	Radon-Flux Density ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P2-051-111891	P2-051	1910	-1209	1.2
P2-052-111891	P2-052	2045	-1311	0.6
P2-053-111891	P2-053	2027	-1301	0.8
P2-054-111891	P2-054	2009	-1290	0.6
P2-055-111891	P2-055	1990	-1280	0.9
P2-056-111891	P2-056	1972	-1269	1.1
P2-057-111891	P2-057	1954	-1259	8.5
P2-058-111891	P2-058	1936	-1248	3.6
P2-059-111891	P2-059	1918	-1238	0.9
P2-060-111891	P2-060	1900	-1227	8.8
P2-061-111891	P2-061	1881	-1217	18.8
P2-062-111891	P2-062	2035	-1329	1.9[b]
P2-063-111891	P2-063	2016	-1319	2.4
P2-064-111891	P2-064	1998	-1308	2.1
P2-065-111891	P2-065	1980	-1298	2.8
P2-066-111891	P2-066	1962	-1287	2.1
P2-067-111891	P2-067	1944	-1277	6.3
P2-068-111891	P2-068	1925	-1266	81.0
P2-069-111891	P2-069	1907	-1256	5.6
P2-070-111891	P2-070	1889	-1245	3.9
P2-071-111891	P2-071	2024	-1347	0.6
P2-072-111891	P2-072	2006	-1337	6.6
P2-073-111891	P2-073	1988	-1326	6.5
P2-074-111891	P2-074	1969	-1316	2.8
P2-075-111891	P2-075	1951	-1305	5.2
P2-076-111891	P2-076	1933	-1295	12.5
P2-077-111891	P2-077	1915	-1284	65.7
P2-078-111891	P2-078	1897	-1274	10.0
P2-079-111891	P2-079	1879	-1263	2.1
P2-080-111891	P2-080	2014	-1366	3.0
P2-081-111891	P2-081	1995	-1355	15.7
P2-082-111891	P2-082	1977	-1345	42.3
P2-083-111891	P2-083	1959	-1334	3.5
P2-084-111891	P2-084	1941	-1324	10.2
P2-085-111891	P2-085	1923	-1313	12.6
P2-086-111891	P2-086	1904	-1303	4.8
P2-087-111891	P2-087	1886	-1292	3.4
P2-088-111891	P2-088	2003	-1384	5.9
P2-089-111891	P2-089	1985	-1373	65.0
P2-090-111891	P2-090	1967	-1363	27.6
P2-091-111891	P2-091	1948	-1352	6.6
P2-092-111891	P2-092	1930	-1342	18.5
P2-093-111891	P2-093	1912	-1331	29.0
P2-094-111891	P2-094	1894	-1321	2.4
P2-095-111891	P2-095	1876	-1310	2.3
P2-096-111891	P2-096	1993	-1402	3.8
P2-097-111891	P2-097	1974	-1391	26.4
P2-098-111891	P2-098	1956	-1381	5.1
P2-099-111891	P2-099	1938	-1370	8.1
P2-100-111891	P2-100	1920	-1360	2.6

[b]Seal around LAACC disturbed during exposure.

Table 3
Standard LAACC Measurement Results
for Waste Pit 3

Sample ID	Sample Location	East Coordinate (ft.)	North Coordinate (ft.)	Radon-Flux Density ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P3-001-111491	P3-001	1383	-1313	1.3
P3-002-111491	P3-002	1407	-1362	1.4
P3-003-111491	P3-003	1407	-1313	0.7
P3-004-111491	P3-004	1407	-1264	0.8
P3-005-111491	P3-005	1407	-1215	0.9
P3-006-111491	P3-006	1407	-1166	0.6
P3-007-111491	P3-007	1456	-1362	1.9
P3-008-111491	P3-008	1456	-1313	1.0
P3-009-111491	P3-009	1456	-1264	10.4
P3-010-111491	P3-010	1456	-1215	1.2
P3-011-111491	P3-011	1456	-1166	2.3
P3-012-111491	P3-012	1456	-1117	0.6
P3-013-111491	P3-013	1505	-1362	1.1
P3-014-111491	P3-014	1505	-1313	0.7
P3-015-111491	P3-015	1505	-1264	1.7
P3-016-111491	P3-016	1505	-1215	0.5
P3-017-111491	P3-017	1505	-1166	0.7
P3-018-111491	P3-018	1505	-1117	0.4
P3-019-111491	P3-019	1505	-1068	1.0
P3-020-111491	P3-020	1554	-1362	3.2
P3-021-111491	P3-021	1554	-1313	1.1
P3-022-111491	P3-022	1554	-1264	22.4
P3-023-111491	P3-023	1554	-1215	1.4
P3-024-111491	P3-024	1554	-1166	1.3
P3-025-111491	P3-025	1554	-1117	0.6
P3-026-111491	P3-026	1554	-1068	1.0
P3-027-111491	P3-027	1603	-1264	1.1
P3-028-111491	P3-028	1603	-1215	48.0
P3-029-111491	P3-029	1603	-1166	0.7
P3-030-111491	P3-030	1603	-1117	0.4
P3-031-111491	P3-031	1603	-1068	0.4
P3-032-111491	P3-032	1603	-1034	1.0
P3-033-111491	P3-033	1603	-970	14.2
P3-034-111491	P3-034	1652	-1264	0.9
P3-035-111491	P3-035	1652	-1215	11.1
P3-036-111491	P3-036	1652	-1166	2.3
P3-037-111491	P3-037	1652	-1117	0.7
P3-038-111491	P3-038	1652	-1068	0.7
P3-039-111491	P3-039	1652	-1019	1.2
P3-040-111491	P3-040	1652	-970	15.0
P3-041-111491	P3-041	1652	-921	1.4
P3-042-111491	P3-042	1652	-872	0.6
P3-043-111491	P3-043	1652	-823	0.3
P3-044-111491	P3-044	1701	-1215	0.7
P3-045-111491	P3-045	1701	-1166	5.5
P3-046-111491	P3-046	1701	-1117	0.7
P3-047-111491	P3-047	1701	-1068	1.7
P3-048-111491	P3-048	1701	-1019	5.7
P3-049-111491	P3-049	1701	-970	2.2
P3-050-111491	P3-050	1701	-921	0.6

Table 3 (continued)
Standard LAACC Measurement Results
for Waste Pit 3

Sample ID	Sample Location	East Coordinate (ft.)	North Coordinate (ft.)	Radon-Flux Density ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P3-051-111491	P3-051	1701	-872	0.3
P3-052-111491	P3-052	1701	-829	0.8
P3-053-111491	P3-053	1701	-774	0.5
P3-054-111491	P3-054	1750	-1215	1.1
P3-055-111491	P3-055	1750	-1166	0.6
P3-056-111491	P3-056	1750	-1117	6.0
P3-057-111491	P3-057	1750	-1068	5.1
P3-058-111491	P3-058	1750	-1019	0.8
P3-059-111491	P3-059	1750	-970	0.5
P3-060-111491	P3-060	1750	-921	0.5
P3-061-111491	P3-061	1750	-872	0.8
P3-062-111491	P3-062	1750	-823	1.0
P3-063-111491	P3-063	1750	-774	0.6
P3-064-111491	P3-064	1799	-1166	1.4
P3-065-111491	P3-065	1799	-1117	1.2
P3-066-111491	P3-066	1799	-1068	20.6
P3-067-111491	P3-067	1799	-1019	20.8
P3-068-111491	P3-068	1799	-970	0.9
P3-069-111491	P3-069	1799	-921	0.6
P3-070-111491	P3-070	1799	-872	0.9
P3-071-111491	P3-071	1799	-823	0.3
P3-072-111491	P3-072	1799	-774	0.8
P3-073-111491	P3-073	1848	-1166	0.8
P3-074-111491	P3-074	1848	-1117	0.5
P3-075-111491	P3-075	1848	-1068	0.6
P3-076-111491	P3-076	1848	-1019	0.6
P3-077-111491	P3-077	1848	-970	0.4
P3-078-111491	P3-078	1848	-921	0.6
P3-079-111491	P3-079	1848	-872	0.6
P3-080-111491	P3-080	1848	-823	0.3
P3-081-111491	P3-081	1897	-1117	5.3
P3-082-111491	P3-082	1897	-1068	1.5
P3-083-111491	P3-083	1897	-1019	0.6
P3-084-111491	P3-084	1897	-970	0.3
P3-085-111491	P3-085	1897	-921	0.9
P3-086-111491	P3-086	1897	-872	0.3
P3-087-111491	P3-087	1897	-823	0.4
P3-088-111491	P3-088	1946	-1117	1.3
P3-089-111491	P3-089	1946	-1068	0.6
P3-090-111491	P3-090	1946	-1019	0.3
P3-091-111491	P3-091	1946	-970	0.6
P3-092-111491	P3-092	1946	-921	0.8
P3-093-111491	P3-093	1946	-872	0.3
P3-094-111491	P3-094	1946	-823	0.3
P3-095-111491	P3-095	1995	-1019	0.7
P3-096-111491	P3-096	1995	-970	0.3
P3-097-111491	P3-097	1995	-921	0.4
P3-098-111491	P3-098	1995	-872	0.9
P3-099-111491	P3-099	1995	-823	0.4
P3-100-111491	P3-100	2044	-872	0.5

Table 4 gives a summary of the Standard LAACC Measurement results. Samples P1-014-112191, P1-015-112191, and P1-020-112191 were situated on a section of paved roadway that crosses the southern portion of Waste Pit 1. The radon transport properties of the roadway are considered atypical compared to the remainder of the waste pit covering. Therefore, these samples were excluded from the summary calculations.

Samples P2-008-111891 and P2-062-111891 were also excluded from the summary calculations. Sample P2-008-111891 was excluded because it was later determined to be outside the waste pit boundary. During the retrieval of the LAACCs from Waste Pit 2, it was noted that sample P2-062-111891 had been disturbed, and the sand seal was not intact. This sample was, therefore, considered invalid.

All Standard LAACC results from Waste Pit 3 are considered valid.

As shown in Table 4, the arithmetic mean of the measured radon-flux for each of the three pits is well below the National Emission Standards for Hazardous Air Pollutants (NESHAP) emission limit of 20 $pCi \cdot m^{-2} \cdot sec^{-1}$ for ^{222}Rn. It is also significant to note that the upper limit of the 99 percent confidence interval of the mean lies well below the NESHAP limit for all three pits.

Table 4
Summary of Standard LAACC Measurements[a]

	Waste Pit 1	Waste Pit 2	Waste Pit 3
Number of Samples	99[b]	98[c]	100
Arithmetic Mean	9.1	6.4	2.6
Median	3.3	2.1	0.8
Mode	3.3	2.1	0.8
Geometric Mean	4.5	2.1	1.0
Variance	180.5	180.5	39.0
Standard Deviation	13.4	13.4	6.2
Standard Error	1.4	1.4	0.6
Minimum	0.6	0.2	0.3
Maximum	75.2	81.0	48.0
Range	74.6	80.8	47.7
99 percent Confidence Interval of the Mean	5.6 - 12.7	2.9 - 9.9	1.0 - 4.2
Pit Area in m^2	7,430	4,460	22,300

[a]All values are given in units of $pCi \cdot m^{-2} \cdot sec^{-1}$ unless otherwise noted.

[b]Samples P1-014-112191, P1-015-112191, and P1-020-112191 were excluded from the summary calculations.

[c]Samples P2-008-111891 and P2-062-111891 were excluded from the summary calculations.

Figures 6, 8, and 10 show radon-flux density contour maps of Waste Pits 1, 2, and 3, respectively. Figures 7, 9, and 11 show surface trend maps of the radon-flux data for Waste Pits 1, 2, and 3, respectively.

Most of the area of Pit 1 is occupied by the 0 to 10 $pCi \cdot m^{-2} \cdot sec^{-1}$ contour interval. Three areas of elevated radon-flux stand apart from this. The most significant of these areas lies on the western boundary of the pit, adjacent to the Clear Well. Interestingly, this corresponds to a change in topographic slope of the pit edge. This observation may warrant further investigation into the stability of the cover on the west side of the pit.

The bulk of Pit 2 (Figure 8) is occupied by the 0 to 10 $pCi \cdot m^{-2} \cdot sec^{-1}$ contour interval. Two areas of higher flux measurements occur in the southwestern portion of the pit. Although the highest value (81 $pCi \cdot m^{-2} \cdot sec^{-1}$) occurs here, the areal extent of this feature is limited; near background values are found within approximately 6 to 7 m to the northwest, north, and southeast. No obvious differences in the cover of the pit were noticed during the field activities that coincide with these regions of high flux.

In general, the radon-flux density values measured on Waste Pit 3 were much lower than those measured on Pits 1 and 2. Figure 10 shows that the bulk of the area of Pit 3 is occupied by the 0 to 10 $pCi \cdot m^{-2} \cdot sec^{-1}$ contour interval with only two regions, again of limited areal extent, showing elevated radon-flux measurements.

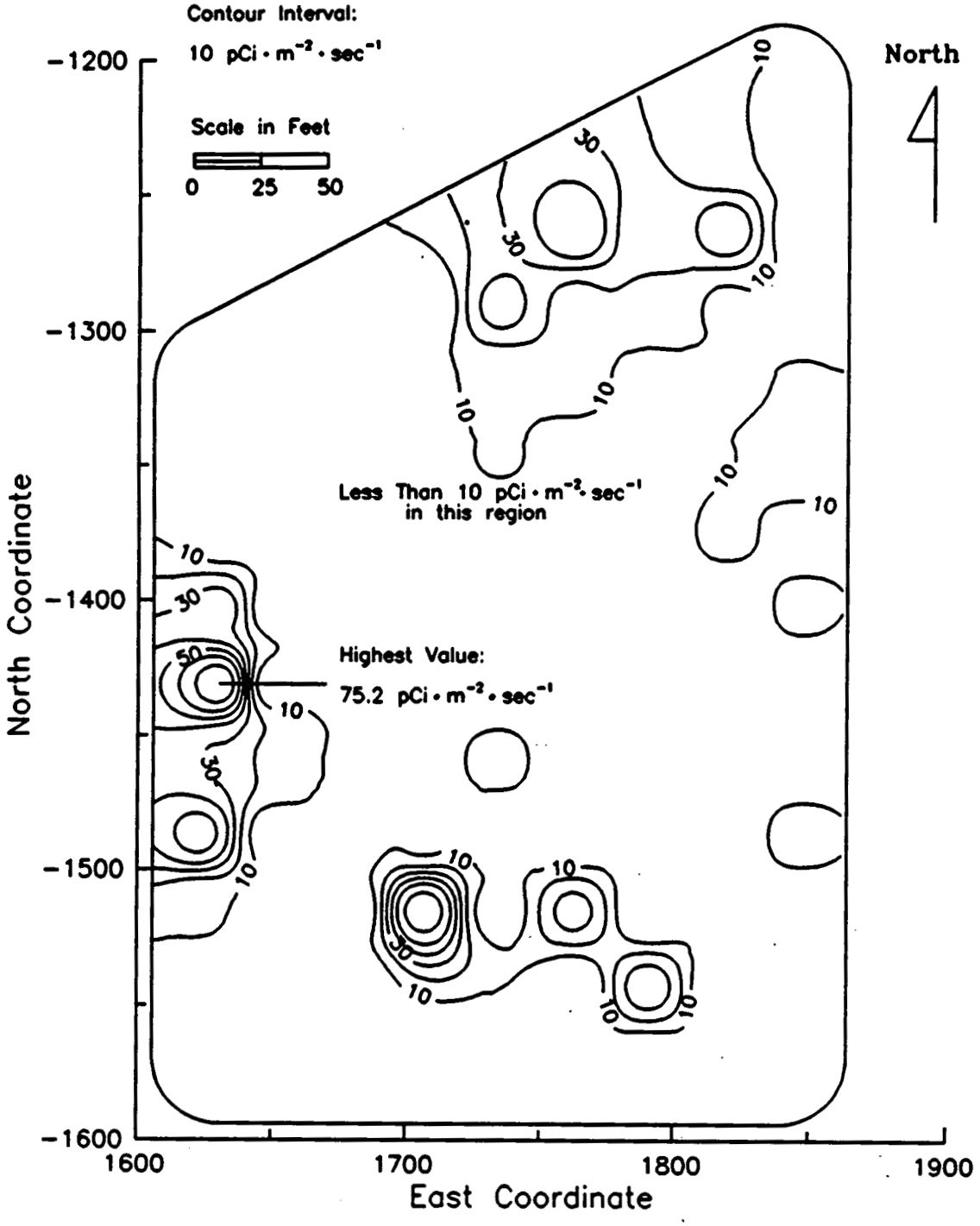

Figure 6. Contour map of the measured radon-flux density for Waste Pit 1. The contour interval is 10 $pCi \cdot m^{-2} \cdot sec^{-1}$.

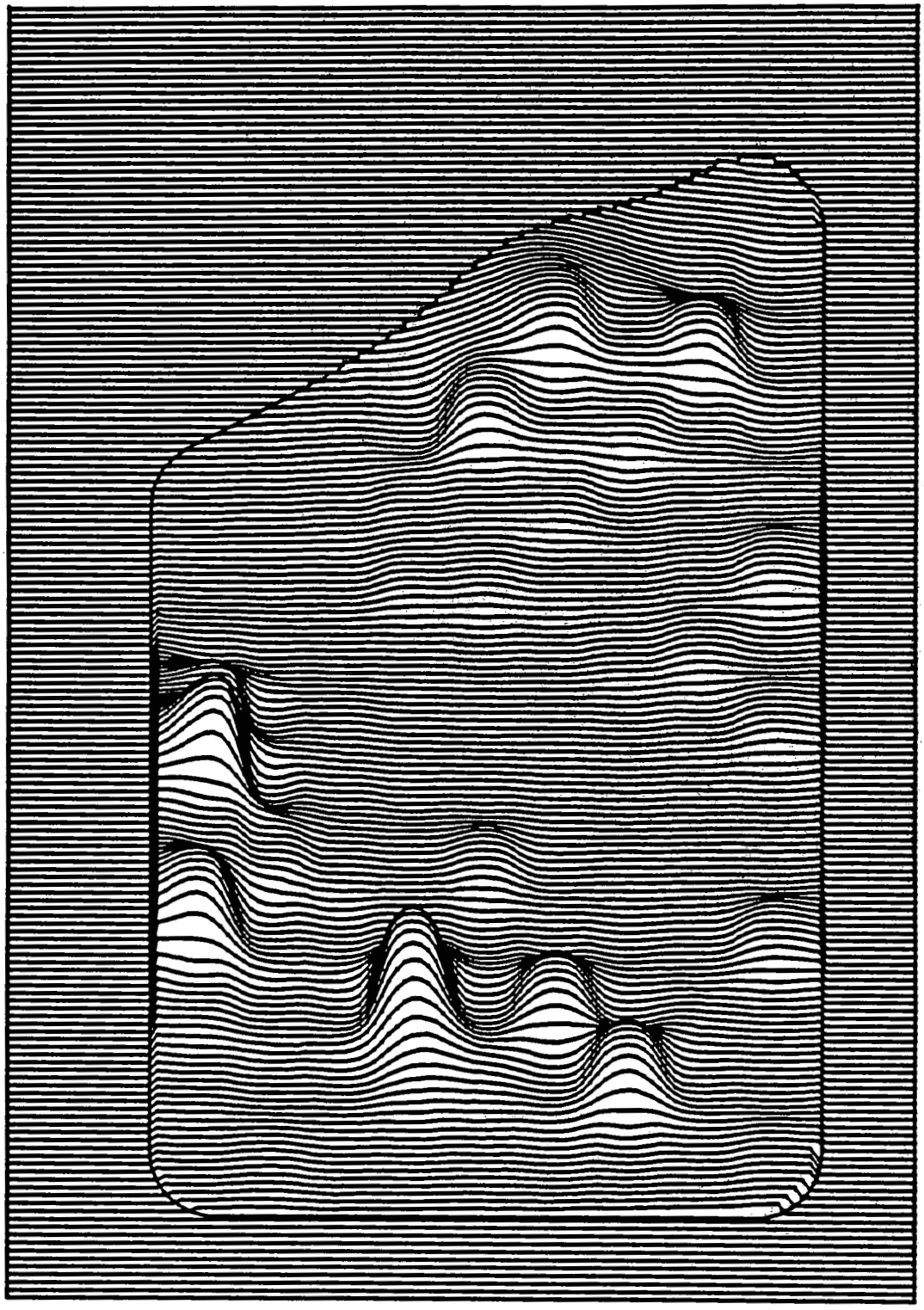

Figure 7. Surface trend of the measured radon-flux density for Waste Pit 1. The view is from a high angle, looking north.

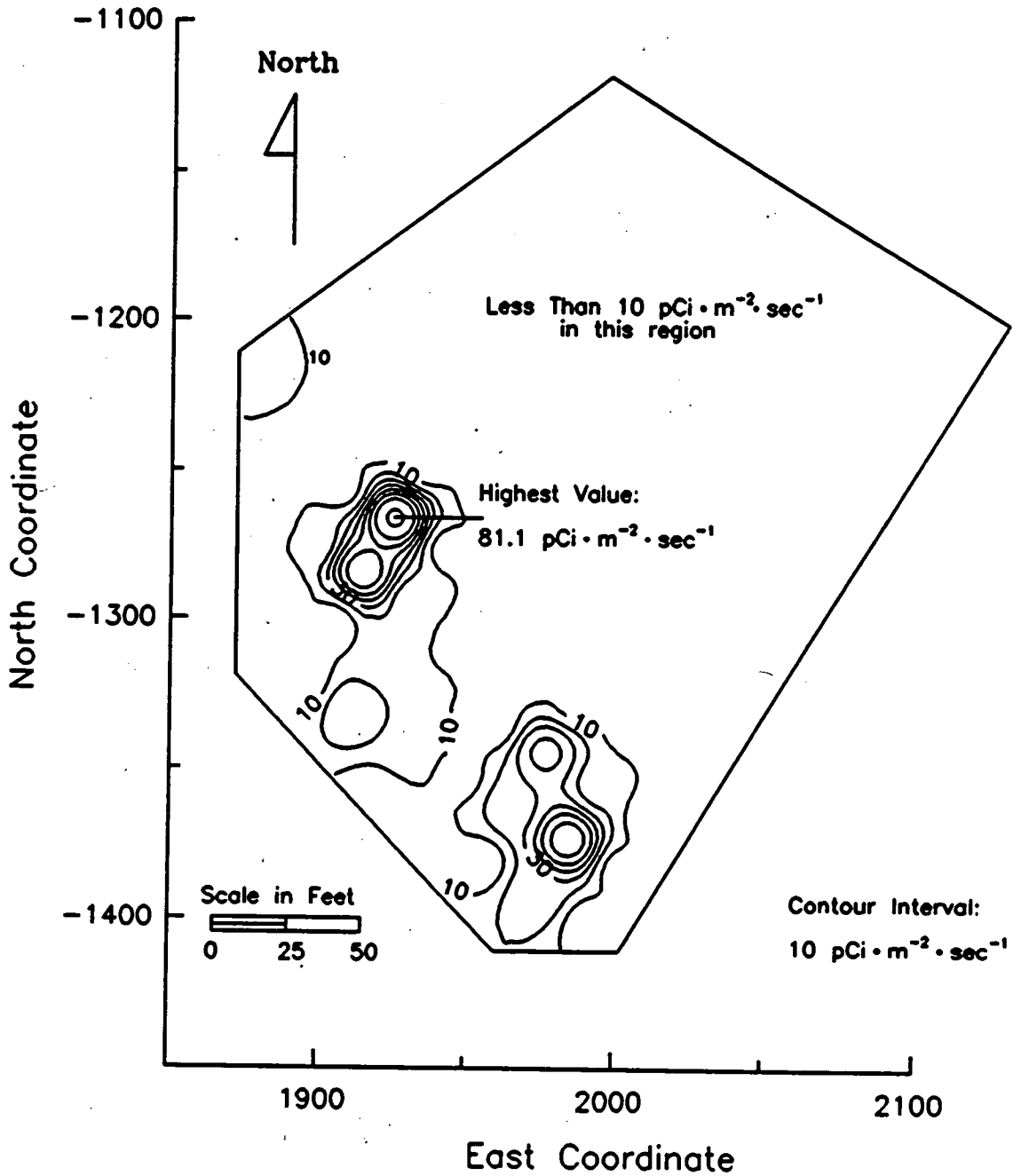

Figure 8. Contour map of the measured radon-flux density for Waste Pit 2. The contour interval is 10 $pCi \cdot m^{-2} \cdot sec^{-1}$.

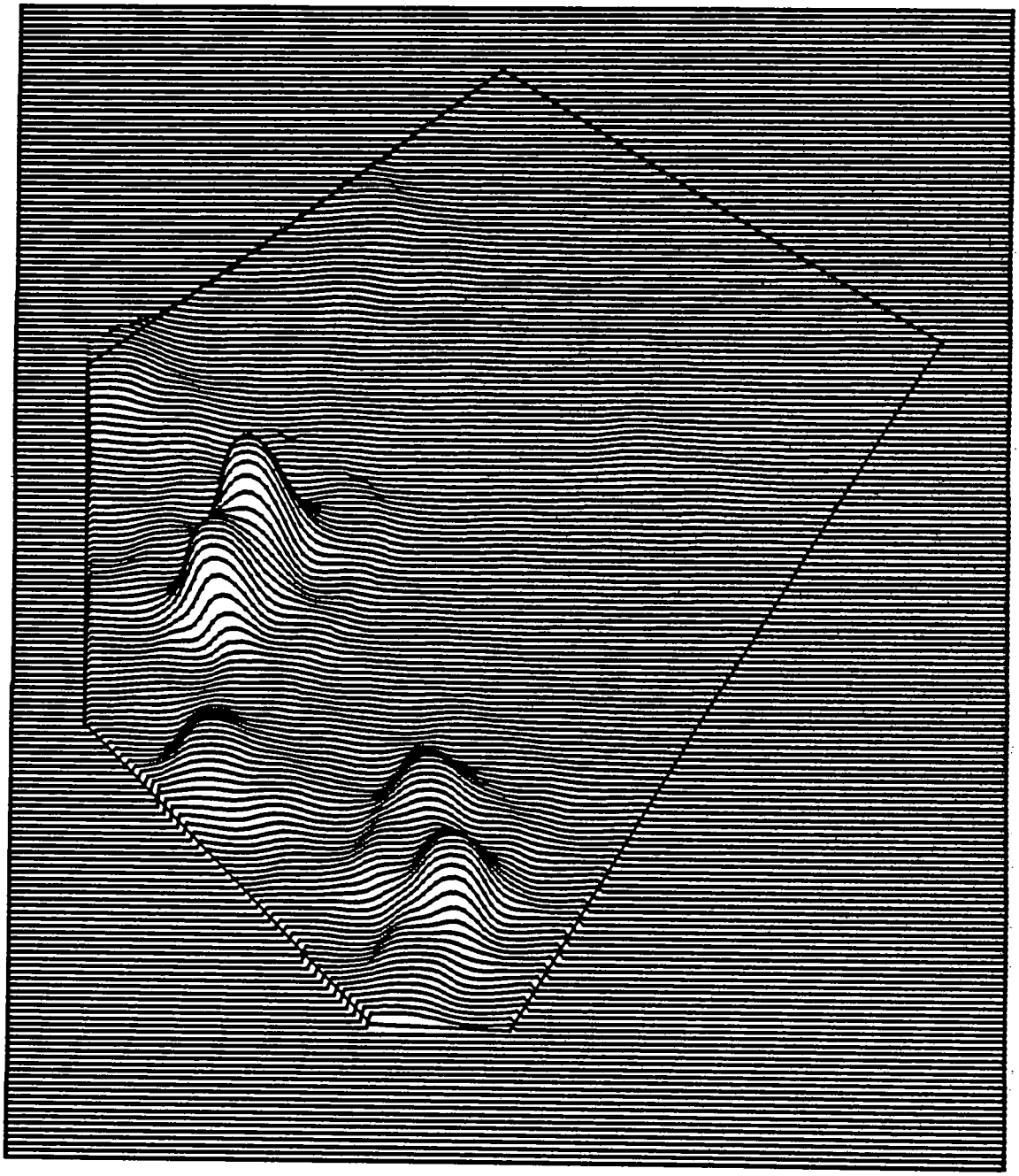

Figure 9. Surface trend of the radon flux-density for Waste Pit 2. The view is from a high angle looking north.

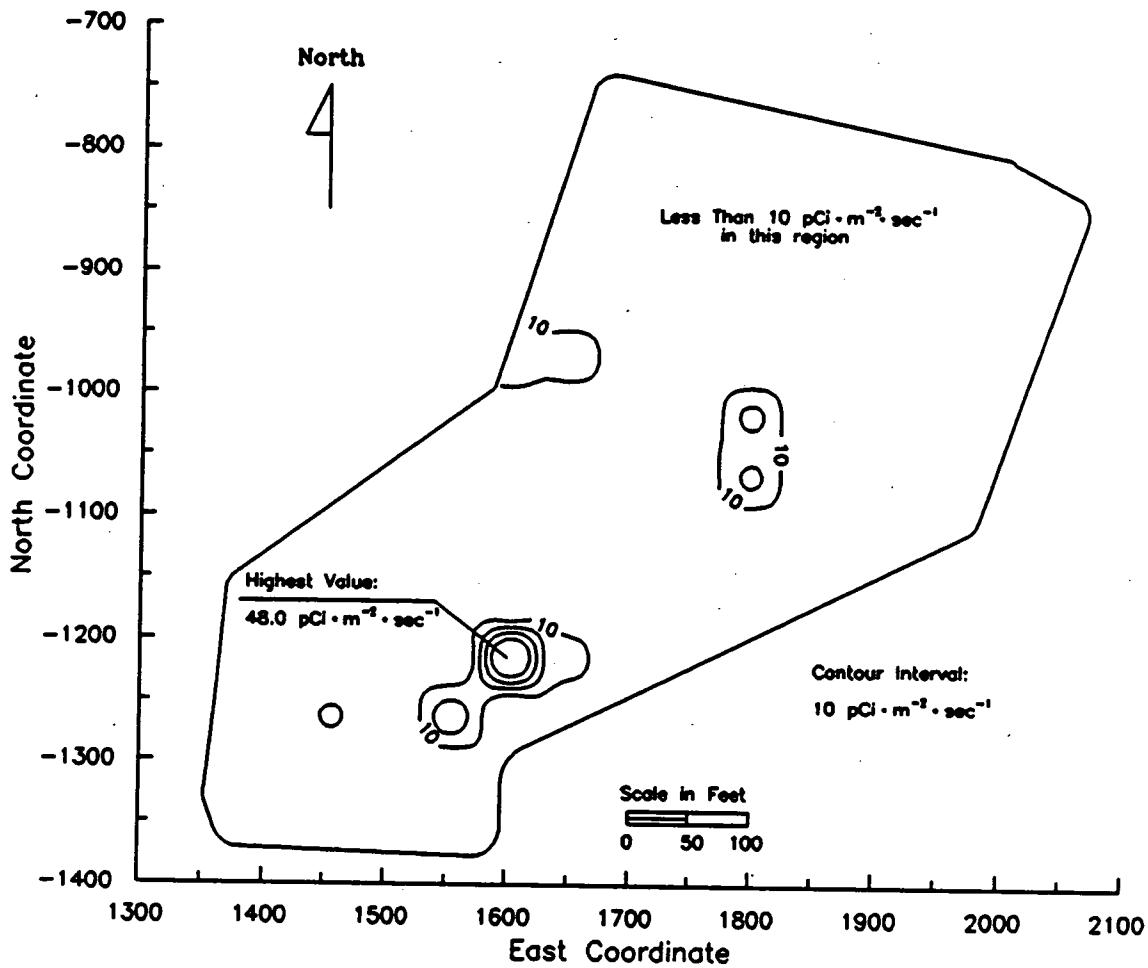

Figure 10. Contour map of the measured radon-flux density for Waste Pit 3. The contour interval is 10 $pCi \cdot m^{-2} \cdot sec^{-1}$.

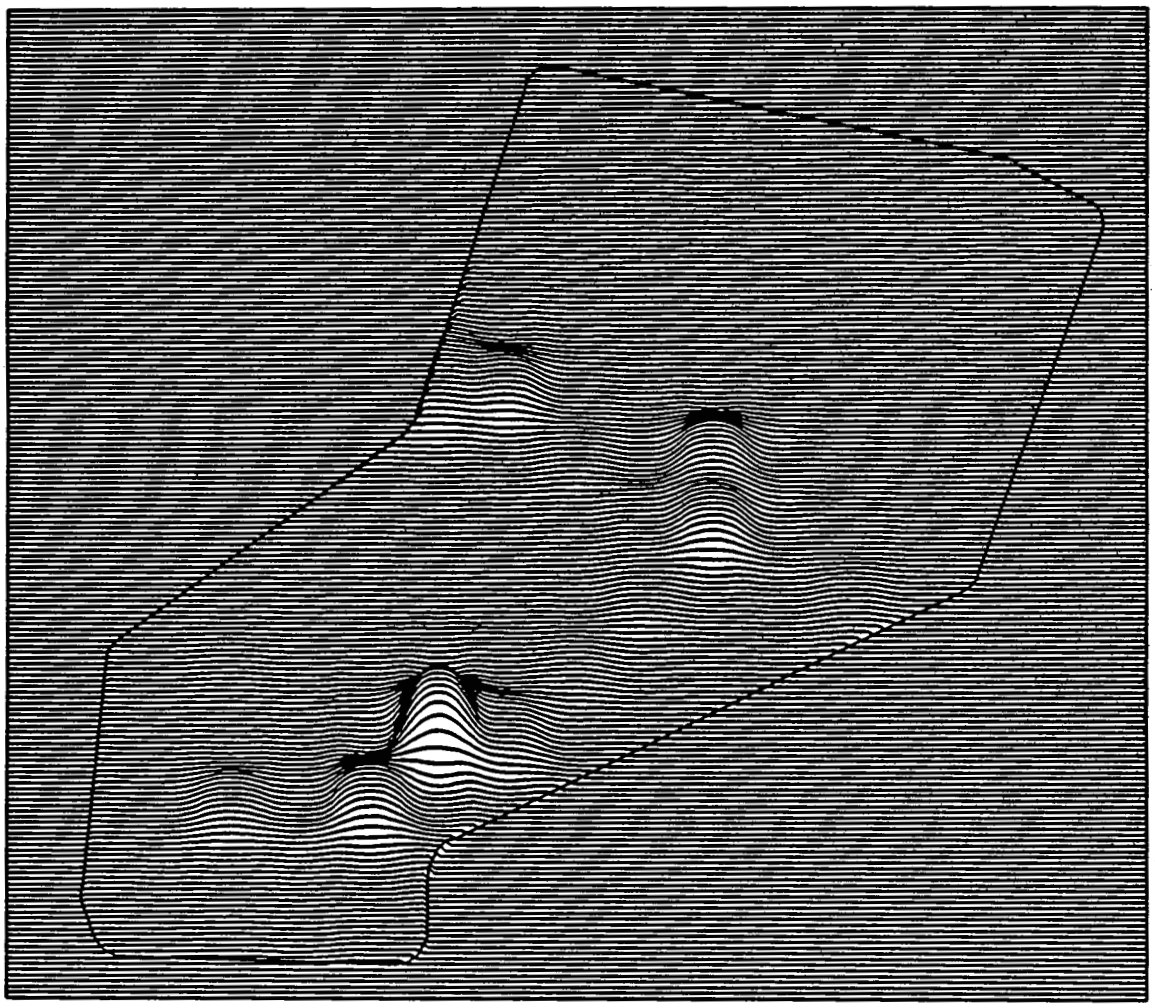

Figure 11. Surface trend of the measured radon-flux density for Waste Pit 3. The view is from a high angle looking north.

Precision and Accuracy

To assess the precision of the gamma counting technique, approximately 10 percent of the LAACC samples were counted twice. As directed by the procedure RN-FLUX-U, these recounts were performed at the end of the scheduled counting for the day, because the most significant factor affecting the precision of the counting system is a temperature driven shift of the gamma spectrum. By recounting the samples at the end of the workday the temperature change is maximized, and the potential differences in the results are also maximized.

The data quality objectives stated at the outset of the project were to produce analytical results with a precision within 10 percent for samples having measured radon-flux densities of 1 $pCi \cdot m^{-2} \cdot sec^{-1}$ or greater.

Tables 5, 6, and 7 list the recount results for the LAACC samples from Waste Pits 1, 2, and 3, respectively. All values given in these three tables, except the relative precision, are in units of $pCi \cdot m^{-2} \cdot sec^{-1}$. The relative precision listed in the tables is determined by expressing the difference between the two count results divided by their mean as a percentage. All of the samples exhibiting measurements above 1 $pCi \cdot m^{-2} \cdot sec^{-1}$ show relative precisions within the 10 percent target limit.

Table 5[a]
Recount Results for LAACC Samples for Waste Pit 1

Sample ID	Count No. 1	Count No. 2	Mean	Relative Precision (%)
P1-010-112191	2.28	2.30	2.29	-0.9
P1-020-112191	0.46	0.42	0.44	9.1
P1-030-112191	0.76	0.76	0.76	0.0
P1-040-112191	1.33	1.37	1.35	-3.0
P1-050-112191	3.07	3.07	3.07	0.0
P1-060-112191	2.41	2.31	2.36	4.2
P1-070-112191	2.30	2.28	2.29	0.9
P1-080-112191	0.93	0.95	0.94	-2.1
P1-090-112191	0.70	0.71	0.71	-1.4
P1-100-112191	47.42	46.51	46.96	1.9
P1-068-A-112191	2.59	2.49	2.54	3.9
P1-CCC-112191[b]	-0.02	-0.02	-0.02	0.0

[a]All values are given in units of $pCi \cdot m^{-2} \cdot sec^{-1}$ unless otherwise noted.
[b]P1-CCC-112191 is a blank sample

Table 6[a]
Recount Results for LAACC Samples for Waste Pit 2

Sample ID	Count No. 1	Count No. 2	Mean	Relative Precision (%)
P2-010-111891	0.33	0.32	0.33	3.1
P2-020-111891	0.92	0.94	0.93	-2.2
P2-025-111891	1.19	1.19	1.19	0.0
P2-030-111891	1.32	1.33	1.33	-0.8
P2-040-111891	0.42	0.44	0.43	-4.6
P2-050-111891	0.53	0.57	0.55	-7.3
P2-060-111891	8.84	8.82	8.83	0.2
P2-070-111891	3.94	3.92	3.93	0.5
P2-080-111891	2.94	3.02	2.98	-2.7
P2-090-111891	27.49	27.64	27.57	-0.5
P2-100-111891	2.66	2.64	2.65	0.8
P2-079-A-111891	3.07	3.04	3.06	1.0
P2-EEE-111891[b]	0.00	0.00	0.00	0.0

[a]All values are given in units of $pCi \cdot m^{-2} \cdot sec^{-1}$ unless otherwise noted.
[b]P2-EEE-111891 is a blank sample

Table 7[a]
Recount Results for LAACC Samples for Waste Pit 3

Sample ID	Count No. 1	Count No. 2	Mean	Relative Precision (%)
P3-010-111491	1.11	1.19	1.15	-7.0
P3-019-111491	0.98	0.95	0.97	3.1
P3-028-111491	48.06	47.93	48.00	0.3
P3-030-111491	0.38	0.44	0.41	-14.6
P3-038-111491	0.73	0.62	0.68	16.2
P3-047-111491	1.71	1.75	1.73	-2.3
P3-056-111491	5.99	6.00	6.00	-0.2
P3-FFF-111491[b]	0.06	0.00	0.03	200
P3-075-111491	0.63	0.61	0.62	3.2
P3-082-111491	1.46	1.54	1.50	-5.3
P3-084-111491	0.29	0.36	0.32	-21.2
P3-094-111491	0.36	0.31	0.33	14.7
P3-022-A-111491	19.32	19.12	19.22	1.0

[a]All values are given in units of $pCi \cdot m^{-2} \cdot sec^{-1}$ unless otherwise noted.
[b]P3-FFF-111491 is a blank sample

To ensure that the data being collected during the counting were valid, and to assess the accuracy of the counting system, two calibration standards were counted both before and after each day's scheduled counting. A detailed description of the fabrication of these standards may be found in the Radon Laboratory Technical Procedure "Calibration of a Computer Automated Gamma Counting System for Radon Flux Measurements" RN-FLUX-C (Appendix A).

In brief, each standard was made by quantitatively transferring and uniformly distributing a liquid ^{226}Ra standard solution over 180 grams of activated charcoal. The activated charcoal was transferred into a sample can identical to that used for the field samples, and allowed to grow into equilibrium for a period of at least 30 days prior to use.

Two different radium standard solutions were used. One was prepared from a National Institute of Standards and Technology (NIST) ^{226}Ra solution (SRM 4953-C) with an activity of 43,500 pCi of ^{226}Ra; the second standard was prepared from an Isotope Products Liquid ^{226}Ra solution (IP-388-7) with an activity of 107,900 pCi of ^{226}Ra. For each ROI, the calibration constants determined from the two standards differed by approximately 2.5 percent. This is well within the combined uncertainties of the two standards, 1.32 percent for the NIST standard and 3.7 percent for the Isotope Products standard. The calibration constants used were obtained by averaging the individual calibration constants, for each ROI, derived from these two standards.

Analyses of the standards were used as point indicators of the accuracy of the counting system. In effect they were being used as check sources to identify potential problems with the system operation. Table 8 presents the analytical results of these two calibration standards. The indicated bias is computed by expressing, as a percentage, the difference of the measured activity from the certified activity divided by the certified activity. These results indicate that the counting system performed within the target accuracy limits, ± 10 percent.

Table 8
Results from Analysis of Calibration Standards

Standard	Date Counted	Time Counted (MST)	Measured Activity (pCi)	Indicated Bias (%)	Counted with Samples from
IP-388-7	11-26-91	10:40	107,934	0.03	Pit 1
SRM 4953-C	11-26-91	10:46	44,122	1.3	Pit 1
SRM 4953-C	11-26-91	16:42	44,217	1.6	Pit 1
IP-388-7	11-26-91	16:48	107,332	-0.5	Pit 1
SRM 4953-C	11-27-91	06:18	45,014	3.4	Pit 1
IP-388-7	11-27-91	06:24	107,736	-0.2	Pit 1
SRM 4953-C	11-27-91	14:27	44,985	3.3	Pit 1
IP-388-7	11-27-91	14:33	108,914	0.9	Pit 1
IP-388-7	11-22-91	13:51	107,185	-0.7	Pit 2
SRM 4953-C	11-22-91	13:58	44,563	2.3	Pit 2
IP-388-7	11-22-91	17:54	106,839	-1.0	Pit 2
SRM 4953-C	11-22-91	18:00	43,954	0.9	Pit 2
IP-388-7	11-25-91	07:09	107,346	-0.5	Pit 2
SRM 4953-C	11-25-91	07:15	44,367	1.9	Pit 2
IP-388-7	11-25-91	18:13	106,622	-1.2	Pit 2
SRM 4953-C	11-25-91	18:19	44,359	1.9	Pit 2
IP-388-7	11-21-91	08:51	106,894	-0.9	Pit 3
SRM 4953-C	11-21-91	08:57	44,436	2.1	Pit 3
SRM 4953-C	11-21-91	21:57	44,124	1.3	Pit 3
IP-388-7	11-21-91	22:03	107,543	-0.3	Pit 3
IP-388-7	11-22-91	08:10	106,392	-1.4	Pit 3
SRM 4953-C	11-22-91	08:16	44,328	1.8	Pit 3
SRM 4953-C	11-22-91	13:02	44,458	2.1	Pit 3
IP-388-7	11-22-91	13:09	107,727	-0.2	Pit 3

Another means of checking proper system operation was the analysis of blank charcoal samples. As described earlier, 6 blanks were prepared and incorporated into the standard LAACC samples from each waste pit. These blanks were analyzed in the same manner as the other LAACC samples. The results of these analyses are presented in Table 9. The detection limit of this analytical technique is estimated to be approximately 0.1 $pCi \cdot m^{-2} \cdot sec^{-1}$ for these samples. The analysis of the blank charcoal samples show results that are well below the detection limit, and reasonably uniformly distributed about zero. These results demonstrate the absence of any significant measurement bias in the LAACC results.

Table 9
Results of Blank Charcoal Sample Analysis

Sample ID	Measurement Result ($pCi \cdot m^{-2} \cdot sec^{-1}$)	Sample ID	Measurement Result ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P1-AAA-112191	0.01	P1-DDD-112191	0.00
P1-BBB-112191	-0.02	P1-EEE-112191	0.00
P1-CCC-112191	-0.02	P1-FFF-112191	-0.02
P2-AAA-111891	0.01	P2-DDD-111891	0.01
P2-BBB-111891	0.01	P2-EEE-111891	0.00
P2-CCC-111891	-0.02	P2-FFF-111891	0.00
P3-AAA-111491	0.01	P3-DDD-111491	0.04
P3-BBB-111491	0.04	P3-EEE-111491	-0.01
P3-CCC-111491	0.02	P3-FFF-111491	0.03

Repeat Measurements

The five locations selected for repeat measurement on Waste Pit 3 were: P3-028, P3-047, P3-064, P3-067, and P3-089. Table 10 lists the results of these repeat measurements. The initial measurements on Waste Pit 3 were conducted on 11-14-91; The repeat measurements were conducted on 11-18-91 and again on 11-21-91.

Table 10
Results of Repeat LAACC Measurements on Waste Pit 3

Location	Column A 11-14-91 ($pCi \cdot m^{-2} \cdot sec^{-1}$)	Column B 11-18-91 ($pCi \cdot m^{-2} \cdot sec^{-1}$)	Column C 11-21-91 ($pCi \cdot m^{-2} \cdot sec^{-1}$)
P3-028	48.0	31.7	45.0
P3-047	1.7	2.9	2.4
P3-064	1.4	1.5	1.3
P3-067	20.8	17.8	23.0
P3-089	0.6	1.2	0.7

A two-tailed, paired t-test was used to determine if there were significant differences in the results for these five locations from one measurement period to another. The statistic used was the difference of the individual paired results. Three separate tests are necessary to compare the results from each measurement set with the results obtained from the other two measurement sets.

Test 1 compares the results obtained from the initial (11-14-91) measurement of Waste Pit 3 (column A in table 10) with those obtained on 11-21-91 (column C). In this case the difference (d) was computed as (column A - column C) for each of the measurement locations. Test 2 compares the initial results with those made on 11-18-91 (d = column A - column B). The third test compares the results from the 11-18-91 and the 11-21-91 measurements (column B - column C).

The null and alternative hypotheses were stated as follows:

$H_0: \mu_d = 0$ (μ_d is mean difference)
$H_a: \mu_d \neq 0$

The following results were obtained for the 95 percent Confidence level ($\alpha = 0.05$)

	Mean Difference ($pCi \cdot m^{-2} \cdot sec^{-1}$)	t-statistic	Sig. Level	Conclusion
Test 1	0.07	0.085	0.936	Fail to reject H_0
Test 2	3.46	1.055	0.351	Fail to reject H_0
Test 3	-3.39	-1.055	0.276	Fail to reject H_0

On the basis of these results it can be concluded that there are no statistically significant differences in the results obtained during the three different measurement periods. However, because of the small sample size, the uncertainty in the mean difference is large, which diminishes the ability of the test to detect real differences in the data pairs, that are small compared to the variability of the difference.

Control Measurements

The assumption that two LAACCs placed within 2 m of each other would measure the same radon-flux density, with no accumulator present, was in fact a poor assumption. The Standard and Control LAACCs were placed no closer than 2 m to ensure that the presence of the accumulator tub would not interfere with the Standard LAACC result. Table 11 shows the results of the Control Measurements, both the radon-flux and charcoal canister radon measurements, for all three waste pits.

A significant number of locations exhibited radon-flux values measured under the accumulators lower than the values measured by the paired Standard LAACCs, (Table 11). This is probably the result of the extremely high spatial variability of the radon-flux values. For example, location P1-054 had the highest value measured on Pit 1 (75.2 $pCi \cdot m^{-2} \cdot sec^{-1}$), while an adjacent sample P1-053 had a measurement result of only 3.3 $pCi \cdot m^{-2} \cdot sec^{-1}$.

Because of the significant number of locations that exhibited negative increases in the measured radon-flux under the accumulators, a meaningful correction factor could not be determined for any of the waste pits. However, the need to apply correction factors was absent, because the measurements were conducted during periods of normal atmospheric radon levels. The average outdoor radon concentration, as measured by the diffusion barrier charcoal canisters, for Waste Pits 1, 2, and 3 was 1.7, 0.3, and 0.4 pCi/L, respectively. Therefore no correction of the Standard LAACC results was made.

Table 11
Control Measurement Results
Waste Pits 1, 2, and 3

Location	Standard LAACC (J_S)	Control LAACC (J_A)	Flux Difference (J_A - J_S)	DBCC Outside (C_S)	DBCC Inside (C_A)	DBCC Difference (C_A - C_S)	Correction Factor (F)
P1-009	2.7	3.8	1.1	2.9	70.0	67.1	0.02
P1-011	2.2	4.0	1.8	2.3	142.1	139.8	0.01
P1-012	34.3	5.7	-28.6	2.4	185.2	182.8	-0.16
P1-027	11.0	8.1	-2.9	2.7	174.6	171.9	-0.02
P1-033	7.2	8.7	1.5	0.6	99.0	98.4	0.02
P1-055	12.1	13.3	1.2	0.0	156.0	156.0	0.01
P1-056	2.9	2.3	-0.6	1.2	33.1	31.9	-0.02
P1-061	5.5	14.1	8.6	0.9	396.1	395.2	0.02
P1-068	0.8	2.5	1.7	1.8	28.7	26.9	0.06
P1-072	4.4	2.3	-2.1	1.7	23.3	21.6	-0.10
P2-007	0.4	0.7	0.3	0.5	3.4	2.9	0.10
P2-008	0.8	1.0	0.2	-0.2	8.3	8.5	0.02
P2-021	0.6	0.8	0.2	1.0	1.9	0.9	0.22
P2-026	2.8	1.9	-0.9	0.2	7.0	6.8	-0.13
P2-045	1.2	1.5	0.3	-0.4	10.4	10.8	0.03
P2-046	2.0	1.5	-0.5	-0.4	6.1	6.5	-0.08
P2-052	0.6	0.6	0.0	0.3	2.6	2.3	0.00
P2-078	10.0	6.0	-4.0	0.6	39.9	39.3	-0.10
P2-079	2.1	3.1	1.0	0.3	9.6	9.3	0.11
P2-081	15.7	37.0	22.0	1.5	224.1	222.6	0.10

J_A = Measured flux under accumulator [$pCi \cdot m^{-2} \cdot sec^{-1}$]
J_S = Measured flux of the standard measurement [$pCi \cdot m^{-2} \cdot sec^{-1}$]
F = Empirical correction factor [$(pCi \cdot m^{-2} \cdot sec^{-1})/(pCi/L)$]

C_A = Average atmospheric radon concentration in the accumulator [pCi/L]
C_S = Average atmospheric radon concentration for the standard measurement [pCi/L]

Table 11 (continued)
Control Measurement Results
Waste Pits 1, 2, and 3

Location	Standard LAACC (J_S)	Control LAACC (J_A)	Flux Difference (J_A - J_S)	DBCC Outside (C_S)	DBCC Inside (C_A)	DBCC Difference (C_A - C_S)	Correction Factor (F)
P3-004	0.8	1.2	0.4	-0.4	12.7	13.1	0.03
P3-016	0.5	0.9	0.4	-0.9	8.7	9.6	0.04
P3-021	1.1	1.5	0.4	1.3	7.9	6.6	0.06
P3-022	22.4	19.2	-3.2	8.3	302.3	294.0	-0.01
P3-047	1.7	0.9	-0.8	-1.5	6.0	7.5	-0.11
P3-065	1.2	1.1	-0.1	0.8	5.5	4.7	-0.02
P3-090	0.3	0.5	0.2	-0.5	3.2	3.7	0.05
P3-097	0.4	0.6	0.2	-0.7	12.7	13.4	0.01
P3-098	0.9	1.1	0.2	-2.0	7.4	9.4	0.02
P3-099	0.4	0.7	0.3	-0.1	6.9	7.0	0.04

J_A = Measured flux under accumulator [$pCi \cdot m^{-2} \cdot sec^{-1}$]
J_S = Measured flux of the standard measurement [$pCi \cdot m^{-2} \cdot sec^{-1}$]
F = Empirical correction factor [$(pCi \cdot m^{-2} \cdot sec^{-1})/(pCi/L)$]

C_A = Average atmospheric radon concentration in the accumulator [pCi/L]
C_S = Average atmospheric radon concentration for the standard measurement [pCi/L]

On the basis of this data, any attempt to develop a means of correcting a Standard LAACC Measurement for high outdoor radon levels would require a significantly greater expenditure of time and effort. In the context of future radon-flux measurements that might be conducted in the FEMP Waste Pit Area it would be far easier to simply monitor outdoor radon levels during the measurements and repeat the measurements if the outdoor radon levels are found to be significantly elevated.

Meteorological Parameters

The month of November was not an ideal time to conduct these measurements from a weather standpoint because of the seasonally cold temperatures. Method 115 restricts measurements to ambient temperatures above 35 °F (1.7 °C). The decision to go ahead with the measurements in November was primarily driven by non-technical considerations on the part of FEMP.

Fortunately a warming trend occurred beginning about November 13, that lasted long enough to complete the measurements. This warming trend raised the nighttime low temperatures well above the freezing point for both the ambient air temperatures and the near-surface soil temperatures.

Tables B-1, B-2 and B-3 in Appendix B present the hourly weather data for the periods of concern for the measurements conducted on Waste Pits 1, 2, and 3, respectively. The time is shown as Eastern Standard Time (EST), and is the end of a one hour record. The data shown begin 24 hours before the interval in which the first LAACC was placed, and end with the interval in which the last LAACC was retrieved. All times given in the following sections are in EST.

The first LAACC was placed on Waste Pit 1 at 10:47 on November 21, 1991, and the last LAACC was retrieved at 12:20 on November 22, 1991. In the 24 hours preceding the exposure period, a total of 0.02 in. of rain was recorded. This occurred during the one hour interval ending at 22:00 on November 20. No precipitation events were recorded during the exposure period. The minimum temperatures recorded during the exposures for Pit 1 were 8.2 °C at the 10 m station of the FEMP Meteorological Tower (Met. Tower), 6.1 °C for the air temperature 10 cm above the waste pit surface, and 9.4 °C for the ground temperature 2 cm deep. These minimum temperatures were recorded at approximately 04:00 on November 22.

The first LAACC was placed on Waste Pit 2 at 07:52 on November 18, 1991, and the last LAACC was retrieved at 10:10 on November 19. A total of 0.01 in. of rain was recorded in the 24 hours preceding the exposure period. 0.08 in. was recorded for the interval from 07:00 to 08:00 on November 17, only 0.01 in. of which occurred from 07:45 to 08:00 (Table B-1, Appendix B).

The exposure was started so soon following the last recorded precipitation event because rain had been forecast for the morning of November 18. A total of 0.15 in. of rain was recorded for the period from 09:00 to 10:00 on November 18. The last LAACC had just been placed when the rain began. No other precipitation events were recorded during the remainder of the exposure.

The minimum temperatures recorded during the exposures for Pit 2 were 14.5 °C at the 10 m station of the Met. Tower, 12.3 °C for the air temperature 10 cm above the waste pit surface, and 8.8 °C for the ground temperature 2 cm deep. The 14.5 °C temp from the Met. Tower was recorded at 08:00 on November 18. The minimum air temperature over the pit was recorded at approximately 10:00 on November 19. The minimum ground temperature was recorded at approximately 09:00 on November 18.

The first LAACC was placed on Waste Pit 3 at 10:21 on November 14, 1991, and the last LAACC was retrieved at 12:20 on November 15. A Met. Tower reading of 0.07 in. of rainfall in the 24 hours preceding this exposure period was invalidated by the FEMP technical personnel responsible for maintenance of the meteorological station. It was later learned, through a maintenance check of the Met Tower, that a spider web within the rain gage may have caused these erroneous readings. Therefore, no precipitation was recorded in the 24 hour period before the exposure began, nor was any recorded during the exposure.

The minimum temperature recorded by the Met. Tower during the exposures conducted on Waste Pit 3 was 10.2 °C at the 07:00 record on November 15. The Metrosonics data logger experienced a power failure at approximately 18:00 on November 14 and failed to record any further temperatures following that time. Therefore there are no data from the Metrosonics data logger for the interval of lowest temperatures recorded by the Met Tower. The air temperatures recorded by the Metrosonics data logger are significantly lower than the Met. Tower readings for the morning of November 14. This most probably results from a mild temperature inversion that was in effect during the morning hours.

SUMMARY

The results of the measurements conducted on Waste Pits 1, 2, and 3 exhibit average values well below the NESHAP emission limit of 20 $pCi \cdot m^{-2} \cdot sec^{-1}$. The average radon-flux densities calculated for Pits 1, 2, and 3 are 9.1, 6.4, and 2.6 $pCi \cdot m^{-2} \cdot sec^{-1}$, respectively. The occurrence of several regions of elevated radon-flux values results in high variances for the measurement data. These regions of elevated flux measurements are, however, limited in areal extent and are the result of a relatively few high measurement results.

The region of elevated radon-flux situated on the western edge of Waste Pit 1 is of note because it correlates with a topographic change in slope towards the Clear Well. This observation may warrant further investigation into the condition of the cover in that region.

The data quality objectives (10% precision, ± 10% accuracy, and 85% completeness) were met for the measurements conducted on all three waste pits. Although the weather conditions were not ideal during the course of the measurements, these measurements were conducted under conditions that are consistent with the requirements given in Method 115, as interpreted by technical representatives from EPA Region V. Therefore these measurement results are deemed representative of the long-term average radon emissions that can be expected from these waste pits.

In anticipation of encountering elevated atmospheric radon levels in the Waste Pit Area an attempt was made to determine an empirical correction factor that could be used to correct the measurement bias of the LAACCs. The approach relied on an assumption that two LAACCs placed within 2 m of each other would measure approximately the same radon-flux. Because of the high spatial variability in the measured flux values, this assumption was invalid. Fortunately, the measurements were conducted during periods when the atmospheric radon levels were not elevated above common background levels, and the correction factor was not needed.

REFERENCES

Hartley, J. N. and H. D. Freeman, 1986. Radon Flux Measurements on Gardinier and Royster Phosphogypsum Piles Near Tampa and Mulberry, Florida. U.S. Environmental Protection Agency Report, EPA 520/5-85-029, U.S. Environmental Protection Agency, Washington DC., January, 1986.

U.S. Department of Energy, 1991. Initial Screening of Alternatives for Operable Unit 1, Task 12 Report, Feed Materials Production Center, Fernald, Ohio, Remedial Investigation and Feasibility Study. U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tennessee.

U.S. Environmental Protection Agency, 1990. Method 115-Monitoring for Radon-222 Emissions. in the Code of Federal Regulations, Title 40 (Protection of Environment) Part 61 (National Emission Standards for Hazardous Air Pollutants), Appendix B. Office of the Federal Register, National Archives and Records Administration, Washington D.C., 1990.

APPENDIX A

U.S. Department of Energy
Grand Junction Projects Office

Chem-Nuclear Geotech
Radon Laboratory Technical Procedures

Calibration of Computer Automated Gamma Counting System for Radon Flux Measurements, (RN-FLUX-C), Rev. 0

Measuring Radon Concentrations With Diffusion Barrier Charcoal Canisters, (RN-DBCC-U), Rev. 0

Radon Flux Measurements Using the Large Area Activated Charcoal Collector Method, (RN-FLUX-U), Rev. 0

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Revision 01
October 31, 1991
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Radon Laboratory
Technical Procedure RN-FLUX-C
Calibration of a Computer Automated Gamma Counting System
for Radon Flux Measurements

1.0 Introduction

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7.0 Calibration Procedures

8.0 Data Reduction

9.0 Record Keeping

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1.0 INTRODUCTION

Various federal regulations (40 CFR Parts 61 and 192, at this time) impose limits on the emission of radon gas from a variety of sources either owned or operated by the US Department of Energy (DOE). Measurement of radon flux density, using a passive charcoal collector, is often the method of choice for determining radon emissions from these sources. Details of this measurement method are given in 40 CFR Part 61, Appendix B, Method 115. Method 115 also references an EPA document authored by Hartley and Freeman [1], which describes the large area activated charcoal collector (LAACC) in detail, gives general field methods for its use, and provides specifications for calibration standards to be used in implementing the measurement technique.

2.0 PURPOSE

The purpose of this document is to delineate the steps necessary to set-up and calibrate a computer automated gamma counting system for radon flux measurements made using the large area activated charcoal collector (LAACC) following the requirements given in 40 CFR Part 61, Appendix B, Method 115.

3.0 REFERENCES

1. Hartley, J. N., and Freeman, H. D., 1986. Radon Flux Measurements on Gardinier and Royster Phosphogypsum Piles Near Tampa and Mulberry, Florida, US EPA, Report No. EPA 520/5-85-029.

2. Radon Laboratory Technical Procedure RN-FLUX-U, Radon Flux Measurements Using The Large Area Activated Charcoal Collector Method.

4.0 EQUIPMENT AND SUPPLIES

- Activated Charcoal (6 by 16 mesh size, or smaller, coconut husk type charcoal is recommended)
- Notebook for the Automated Gamma Counting System
- Sample Cans (4" Diam. by at least 2" High)
- Can Sealer
- NaI Gamma Counting System
  Recommended apparatus consists of:
  3" x 3" NaI detector and High Voltage Supply
  Linear Amplifier
  Nucleus PCA-I, Multi-Channel Analyzer Card and supporting TSR software
- Two NIST traceable Ra-226 solutions, approximately 0.1 μCi each

- Standard Blank
- Two 80 ml Beakers
- ACS Reagent Grade Hydrochloric Acid (0.1 N)
- Two sheets of 2 mil Polyethylene plastic (minimum size 15 " x 15")
- Absorbent Laboratory Bench Paper
- Two-Part Epoxy Resin
- 14 inch diameter metal pizza pan
- Food Tray or Other Shallow Container
- Drying Oven
- Heat Lamp and Variable Autotransformer Variac
- Natural Uranium Source
- Zenith personal computer (286 or 386), or equivalent with BASICA
- Executable code for the following basic programs:
  FLUX1.BAS
  FLUX2.BAS
  FLUX4.BAS
  FILREAD1.BAS

5.0 EQUIPMENT SET-UP

The 3 x 3 inch sodium iodide detector should be housed in a minimum of 2 inches of lead shielding (preferable 4 inches) to reduce the background count rate. A voltage supply capable of providing up to 1200 volts is needed to operate the detector. A linear amplifier is used to amplify the pulse output from the crystal pre-amp to between 0 and 10 volts for input into the Nucleus PCA-I multichannel analyzer card mounted in a personal computer. In setting up a sodium iodide counting system determine the polarity required for the detector photomultiplier tube. Most recent detectors are wired for positive high voltage, but some early tubes require a negative bias.

When installing the Nucleus PCA-I card in the computer for the first time, set the DIP switches for the desired memory location. The counts are stored at this computer memory location and the counting software that recovers the counts must know where to look. Mount the PCA-I card in the last full slot on the left side as you face the personal computer (follow the directions on the PCA manual). Create a sub-directory on the computer hard disk and transfer the Nucleus supplied control software to this sub-directory. Also transfer BASICA.EXE and the Nucleus counting software to this sub-directory.

In setting up the counting system for the first time, use an oscilloscope to monitor the pulses coming from the sodium iodide detector and from the linear amplifier to set the proper high voltage bias on the photomultiplier tube. Usually a HV setting of 600 to 800 volts provides appropriate pulses. The pulses from the highest energy photons expected from uranium (2200 keV) and thorium progeny (2614 keV) should not flat-top at the output of the linear amplifier and should not exceed 10 volts in order to avoid over-driving the internal PCA board amplifier. The high voltage bias setting and coarse gain setting can be varied to accomplish this. A time constant of 1 to 3 microseconds on the linear shaping amplifier is best for sodium iodide. The linear amplifier output pulses must be positive and should rise to the peak in less than 1 microsecond. If the pulses do not fall smoothly to zero with very little undershoot, the pole-zero should be adjusted to accomplish this. Refer to the appropriate amplifier manuals for instructions on setting pole-zero.

Once the proper positive output pulses in the 0 to 10 volt range from a uranium source have been observed on the oscilloscope, connect the linear amplifier output to the input BNC of the PCA board. Change to the computer sub-directory and execute the batch command to bring the PCA board up in the manual mode (pcadhr, pcaehr or others, depending on the selected memory location). Follow the instructions in the PCA manual for setting the number of channels desired (F3 followed by up or down arrows, then return) and conversion gain (F3, F5 followed by up or down arrows to toggle the conversion gain setting). For counting radon progeny in charcoal, the BASICA software is designed to use 256 channels with a conversion gain of 512 to spread the lower energy portion of the energy spectrum from about 80 keV to about 1000 keV over the 256 channels.

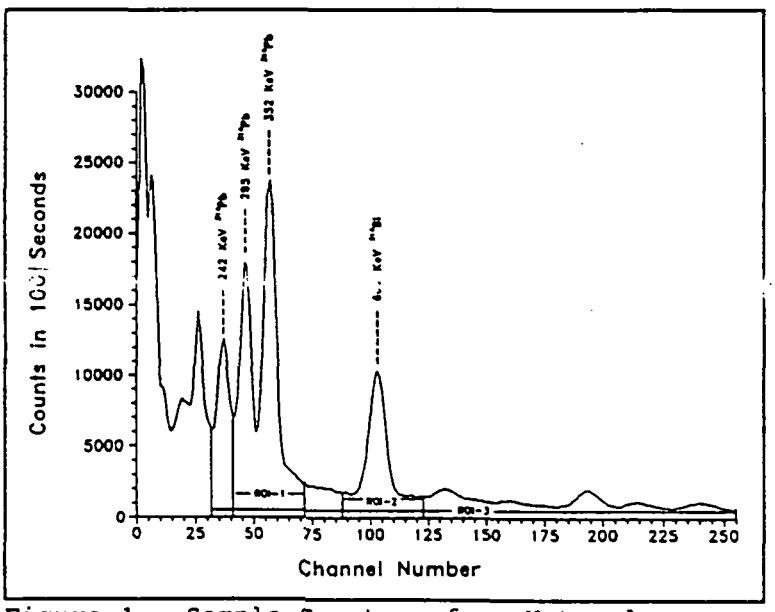

Figure 1. Sample Spectrum from Natural Uranium Source.

Collect a gamma spectrum using "acquire" (the F1 function key). Figure 1 shows an example of a spectrum collected from the natural uranium source, with appropriate regions of interest located. Move the cursor to locate the channel numbers corresponding to the 242, 295 and 352 keV Pb-214 peaks, and the 609 keV Bi-214 peak. The FLUX1.BAS program that automatically locates these channel numbers must know what region of the spectrum it should search to locate the desired peak channel numbers. The search sub-routine used in the program FLUX1.BAS looks for maxima and minima only within specific regions. If the numbers used in FLUX1.BAS program do not direct the search over the proper region, the numbers in the search section can be changed to match the gain settings or the gain settings can be adjusted to match the numbers. This is fundamental to the proper operation of the computer analysis.

6.0 PREPARATION OF RADON-ON-CHARCOAL REFERENCE STANDARDS

Reference Standard Solutions

The two reference standard solutions must have calibration certificates which are NIST traceable. The allowable uncertainty on the certified value is 5%. The solutions need not be NIST Standard Reference Materials (SRM), although this is preferable. The standards should be delivered in 5 ml flame sealed ampoules.

Health and Safety Considerations

Preparation of the standards involves some degree of risk of personal contamination with radium-226. Therefore appropriate caution and precautionary measures should be taken to minimize this risk. The greatest potential for personal contamination comes from an accident involving splashing of the standard solution. It is recommended that the operator wear a rubber apron, rubber gloves, and splash proof type safety glasses when handling the radium solutions.

A radiological area must be established by an appropriate technical representative of Health, Safety and Security. This area should include the immediate work area where the procedure is to be conducted and provide a suitable location for a personnel frisking station. This procedure should be conducted in a hood. The hood sash should be opened sufficiently, such that the air velocity in the vicinity of the charcoal will not be great enough to disturb the finer sized grains when the hood is on. The work area should be surveyed by a technician from Health Safety and Security for evidence of radiologic contamination prior to the start of the procedure, and again at the completion of the transfer process. A personal frisk must be performed prior to exiting the work area.

The work area should be cleaned of all unnecessary clutter, and covered with absorbent paper. It is preferable that the handling of the solutions be done over a shallow container, such as a food tray, which is lined with absorbent paper. The volume of this container should be large enough to contain all of the solution which would be generated, if a spill were to occur. Before performing this procedure it is

recommended that it be practiced with 0.1 N HCl solution instead of the radium solution.

Transfer of Radium Solution onto Charcoal

The radium solution must be uniformly distributed throughout the 185 grams of activated charcoal. The approach taken to assure this, is to spread the charcoal out in a thin layer (ideally 1 to 2 grains thick) on a polyethylene liner. The radium solution, diluted to an appropriate volume with HCl, is poured over the charcoal and the solution is allowed to evaporate to dryness. Then the polyethylene liner and the charcoal are transferred to a sample can and sealed.

Prepare the charcoal by drying in an oven at 110°C for several hours. Allow the charcoal to cool, and weigh out 185 ± 5 g. Cut a circular sheet of polyethylene approximately 15 inches in diameter and place this on the pizza pan as a liner. Spread the charcoal out on the polyethylene liner into an even circle, approximately 1 to 2 grains thick. Carefully pour approximately 80 ml of 0.1 N HCl over the charcoal, ensuring that all grains are wetted with the solution. When the charcoal is first wetted it will bubble and sputter somewhat. This step is done so that the sputtering will not occur when the radium solution is applied.

The radium solution is transferred to an 80 ml beaker by breaking the ampoule neck, while over the beaker. The contents of the ampoule are transferred into the beaker carefully, avoiding any splashing. Both the ampoule body and the neck are rinsed with three to five 3-ml portions of 0.1 N HCl into the beaker. Dilute the solution in the beaker to approximately 60 ml with 0.1 N HCl. Carefully pour this solution over the pre-wetted charcoal, ensuring that the contents of the beaker are evenly distributed over the charcoal. Rinse the beaker with three to five 5-ml portions of 0.1 N HCl onto the charcoal. Retain both the beaker and the ampoule pieces for subsequent gamma analysis.

The solution applied to the charcoal is allowed to evaporate to dryness in the hood. This process may be speeded up by the use of a heat lamp. If using a heat lamp be careful not to overheat the charcoal, e.g. boil the solution or melt the plastic sheet. A variac may be used to reduce the heat output from the lamp.

Once the solution has been evaporated the polyethylene sheet and the charcoal are transferred into a sample can. This is accomplished by gathering the edges of the plastic sheet over the center of the pan, being careful not to touch the plastic where it has been in contact with the solution. Transfer this bundle into the sample can, and fold the extra plastic down evenly across the top of the charcoal so that the can lid may be emplaced. Prior to sealing the can a bead of epoxy resin should be applied to the sealing grove on the can lid. Coating the sealed surface with epoxy will ensure that the can is hermetically sealed. The can may now be sealed using a can sealing machine. After the can has been sealed apply another bead of epoxy around the exposed seam where the can body joins the lid. Clearly label the cans with the

isotope, activity, source serial number, date created, and the appropriate radioactive materials label.

Analysis of Glassware

The analysis of the glassware for residual radium is performed to document that quantitative transfer of the standard from the ampoule, and subsequently from the beaker was accomplished. Prior to its use the 80 ml beaker, which will be used to hold the diluted radium solution, should be background counted a minimum of 12 hours on a NaI gamma counting system. The beaker should be placed in a clean empty sample can, covered with a can lid, but not sealed.

Following use of the glassware with the radium solution it should be counted again. In the second count the remains of the ampoule, in which the radium solution was delivered, and the beaker should be sealed in the same can used to perform the background count. The sealed can should be allowed to grow-in for a period of at least 15 days prior to counting. The total counting time should be approximately the same as used for the background count. The count rate for the follow-up count should be statistically the same as the background count at the 99% confidence level.

7.0 CALIBRATION PROCEDURES

Overview

The method of analysis described in reference [2] utilizes three different regions of interest from the gamma spectra collected for analysis, see Figure 1. The first encompasses both the 295 keV and 352 keV spectral lines from Pb-214, while the second is centered about the 609 keV line from bismuth-214. The third ROI includes all of the channels from 10 channels before the minimum between the 242 and 295 keV Pb-214 lines to channel 255.

The calibration constant is a means of correcting the measured net count rate from an unknown into a measure of the activity in pCi. The principle involved with determining these calibration constants is to measure the net count rate obtained from the two radon-on-charcoal standards, for the three regions of interest, with sufficient accuracy. These net count rates are then divided by the certified activity of the standards to produce a calibration constant with units of $counts \cdot sec^{-1} \cdot pCi^{-1}$.

Location of the ROI's is accomplished by collecting a spectrum from a natural uranium source. Then a computer program (FLUX1.BAS), using predetermined starting locations, searches out the channel number of the minimum between the 242 keV and 295 keV peaks from Pb-214, the channel numbers of the peaks from the 295 keV and 352 keV lead lines, and the peak from the 609 keV bismuth line. The channel numbers of these reference points, the window parameters, and the count rates for the

three ROI's are written to two files. The first file (CHANNELS.HST) documents the history of execution of FLUX1.BAS. The second file (CHANNELS.DAT) is used to temporarily store this same information for use by other succeeding programs. The information in this file is updated each time that FLUX1.BAS is executed.

A second program (FLUX2.BAS) is used to collect the gross gamma counts in the three ROI's for the standard blank. A standard blank is prepared by sealing 185 ± 5 grams of freshly baked charcoal in a sample can. A standard blank is a blank which is known to be free of radon. This program collects a spectrum for the standard blank, reads the file containing the reference channel numbers, window parameters, and establishes the three ROI's. The number of counts in each of the ROI's are displayed on the screen and written to two files. The first file (BKGSTD.HST) documents a history of the standard blanks counted and contains the date and time counted, and the count rate, in counts/sec, for ROI-1, ROI-2, and ROI-3. The second file (BKGSTD.DAT) is used to temporarily store the count rate from the three ROI's to be used by other programs during the remainder of the day's counting.

The final program (FLUX4.BAS) is used to acquire a spectrum, and to determine the net count rate for each of the three ROI's from each of the standards counted. This is the same program used to count unknown samples when using the Radon Laboratory Technical Procedure RN-FLUX-U [2]. Because of this the output data file will contain a number of fields which are not used when counting standards.

FLUX4.BAS inputs the reference points for the three ROI's, and the standard blank count rate from the appropriate files. The net counts in the three ROI's are then computed, printed, and written to output file. FLUX4.BAS reads a data file called PROJECT.DAT, which contains a name of up to eight characters used to identify the project. Before beginning the calibration this file should be edited with a general purpose text editor which produces an ASCII file as a final product. The name should be replaced with the name CALMMYY, where MM is the two digit designation for the current month, and YY is the two digit designation for the current calendar year. Additionally the preset live time should be changed from 300 seconds to 1200 seconds. The preset live time is assigned the variable name "PT" in the program. The value is assigned in the constant listing in line number 130.

This program produces output to two files each time a standard is counted. The first file (FILE$.DAT) includes the following fields: sample ID, sample location, date and time counted, date and time placed and retrieved, the ROI parameters used, the net counts for the three ROI's, and the calculated flux results. When counting standards the following fields will have "no" values in FILE$.DAT: date and time placed, date and time retrieved, and the calculated flux values. The second file (FILE$.SPM) contains the sample ID, sample location, and the spectrum.

Sequential Instructions

1. Power up the Nim-Bin which houses the electronics for the NaI crystal.

2. Turn on the computer and verify that the printer is turned on and is "ON LINE". At the menu type MCA <cr> to start the terminate-and-stay-resident (TSR) software for the MCA card. Press any key to bring up the graphics mask for the MCA card.

3. When the graphics mask for the card appears, terminate execution of the software and return to DOS by pressing F-10 (MORE) followed by F-9 (DOS).

4. Check the date of the computer by typing DATE <cr>. Enter the correct date if needed. Check the time of the computer by typing TIME <cr>. Enter the correct time if needed.

5. Enter the basic interpreter by typing BASICA <cr>.

6. Load and run the program FLUX1.BAS. To load a program either type LOAD", followed by the filename that you wish to load and a <cr>, or press the F-3 function key, type the file name that you wish to load, then a <cr>. To run a program either type RUN <cr>, or press the F-2 function key. At the prompt place the natural uranium source, red side up, exactly centered on the crystal, and close the lid on the lead shield.

7. When the program has completed execution the spectrum will be displayed on the screen for inspection. Press "ENTER" to continue. The channel reference points, and the count rates for the three ROI's will be displayed on the screen. Record this information in the log book for the counting system, along with the date and time that the source was counted. Remove the natural uranium source and return it to its designated storage location.

8. Load and run the program FLUX2.BAS. Place the standard blank exactly centered on the crystal, and close the lid on the lead shield. Enter "Y" to acquire the spectrum.

9. When the program has completed execution the spectrum will be displayed on the screen, and the prompt "press ENTER to continue" will appear in the lower left portion of the screen. Continuing execution of the program at this point will extract the data from the spectrum and write the necessary output.

10. Ensure that the printer is turned on, and is on-line. Load and run the program FLUX4.BAS. It is not necessary to run the program FLUX3.BAS during the calibration.

11. Begin by counting the first of the Radium-on-Charcoal standards. At the prompt "Is this a standard ?" type Y <cr>. Then enter the standard ID number (the source serial number), place the standard exactly centered on the crystal with the lid up, and close the lid on the lead shield. Enter "Y" to acquire the spectrum.

12. When the program has completed execution, the spectrum will be displayed on the screen, and the prompt "press ENTER to continue" will appear in the lower left portion of the screen. Press "ENTER" to continue.

13. Run program FLUX4.BAS again by pressing the F-2 function key. Replace the first standard with the second and repeat steps 11 and 12.

15. Continue to count the standards in sequence until they have each been counted 10 times.

16. To obtain a print-out of the data, load and run the basic program FILREAD1.BAS. This program reads the data file (FILE$) and reproduces the print-out obtained during the counting.

17. When the counting has been completed the following files should be backed-up to floppy disks and filed with the calibration records:

    CHANNELS.HST
    BKGFLUX.HST
    FILE$.DAT Where FILE$ is "CALMMYY" as described above
    FILE$.SPM

8.0 DATA REDUCTION

The calibration constants for each ROI are determined by computing the average net count rate (in counts•sec^{-1}) for both standards, and dividing this number by the average of the certified values of the two standards (in pCi). The results are the calibration constants for each ROI which have the units (cps•pCi^{-1}).

The program FLUX4.BAS must be edited to incorporate the revised calibration constants. This is accomplished be entering the BASICA editor, loading the program FLUX4.BAS, and changing the calibration constants (CALROI1, CALROI2, CALROI3) in the listing of constants, lines 100 through 120. The revised program must then be saved to the same program name (FLUX4.BAS).

9.0 RECORD KEEPING

A logbook is maintained for the counting system. The logbook is used to record the calibration activities associated with the system along with a running history of the system usage. An entry in the logbook must be made each time that any components in the system are changed, or the settings are changed, such as gain settings on the amplifier. Any change in the operating parameters of the components of the system will require recalibration of the system.

Any entry in the logbook must be accompanied by the date and the initials of the person making the entry.

The logbook contains an updated listing of the components of the system, and the current settings for all controls. The components are identified by the manufacturer's name, model number and serial number.

During routine usage an entry is made in the logbook each time that the natural uranium source is counted, eg. each time that FLUX1.BAS is run. The following information is recorded in the logbook:

- Date and Time That the Standard was Counted
- M2; Channel No. of the minimum before the 295 keV Peak
- P2 ; Channel No. of the 295 keV Peak
- P4 ; Channel No. of the 352 keV Peak
- P6 ; Channel No. of the 609 keV Peak
- The Channels Included in ROI-1, and ROI-2
- The Count Rate (counts/sec) for ROI-1, ROI-2, and ROI-3
- Initials of Operator and Date

The following entries are made in the log book each time that the system undergoes recalibration:

- Date and time that the calibration was performed
- A complete description and identification of the standards, and blank which were used.
- A copy of the printout of the counting results, for both standards and the blank.
- A tabulation of the net count rate results for each ROI for both standards, with the computed average and the computed average of the certified activity levels of the two standards
- The computations of the calibration constants for each ROI.

1.0 Introduction

2.0 Purpose

3.0 References

4.0 Equipment and Supplies

5.0 Field Sampling

6.0 Laboratory Analysis

7.0 Calibration

8.0 Record Keeping

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1.0 INTRODUCTION

The remarkable ability of activated charcoal to adsorb airborne radon atoms at room temperatures is the basis for using charcoal canisters as passive radon monitors. Several types of charcoal canisters have been developed for radon monitoring, including the four-inch diameter open face canister, the four-inch filtered canister recommended by the U. S. Environmental Protection Agency as an industry standard, and the three-inch diffusion barrier canister developed by the Radon Project, Pittsburgh, PA. All of these charcoal canisters are available commercially from Ramses, Ltd., Denver, CO.

2.0 PURPOSE

The purpose of this document is to delineate the required procedures for exposing and analyzing three-inch diameter diffusion barrier charcoal canisters used by the Grand Junction Projects Office Radon Laboratory for measuring airborne radon concentrations.

3.0 REFERENCES

1. Cohen, Bernard L.; Nason, Richard; "A diffusion barrier charcoal adsorption collector for measuring Rn concentrations in indoor air." Health Physics, Vol. 50, 457-463, 1986.

2. Martz, D. E.; George, J. L.; Mamich, S. T.; Langner, G. H., Jr.; "Validation of the diffusion-barrier charcoal canister method." Report No. DOE/ID/12584-38, UNC/GJ-47(TMC), 1989.

3. "Personal Computer Analyzer (PCA) Instruction Manual", The Nucleus, 761 Emory Road, Oak Ridge, TN, July, 1987.

4.0 EQUIPMENT AND SUPPLIES

Three-inch diffusion barrier charcoal canisters

NaI gamma counting system
- Recommended apparatus consists of:
  - 3" x 3" NaI detector and high voltage supply
  - Linear amplifier
  - Nucleus PCA-1 multi-channel analyzer card and supporting control software supplied by the Nucleus
  - Zenith 286 or 386 personal computer
  - BASICA interpreter

Natural Uranium Source

Temperature regulated oven

Electrical tape

Duct tape

Aluminum foil

Executable code for the following BASIC programs:

CHARCO1.BAS CHARCO2.BAS CHARCO3.BAS

5.0 FIELD SAMPLING

When activated charcoal is exposed to a humid atmosphere it will adsorb water vapor, and this adsorbed water can reduce or partially block the uptake of radon. To make certain the charcoal canisters used for measuring radon concentrations are initially free of adsorbed water and any residual radon that may be present, they must be baked for a minimum of twelve hours at 100 to 110 degrees Celsius prior to use. Remove the lids from the three-inch diffusion barrier canisters and place the lower part of the canister that contains the charcoal in a temperature regulated oven set at approximately 105 degrees. Do not bake the lid containing the nylon diffusion barrier since this may weaken the glued seal or damage the barrier. Remove the small package of Drierite if present and discard. Examine the diffusion barrier seal to make sure there are no cracks around the edges that would allow the radon to enter without passing through the barrier mesh. After inspection cover the port in the lid with electrical tape or duct tape. The tape should have a foil center so the adhesive will not come into contact with the nylon diffusion barrier. After baking overnight, remove the cans from the oven, replace the lid and seal the flange separation with one layer of electrical tape around the circumference. Baked cans may be stored indefinitely prior to use.

To expose the charcoal canisters, remove the tape covering the diffusion port and place the canister with the port up, in the room or location where the measurement is to be made. Record the number of the canister, the location, and the date and time opened. For a single canister in a residential structure, it is recommended that the measurement be made in the lowest occupied level of the house, preferably in a bedroom away from drafts. The canister should be placed on a table or other support approximately one meter above the floor and at least several centimeters away from walls. Screening measurements should be made with the windows and doors of the structure closed, if the intent is to determine the maximum indoor concentrations.

Leave the canister undisturbed for one to eight days, then re-seal the entrance port with the adhesive tape seal and record the time and date when the canister was closed. The amount of radon collected on the charcoal during the exposure is assumed to represent an integrated average of the variable radon concentrations that existed during the exposure period. Return the canister to the laboratory for counting.

6.0 LABORATORY ANALYSIS

Overview

The gamma activity due to the radon progeny activity adsorbed on the activated charcoal is determined by performing a quantitative gamma ray spectral analysis of each canister.

The counting system utilized by the GJPO Radon Laboratory for the gamma ray analysis of charcoal canisters consists of a 3 x 3 inch NaI detector mounted in a four-inch lead shield, with its associated high voltage bias supply, a linear amplifier, and a multi-channel analyzer (MCA). The MCA is a Nucleus PCA-I multi-channel analyzer card installed in a Zenith personal computer. This allows fully automated operation of the MCA under computer control.

The PCA board is operated as a 256 channel MCA with a conversion gain of 512. Two regions of interest (ROIs) are established. The first ROI includes both the 295 keV and 352 keV gamma peaks due to Pb-214, while the second ROI is centered on the 609 keV peak that is emitted by Bi-214.

Setting the proper channel numbers for the ROIs is accomplished by collecting a gamma spectrum from a Natural Uranium Source using the computer program (CHARCO1.BAS). This program collects the spectrum, then searches for the channel number of the minimum (M2) between the 242 keV and 295 keV peaks from Pb-214, the channel numbers of the peaks from the 295 keV (P2) and 352 keV (P4) lead lines, and the channel number of the peak from the 609 keV (P6) bismuth line. The channel numbers of these reference points are written to a file called PARAMET for use by succeeding programs. The information in the file PARAMET is updated each time that CHARCO1.BAS is executed.

A second program (CHARCO2.BAS) collects the gross gamma background spectrum for 1200 seconds and sums the counts in the two ROIs. This program reads the file PARAMET and sets ROI-1 from the minimum M2 to M2+30 and ROI-2 from P6-20 to P6+20. The program then sums the counts within each ROI, displays the numbers on the computer screen, and writes this information to a file named BACKGND. These data are used for background subtraction in computing the net counts in the two regions of interest during execution of CHARCO3.BAS. CHARCO1.BAS and CHARCO2.BAS are run only once at the beginning of each day.

The third and final program (CHARCO3.BAS) is used to acquire a gamma spectrum from each of the exposed diffusion barrier canisters in turn, and to compute the measured radon concentrations to which the canisters were exposed. CHARCO3.BAS inputs the reference channel numbers for the two ROIs from the file PARAMET, and the background counts from BACKGND file. CHARCO3.BAS also requests the operator to input essential information related to the canister number, location, date and time of opening, and the date and time of closing. The CHARCO3.BAS program corrects the net counts in each ROI for decay during the time after the canister was sealed, and computes the average radon concentrations during the exposure period from the decay corrected counts and the time of exposure.

The equations used to compute the average radon concentrations during the exposure period assume that the build-up of radon in the charcoal canister can be approximated by a constant intake rate with the rate of decay proportional to the number of atoms present at any time. The mathematical expression used in the computation is an inverse exponential function, $A(1-e^{-Bt})$, where the constants A and B were determined from experimental data obtained by exposing a number of diffusion barrier charcoal canisters for various lengths of time to

measured radon concentrations in the GJPO Charcoal Test Chamber (see Martz, et. al, 1989).

The equation for determining the radon concentrations has the following form:

$$Rn_i = (NETROI_i)/A_i(1-e^{-B*E})/(e^{-.00755*H})$$

where Rn_i is the average radon concentration in pCi/L
$NETROI_i$ is the net counts in region of interest i
A_i represents a different constant for each of the two regions of interest

B = .01133/hour, an experimentally determined exposure rate factor
E = exposure time in hours
H = elapsed hours between closing and counting the canister

Sequential Instructions

1. Power up the Nim-Bin housing the electronics for the NaI crystal.

2. Turn on the computer. Check to see if the printer is turned on and is "on line." At the menu type MCA <cr> to start the PCA software for the MCA card. Press any key to remove the logo on the screen and bring up the mask for the MCA card.

3. When the graphics mask for the card appears, terminate execution of the PCA software and return to the DOS operating system by pressing the F10 function key (MORE) followed by the F9 function key (DOS).

4. Check the current date on the computer clock by typing DATE <cr>. Enter a correction for the date if needed. Check the time on the computer by typing TIME <cr>. Enter the correct time if needed.

5. Activate the basic interpreter by typing BASICA <cr>.

6. Load and run the BASIC program CHARCO1.BAS. To load any of the BASIC programs, press the function key F3 and type the file name that you wish to load, then a <cr>. To execute the program, press the F2 function key. At the prompt place the Natural Uranium Source exactly centered on the crystal with the red side up, and close the lid on the lead shield. Press "Y" <cr>.

7. The gamma spectrum is displayed on the screen during the counting period, and the statement "press ENTER to continue" will be displayed on the screen when the count is completed. Press ENTER to continue. The channel reference points, and the counts for the two ROIs will be displayed on the screen. Record this information in the log book for the counting system, along with the date and time that the source was counted. Remove the Natural Uranium Source and return it to its designated storage location.

8. Load and run the program CHARCO2.BAS. At the prompt place a blank canister exactly centered on the crystal, and close the lid on the lead shield. Enter "Y" to acquire the spectrum.

9. When the program has completed execution the spectrum will be displayed on the screen, and the prompt "press ENTER to continue" will appear on the screen. Continuing execution of the program at this point will extract the background counts from the spectrum and write the output to the file BACKGND. The channel reference points, and the background counts for the two ROIs will be displayed on the screen. Record this information in the log book for the counting system, along with the date and time that the blank canister was counted.

10. Load and run the program CHARCO3.BAS. The operator must enter the appropriate information on dates and times of the exposure and respond by typing "Y" when the canister has been placed on the crystal. This program automatically collects the spectral data, computes the estimated radon concentration during the exposure from the net counts in the two regions of interest independently, and computes the average. The gamma spectrum will remain on the screen until the operator presses "Enter". The computed radon concentrations are then displayed on the screen, printed on the printer, and written to a serial file which name can be changed as desired by editing the open statement in line 2301, in the program CHARCO3.BAS.

11. Continue to run the program CHARCO3.BAS by pressing F2 until all of the canisters have been counted.

12. Back-up the serial output file to floppy disc on a daily basis.

7.0 CALIBRATION

General

The daily execution of the CHARCO1.BAS and CHARCO2.BAS programs adjusts the counting system for small gain shifts in the electronics. A check of the calibration constants should be performed annually to ensure the system is producing accurate results. Expose 16 diffusion barrier charcoal canisters to a known concentration of radon in the GJPO Charcoal Test Chamber. Pull two canisters out each day and count (after exposures of 24, 48, 72, 96, 120, 144, 168, and 192 hours) using CHARCO3.BAS. The results obtained for these canisters should compare favorably with the average chamber concentrations during the exposure period. It is important to keep in mind that the indoor radon concentrations inside structures usually have significant diurnal variations due to variable ventilation and circulation patterns, as well as variations induced by atmospheric pressure changes. The diffusion barrier charcoal canister calibration factors are based on the uptake of radon from a test chamber that had a constant concentration during the exposure period. Studies have shown that diffusion barrier canisters exposed over a full seven day exposure period in structures with variable concentrations yielded results which compared very favorably with the integrated radon concentrations recorded by continuous radon

monitors in these same structures (see Martz, et al. 1989). Diffusion barrier canisters exposed for less than seven days also provide reasonably correct results.

The most likely instrumentation problem that may be encountered with the counting equipment is a shift of the gamma energy spectrum due to aging of the electronic components. The system is virtually immune to small gain shifts because these are corrected with the peak search routine in the CHARCO1.BAS during the daily counts of the Natural Uranium Source. However a major gain shift cannot be handled by the peak search routine in CHARCO1.BAS. If a major gain change has occurred due to aging of the equipment or replacement of a component, the fine gain control on the linear amplifier can be used to return the peaks approximately to their former channel numbers. To make this adjustment, re-boot the computer and load the PCA software by typing MCA. This brings the MCA up in the manual MCA mode. Press F3 and toggle the up-down arrows to select 256 channels, press F4 followed by F5 and toggle the conversion gain to 512. Clear the screen by holding down CTRL and pressing F2. Place the Natural Uranium Source on the crystal and press F1 to acquire a spectrum. The left-right arrows may be used to move the cursor to the 295, 352 and 609 keV peaks to determine the channel numbers. Adjust the fine gain repeatedly until the peak locations are at the original channel numbers as recorded in the counting system log book.

8.0 RECORD KEEPING

Field Activities

A field note book is to be kept to record information concerning the field activities associated with conducting the measurements. Specific information which must be recorded in the notebook includes:

- Canister number
- Sample location and description
- Date and time placed
- Date and time retrieved
- Approximate temperatures and relative humidity during exposure
- A Comment Field

A separate logbook is maintained for the counting system. The logbook is used to record the calibration activities associated with the system along with a running history of the system usage. The logbook contains an updated listing of the components of the system, and the current settings for all controls. The components are identified by the manufacturer's name, model number and serial number.

During routine usage an entry is made in the logbook each time that the Natural Uranium Source is counted, e.g. each time that CHARCO1.BAS is run. The following information is recorded in the logbook:

- Date and Time that the Standard was counted
- M2; Channel No. of the minimum before the 295 keV Peak
- P2; Channel No. of the 295 keV Peak
- P4; Channel No. of the 352 keV Peak
- P6; Channel No. of the 609 keV Peak

- The channels included in ROI-1, and ROI-2
- The counts observed in ROI-1 and ROI-2

Also record the following information in the logbook each time that CHARCO2.BAS is run:

- Date and Time that the blank canister was counted
- The channels included in ROI-1, and ROI-2
- The counts observed in ROI-1 and ROI-2

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Radon Laboratory
Technical Procedure RN-FLUX-U
Radon Flux Measurements Using The Large Area Activated Charcoal Collector Method

1.0 Introduction

2.0 Purpose

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8.0 Record Keeping

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1.0 INTRODUCTION

Various federal regulations (40 CFR Parts 61 and 192, at this time) impose limits on the emission of radon gas from a variety of sources either owned or operated by the US Department of Energy (DOE). Measurement of radon flux density, using a passive charcoal collector, is often the method of choice for determining radon emissions from these sources. Details of this measurement method are given in 40 CFR Part 61, Appendix B, Method 115. Method 115 also references an EPA document authored by Hartley and Freeman [1], which describes the large area activated charcoal collector (LAACC) in detail and gives general field methods for its use.

2.0 PURPOSE

The purpose of this document is to delineate the steps necessary to collect and analyze radon flux samples using the large area activated charcoal collector (LAACC) following the methodology given in 40 CFR Part 61, Appendix B, Method 115.

3.0 REFERENCES

1. Hartley, J. N., and Freeman, H. D., 1986. Radon Flux Measurements on Gardinier and Royster Phosphogypsum Piles Near Tampa and Mulberry, Florida, US EPA, Report No. EPA 520/5-85-029.

2. Radon Laboratory Technical Procedure RN-FLUX-C, Calibration of a Computer Automated Gamma Counting System for Radon Flux Measurements.

4.0 EQUIPMENT AND SUPPLIES

- Large Area Activated Charcoal Collector (LAACC), see Figure 1
- Activated Charcoal
  (6 by 16 mesh size , or smaller, coconut husk type charcoal is recommended)
- Field Notebook
- Sample Cans (4 " Diam. by 2 " High)
- Mixing Pad
- Can Sealer

- NaI Gamma Counting System
  Recommended apparatus consists of:
  3" x 3" NaI detector and High Voltage Supply
  Linear Amplifier
  Nucleus PCA II, Multi-Channel Analyzer Card and supporting TSR software

- Two Charcoal Standards, (NIST traceable Ra-226 on activated charcoal)

- Natural Uranium Source

- Zenith personal computer (286 or 386), or equivalent with BASICA

- Executable code for the following basic programs:
  FLUX1.BAS
  FLUX2.BAS
  FLUX3.BAS
  FLUX4.BAS
  FILREAD1.BAS

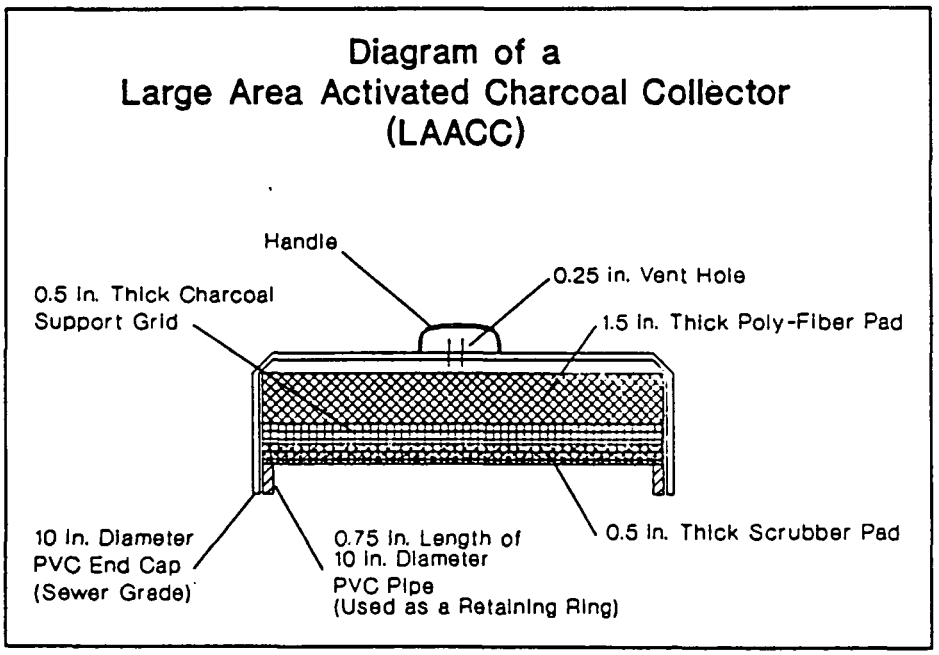

Figure 1 Diagram of a LAACC

5.0 FIELD SAMPLING

The area to be measured should be examined prior to the conduct of measurements to determine the number of measurement locations which

will be required, and to identify any logistical problems which may arise during the sampling. The measurement density will be determined by the intended use of the measurement results. For those surveys that follow the methodology of Method 115, the minimum number of measurements per source will be 100.

To obtain radon flux measurements which are representative of the long term average radon emission the following conditions should be met:

(a) Measurements shall not be initiated within 24 hours after a rainfall.

(b) If a rainfall occurs within the measurement period, the measurement becomes invalid if the seal around the lip of the collector has washed away, or if the collector is surrounded by standing water.

(c) Measurements shall not be performed when the ambient temperature is below 35 °F (≈ 2 °C), or when the ground is frozen.

The activated charcoal to be used in the LAACC's should be thoroughly purged of radon prior to use by heating in an oven at 110 °C for approximately 4 hours. Following this the charcoal should be kept in a radon resistant, sealed container until ready for use in the LAACC.

A minimum of one blank sample is required for each batch of LAACC's to be exposed in the field. The blank is obtained by sealing approximately 180 grams of the same charcoal which will be used to load the LAACC's in a sample can. Label the can with the word "BLANK", the date and time that it was sealed and the initials of the operator. This can should be prepared at the same time that the LAACC's are being loaded.

Assemble and expose the LAACC as follows:

1. Remove the retaining ring and cover pad from the LAACC.

2. Spread a minimum of 180 grams of activated charcoal evenly over the support grid. The correct amount of charcoal is most easily obtained by using an empty sample can as a measuring container. One level can of 6 x 16 mesh charcoal is approximately 190 grams.

3. Replace the cover pad and retaining ring.

4. If the LAACC is not to be placed on the measurement surface immediately, it should be kept in a radon resistant sealed container. A length of 12 inch diameter PVC pipe fitted with end caps will work for this.

5. The surface on which the collector is to be placed should be cleaned of any vegetation and large pebbles which might inhibit forming a good seal between the collector and the soil.

6. Place the collector on the surface to be measured. To ensure a good seal between the surface of interest and the LAACC, 1-2 inches of soil should be packed around the lip of the collector.

7. Record the collector number, sample ID number, date, time, location, and initials of the person placing the device in the field note book.

8. Following an exposure period of 24 hours (± 2 Hrs.) remove the LAACC from the measurement surface.

9. Record the date, time and the initials of the person recovering the LAACC in the field notebook. Remove the collected LAACC's to a staging area away from the measurement area to recover the exposed charcoal. The charcoal should be removed from the LAACC and canned as soon as possible.

10. Remove the retainer ring and cover pad from the LAACC.

11. Gently pour the charcoal from the LAACC onto a mixing pad, being careful to obtain all of the activated charcoal from the LAACC.

12. Mix the charcoal on the mixing pad, and transfer it to an empty can. Seal the can with the can sealer, and affix a label with the sample ID, sample location, the date and time placed, and retrieved, and the initials of the field personnel handling the LAACC.

13. Prepare the cans for return to the laboratory for gamma ray analysis. The cans should be returned to the laboratory as soon as reasonably possible to minimize the loss of measurable activity due to the radioactive decay of radon-222, which has a half-life of 3.825 days.

6.0 LABORATORY ANALYSIS

Overview

The activity due to radon sorbed on the activated charcoal is determined by performing a quantitative gamma ray spectral analysis of each sample.

The counting system utilized for the gamma ray analysis is composed of a 3 x 3 inch NaI detector, with its associated electronics, a linear amplifier, and a multi-channel analyzer (MCA2). The MCA2 is comprised of a Nucleus PCA-II multi-channel analyzer card installed in a Zenith personal computer. This allows computer automated operation of the MCA2.

Three regions of interest (ROI's) are established. The first encompasses both the 295 keV and 352 keV spectral lines from lead-214,

while the second is centered about the 609 keV line from bismuth-214. The third ROI includes all of the channels from 10 channels before the minimum between the 242 and 295 keV lead-214 lines to channel 255. Figure 1 shows a typical spectrum with the three ROI's indicated.

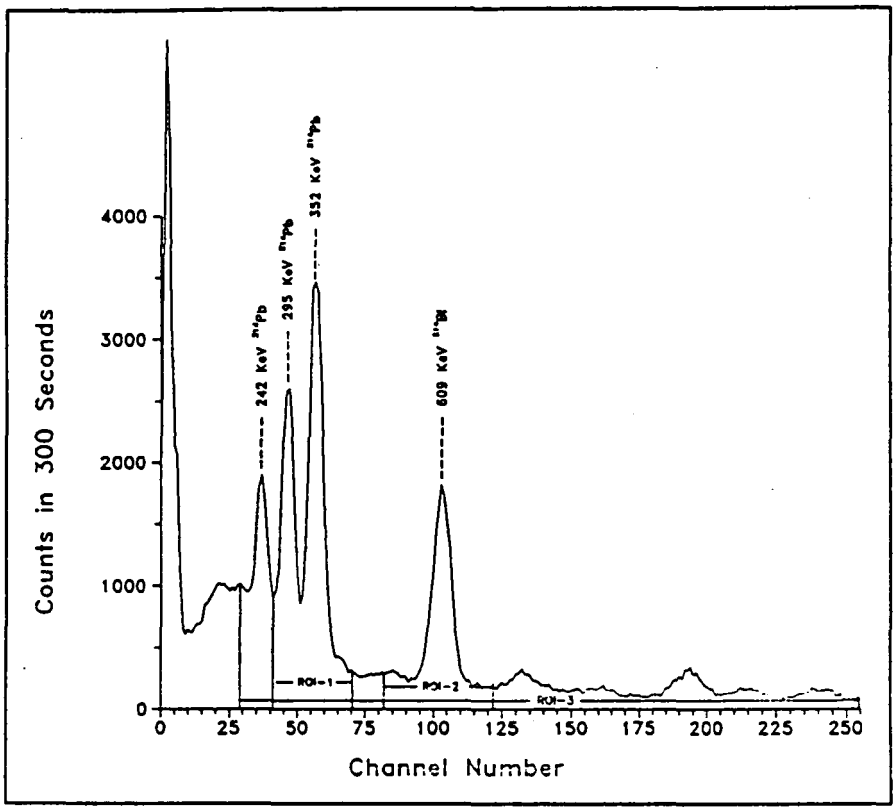

Figure 2. Sample spectrum showing the three ROI's.

Location of the ROI's is accomplished by collecting a spectrum from a Natural Uranium Source. Then a computer program (FLUX1.BAS), using predetermined starting locations, searches out the channel number of the minimum (M2) between the 242 keV and 295 keV peaks from lead-214, the channel numbers of the peaks from the 295 keV (P2) and 352 keV (P4) lead lines, and the peak from the 609 keV (P6) bismuth line. The channel numbers of these reference points, the window parameters, and the count rates for the three ROI's are written to two files. The first file (CHANNELS.HST) documents the history of execution of FLUX1.BAS. The second file (CHANNELS.DAT) is used to temporarily store this same information for use by other succeeding programs. The information in this file is updated each time that FLUX1.BAS is executed.

A second program (FLUX2.BAS) is used to collect the gross counts in the three ROI's for a standard blank sample. A standard blank is a blank which is known to have no radon sorbed on the charcoal. This program

collects a spectrum for the standard blank, reads the file containing the reference channel numbers, window parameters, and establishes the three ROI's. The number of counts in each of the ROI's are displayed on the screen and written to two files. The first file (BKGSTD.HST) documents a history of the standard blank counted and contains information regarding the can label, the date and time counted, and the count rate, in counts/sec, for ROI-1, ROI-2, and ROI-3. The second file (BKGSTD.DAT) is used to temporarily store the count rate from the three ROI's to be used by other programs during the remainder of the day's counting.

A third program (FLUX3.BAS) is used to collect the gross counts in the three ROI's for the field blank. This program collects a spectrum for the field blank, reads the file containing the reference channel numbers, window parameters, and establishes the three ROI's. The number of counts in each of the ROI's are displayed on the screen and written to two files. The first file (BKGFLUX.HST) documents the history of the field blanks counted and contains information from the can label, the date and time counted, the count rate in counts/sec for ROI-1, ROI-2, and ROI-3. The second file (BKGFLUX.DAT) is used to temporarily store the count rate from the three ROI's for future use by other programs during the remainder of the days counting.

The fourth and final program (FLUX4.BAS) is used to acquire a spectrum from each of the samples exposed in the LAACC's, and to compute the measured radon flux density for the samples. Additionally this program is used to count the reference standards.

This program inputs the reference points for the three ROI's, and the blank count rate from the appropriate files. The net counts in the three ROI's are then computed and applied to the following formula to calculate the measured radon flux density.

$$J=\frac{C\lambda^2}{KA\,(1-e^{-\lambda T1})\,(e^{-\lambda(T2-T1)}-e^{-\lambda(T3-T1)})}$$

Where:

J = *Measured Radon Flux Density* ($pCi \cdot m^{-2} \cdot sec^{-1}$)
C = *Net Counts for the ROI* (*counts*)
λ = *Decay Constant for Rn-222* (sec^{-1})
K = *Calibration Factor for the ROI* (*cps/pCi*)
A = *Area of the Collector* (m^2)
$T1$ = *Exposure Time* (sec)
$T2$ = Δt, *Start of Exposure to Start of Counting* (sec)
$T3$ = Δt, *Start of Exposure to End of Counting* (sec)

FLUX4.BAS reads a data file called PROJECT.DAT, which contains an eight character name assigned to the project. Before beginning a new project the user must edit this file and change the name to something appropriate for the project being conducted. Hereafter this project name will be referred to as FILE$. This file may be edited by any general purpose text editor which produces an ASCII file as the end product. The file name must remain PROJECT.DAT. The project name is

used by FLUX4.BAS to name two output data files. The first file (with a .DAT extension) contains the processed data for the sample, such as: sample ID, sample location, date and time counted, date and time placed and retrieved, the ROI parameters used, the net counts for the three ROI's, and the calculated results. The second file (with a .SPM extension) contains the sample ID, sample location, and the spectrum.

Sequential Instructions

1. Power up the Nim-Bin which houses the electronics for the NaI crystal.

2. Turn on the computer. Assure the printer is turned on and is "on line." At the menu type MCA2 <cr> to start the TSR software for the MCA2 card. Press any key to bring up the graphics mask for the MCA2 card.

3. When the graphics mask for the card appears, terminate execution of the software and return to DOS by pressing the F-10 function key (MORE) followed by the F-9 function key (DOS).

4. Check the date of the computer by typing DATE <cr>. Enter the correct date if needed. Check the time of the computer by typing TIME <cr>. Enter the correct time if needed.

5. Enter the basic interpreter by typing BASICA <cr>.

6. Load and run the program FLUX1.BAS. To load a program either type LOAD followed by the filename that you wish to load and a <cr>, or press the F-3 function key, type the file name that you wish to load, then a <cr>. To run a program either type RUN <cr>, or press the F-2 function key. At the prompt place the Natural Uranium Source, exactly centered on the crystal, red side up, and close the lid on the lead pig.

7. When the program has completed execution the spectrum will be displayed on the screen for inspection. Press ENTER to continue. The channel reference points, and the count rates for the three ROI's will be displayed on the screen. Record this information in the log book for the counting system, along with the date and time that the Natural Uranium Source was counted. Remove the Natural Uranium Source and return it to its designated storage location.

8. Load and run the program FLUX2.BAS. Place the standard blank exactly centered on the crystal, and close the lid on the lead pig. Enter "Y" to acquire the spectrum.

9. When the program has completed execution the spectrum will be displayed on the screen, and the prompt "press ENTER to continue" will appear in the lower left portion of the screen. Continuing execution of the program at this point will extract the data from the spectrum and write the necessary output.

10. Load and run the program FLUX3.BAS. At the prompt enter the date and time that the field blank was canned. Place the field blank exactly centered on the crystal, and close the lid on the lead pig. Enter "Y" to acquire the spectrum.

11. When the program has completed execution the spectrum will be displayed on the screen, and the prompt "press ENTER to continue" will appear in the lower left portion of the screen. Continuing execution of the program at this point will extract the data from the spectrum and write the necessary output.

12. Ensure that the printer is turned on, and is on-line. Load and run the program FLUX4.BAS.

13. Begin the sample set by counting the first of the Radium-on-Charcoal standards. Enter the standard ID number (the source serial number), place the standard exactly centered on the crystal with the lid up, and close the lid on the lead pig. At the prompt "Is this a standard ?" type "Y" <cr>. Enter "Y" to acquire the spectrum.

14. When the program has completed execution, the spectrum will be displayed on the screen, and the prompt "press ENTER to continue" will appear in the lower left portion of the screen. Press "ENTER" to continue. Note the result printed on the screen. If the average of the three ROI's for the calculated total activity of the standard differs by more than five percent from the certified value a problem may exist with the counting system, and the situation must be identified and resolved before continuing.

15. Run program FLUX4.BAS again by pressing the F-2 function key. Replace the first standard with the second and repeat steps 13 and 14.

16. If both standards have been successfully counted you may begin counting unknown samples. Inspect each of the unknown samples for possible external contamination. Any evidence of this, such as soil clinging to the can must be removed prior to placing the can on the crystal.

17. Run the program FLUX4.BAS by depressing the F-2 function key. At the prompt "Is this a standard ?" enter "N" or press ENTER to indicate that the sample is not a standard. The program will return with a series of questions concerning the sample ID, location, date and time placed, and the date and time removed. Enter the required information from the data on the can label. Place the can exactly centered on the crystal, and close the lid on the lead pig. Enter "Y" to continue. When the program has completed execution the spectrum will be displayed on the screen, and the prompt "press ENTER continue" will appear in the lower left portion of the screen. Press "ENTER" to continue, this will cause the data to be extracted from the spectrum, the results to be calculated, the data file for the project (FILE$) to be updated, and a print-out of the results to be generated.

18. Continue to run the program FLUX4.BAS until all of the scheduled unknowns, spikes, and blanks have been counted. Five percent of the scheduled counting must include either blanks, or spikes. The standards may be used for spikes. Additionally every 10th can must be counted twice. The recounts should be performed at the end of the scheduled counting.

19. When all of the scheduled counting of the unknowns, spikes and blanks has been accomplished, the two Radium-on-Charcoal standards must be counted again. If the results are not within the specified limits (5%) the problem must be identified and corrected. Additionally the data from that day's counting must be examined to determine its validity. Any cans which yielded questionable data should be recounted when proper operation of the counting system has been restored.

20. To obtain a print-out of the data, load and run the basic program FILREAD1.BAS. This program reads the data file (FILE$) and reproduces the print-out obtained during the counting.

21. The following files should be backed-up to floppy disks and filed with the project files on a daily basis:

    CHANNELS.HST
    BKGFLUX.HST
    FILE$.DAT Where FILE$ is a new name given to each project.
    FILE$.SPM

7.0 CALIBRATION

General

Calibration of the counting system is performed to ensure that the system is functioning properly, and that the calibration coefficients used by the program FLUX4.BAS produce accurate results. Because the counting system may be used intermittently there is no regularly defined calibration interval. The maximum interval between calibrations is six months. Thus under continuous use the system requires recalibration at least every six months. The system requires recalibration if any of the components have been replaced or modified. It is good practice to recalibrate the system before starting any major project, regardless of when the calibration period expires.

Detailed instructions for calibration of the counting system are found in reference [2].

8.0 RECORD KEEPING

Field Activities

A field note book is to be kept to record information concerning the field activities associated with conducting the measurements. Specific information which must be recorded in the notebook includes:

- The name and location of the area where the measurements are to be conducted
- The names of the field crew
- A brief description of how the sampling points were located and identified
- A map of the region on which the measurements are to be made, indicating the individual sample locations.
- Observations of the weather parameters both before and during the measurement period
- A tabulation of the following parameters for each sampling point:

  Collector Number
  Sample ID
  Sample Location
  Date and Time Placed
  Date and Time Retrieved
  Initials of the Person Handling the Collector
  A Comment Field

Each of the sample cans must have a label which contains the following information:

Sample ID
Sample Location
Date and Time Placed
Date and Time Retrieved
Initials of Field Personnel

Laboratory Activities

A logbook is maintained for the counting system. The logbook is used to record the calibration activities associated with the system along with a running history of the system usage. The logbook contains an updated listing of the components of the system, and the current settings for all controls. The components are identified by the manufacturer's name, model number and serial number.

During routine usage an entry is made in the logbook each time that the Natural Uranium Source is counted, eg. each time that FLUX1.BAS is run. The following information is recorded in the logbook:

- Date and Time That the Standard was Counted
- M2; Channel No. of the minimum before the 295 keV Peak
- P2 ; Channel No. of the 295 keV Peak
- P4 ; Channel No. of the 352 keV Peak
- P6 ; Channel No. of the 609 keV Peak
- The Channels Included in ROI-1, and ROI-2
- The Count Rate (counts/sec) for ROI-1, ROI-2, and ROI-3
- Initials of Operator and Date

APPENDIX B

Weather Data

Table B-1: Relevant weather data for measurements on Waste Pit 1

Table B-2: Relevant weather data for measurements on Waste Pit 2

Table B-3: Relevant weather data for measurements on Waste Pit 3

TABLE B-1
RELEVANT WEATHER DATA FOR MEASUREMENTS ON WASTE PIT 1

Date	Time (EST)	FEMP Met. Tower Temp. 10 m Station Deg C	FEMP Met. Tower Rain Fall in.	Metrosonics Data Logger P1-038 Soil Deg C	Metrosonics Data Logger P1-038 Air Deg C	Metrosonics Data Logger P1-029 Soil Deg C	Metrosonics Data Logger P1-029 Air Deg C
11-20-91	11:00	17.9	0.00	-----	-----	-----	-----
	12:00	18.2	0.00	-----	-----	-----	-----
	13:00	18.3	0.00	-----	-----	-----	-----
	14:00	18.5	0.00	-----	-----	-----	-----
	15:00	19.1	0.00	-----	-----	-----	-----
	16:00	19.2	0.00	-----	-----	-----	-----
	17:00	19.0	0.00	-----	-----	-----	-----
	18:00	18.8	0.00	-----	-----	-----	-----
	19:00	18.6	0.00	-----	-----	-----	-----
	20:00	18.6	0.00	-----	-----	-----	-----
	21:00	17.5	0.00	-----	-----	-----	-----
	22:00	12.4	0.02	-----	-----	-----	-----
11-20-91	23:00	11.4	0.00	-----	-----	-----	-----
11-21-91	00:00	11.1	0.00	-----	-----	-----	-----
	01:00	10.9	0.00	-----	-----	-----	-----
	02:00	10.8	0.00	-----	-----	-----	-----
	03:00	10.7	0.00	-----	-----	-----	-----
	04:00	10.6	0.00	-----	-----	-----	-----
	05:00	10.8	0.00	-----	-----	-----	-----
	06:00	11.3	0.00	-----	-----	-----	-----
	07:00	11.1	0.00	-----	-----	-----	-----
	08:00	10.7	0.00	-----	-----	-----	-----
	09:00	10.8	0.00	-----	-----	-----	-----
	10:00	11.0	0.00	-----	-----	-----	-----
First LAACC placed at 10:47 EST							
	11:00	10.6	0.00	11.6	10.7	11.4	10.8
	12:00	10.4	0.00	11.5	9.8	11.3	9.8
	13:00	10.0	0.00	11.6	10.1	11.3	10.0
	14:00	10.0	0.00	11.8	10.2	11.4	10.0
	15:00	10.4	0.00	12.3	10.9	11.8	10.7
	16:00	10.8	0.00	12.1	11.1	11.5	11.0
	17:00	10.8	0.00	11.4	10.2	11.1	10.6
	18:00	10.5	0.00	11.2	9.8	10.9	10.2
	19:00	10.4	0.00	11.1	9.5	10.8	9.9
	20:00	10.3	0.00	10.9	9.3	10.7	9.5
	21:00	10.1	0.00	10.8	9.3	10.7	9.4
	22:00	10.0	0.00	10.7	9.2	10.6	9.3
11-21-91	23:00	9.9	0.00	10.7	9.1	10.5	9.3
11-22-91	00:00	9.8	0.00	10.6	8.9	10.4	9.2
	01:00	9.5	0.00	9.9	6.6	9.9	7.3
	02:00	8.9	0.00	9.5	6.3	9.6	6.9
	03:00	8.6	0.00	9.4	6.1	9.4	6.7
	04:00	8.2	0.00	9.4	6.6	9.4	6.9
	05:00	8.3	0.00	9.7	7.9	9.7	8.1
	06:00	8.8	0.00	9.7	8.4	9.7	8.6
	07:00	9.0	0.00	9.8	8.4	9.7	8.5
	08:00	9.1	0.00	9.7	8.6	9.7	8.8
	09:00	9.4	0.00	9.8	8.9	9.8	9.1
	10:00	9.8	0.00	10.3	9.8	10.1	9.9
	11:00	10.1	0.00	10.9	10.7	10.6	10.4
	12:00	10.6	0.00	11.9	11.7	11.5	11.3
11-22-91	13:00	10.9	0.00	12.6	12.3	12.1	12.1

TABLE B-2
RELEVANT WEATHER DATA FOR MEASUREMENTS ON WASTE PIT 2

Date	Time (EST)	FEMP Met. Tower Temp. 10 m Station Deg C	FEMP Met. Tower Rain Fall in.	Metrosonics Data Logger P1-038 Soil Deg C	Metrosonics Data Logger P1-038 Air Deg C	Metrosonics Data Logger P1-029 Soil Deg C	Metrosonics Data Logger P1-029 Air Deg C
11-17-91	08:00	0.9	0.08	-----	-----	-----	-----
	09:00	1.9	0.00	-----	-----	-----	-----
	10:00	4.3	0.00	-----	-----	-----	-----
	11:00	6.7	0.00	-----	-----	-----	-----
	12:00	8.8	0.00	-----	-----	-----	-----
	13:00	10.6	0.00	-----	-----	-----	-----
	14:00	12.5	0.00	-----	-----	-----	-----
	15:00	13.3	0.00	-----	-----	-----	-----
	16:00	13.2	0.00	-----	-----	-----	-----
	17:00	13.3	0.00	-----	-----	-----	-----
	18:00	12.5	0.00	-----	-----	-----	-----
	19:00	11.6	0.00	-----	-----	-----	-----
	20:00	10.6	0.00	-----	-----	-----	-----
	21:00	9.6	0.00	-----	-----	-----	-----
	22:00	9.2	0.00	-----	-----	-----	-----
11-17-91	23:00	9.2	0.00	-----	-----	-----	-----
11-18-91	00:00	10.1	0.00	-----	-----	-----	-----
	01:00	10.1	0.00	-----	-----	-----	-----
	02:00	10.0	0.00	-----	-----	-----	-----
	03:00	9.9	0.00	-----	-----	-----	-----
	04:00	10.1	0.00	-----	-----	-----	-----
	05:00	11.5	0.00	-----	-----	-----	-----
	06:00	12.5	0.00	-----	-----	-----	-----
	07:00	13.9	0.00	-----	-----	-----	-----
First LAACC place at 07:52 EST							
	08:00	14.5	0.00	-----	-----	-----	-----
	09:00	15.2	0.00	8.8	13.4	8.9	13.9
	10:00	15.8	0.15	10.0	15.1	10.0	15.3
	11:00	17.0	0.00	11.2	15.7	11.1	15.7
	12:00	17.3	0.00	12.3	16.7	12.0	16.3
	13:00	19.2	0.00	12.9	17.0	12.6	16.7
	14:00	18.7	0.00	14.9	19.3	14.1	19.4
	15:00	17.3	0.00	14.2	15.4	13.5	15.6
	16:00	18.1	0.00	14.2	17.1	13.7	17.2
	17:00	18.2	0.00	14.1	16.9	13.7	16.9
	18:00	18.6	0.00	13.8	17.2	13.5	17.7
	19:00	18.6	0.00	13.7	16.6	13.3	15.9
	20:00	18.3	0.00	13.5	16.7	13.2	17.2
	21:00	17.5	0.00	13.5	16.1	13.2	15.8
	22:00	17.9	0.00	13.4	16.3	13.2	16.4
11-18-91	23:00	17.6	0.00	13.2	16.1	12.9	16.6
11-19-91	00:00	17.5	0.00	12.8	15.5	12.7	16.0
	01:00	17.4	0.00	12.8	16.1	12.7	16.6
	02:00	16.9	0.00	11.4	14.6	11.3	15.1
	03:00	17.0	0.00	12.6	15.3	12.5	15.7
	04:00	16.9	0.00	9.9	13.3	9.9	13.7
	05:00	16.5	0.00	11.2	13.6	11.1	14.2
	06:00	16.1	0.00	11.0	13.4	11.0	14.2
	07:00	16.4	0.00	10.9	13.4	10.9	13.8
	08:00	16.4	0.00	11.1	14.3	11.1	14.6
	09:00	17.6	0.00	11.6	13.3	11.6	13.4
	10:00	18.5	0.00	10.7	12.3	10.6	12.7
11-19-91	11:00	18.7	0.00	12.8	15.1	12.7	15.2

TABLE B-3
RELEVANT WEATHER DATA FOR MEASUREMENTS ON WASTE PIT 3

Date	Time (EST)	FEMP Met. Tower Temp. 10 m Station Deg C	FEMP Met. Tower Rain Fall in.	Metrosonics Data Logger P1-038 Soil Deg C	Metrosonics Data Logger P1-038 Air Deg C	Metrosonics Data Logger P1-029 Soil Deg C	Metrosonics Data Logger P1-029 Air Deg C
11-13-91	11:00	6.6	0.00	-----	-----	-----	-----
	12:00	8.1	0.00	-----	-----	-----	-----
	13:00	9.2	0.00	-----	-----	-----	-----
	14:00	9.8	0.00	-----	-----	-----	-----
	15:00	10.7	0.00	-----	-----	-----	-----
	16:00	11.2	0.00	-----	-----	-----	-----
	17:00	10.4	0.00	-----	-----	-----	-----
	18:00	9.6	0.00	-----	-----	-----	-----
	19:00	8.8	0.00	-----	-----	-----	-----
	20:00	8.0	0.00	-----	-----	-----	-----
	21:00	7.9	0.00	-----	-----	-----	-----
	22:00	7.5	0.00	-----	-----	-----	-----
11-13-91	23:00	6.8	0.00	-----	-----	-----	-----
11-14-91	00:00	5.7	~~0.03~~I	-----	-----	-----	-----
	01:00	4.7	~~0.02~~I	-----	-----	-----	-----
	02:00	2.7	0.00	-----	-----	-----	-----
	03:00	1.5	0.00	-----	-----	-----	-----
	04:00	1.2	0.00	-----	-----	-----	-----
	05:00	1.4	0.00	-----	-----	-----	-----
	06:00	1.4	0.00	-----	-----	-----	-----
	07:00	1.3	0.00	-----	-----	-----	-----
	08:00	2.8	~~0.02~~I	-----	-----	-----	-----
	09:00	7.7	0.00	-----	-----	-----	-----
	10:00	11.7	0.00	-0.2	2.2	1.3	2.4
First LAACC place at 10:21 EST							
	11:00	13.0	0.00	-0.1	7.7	0.8	6.6
	12:00	13.9	0.00	4.3	11.9	4.9	12.1
	13:00	14.6	0.00	5.8	11.8	5.7	11.8
	14:00	15.3	0.00	5.1	10.7	4.7	10.5
	15:00	15.5	0.00	7.0	11.3	5.5	11.3
	16:00	14.9	0.00	7.9	12.1	5.8	11.9
	17:00	14.3	0.00	8.9	12.6	6.6	12.1
	18:00	14.1	0.00	8.4	10.7	5.9	10.2
	19:00	13.4	0.00	Data Logger Power Failure			
	20:00	12.4	0.00	-----	-----	-----	-----
	21:00	12.4	0.00	-----	-----	-----	-----
	22:00	12.8	0.00	-----	-----	-----	-----
11-14-91	23:00	12.7	0.00	-----	-----	-----	-----
11-15-91	00:00	11.9	0.00	-----	-----	-----	-----
	01:00	12.4	0.00	-----	-----	-----	-----
	02:00	12.3	0.00	-----	-----	-----	-----
	03:00	11.9	0.00	-----	-----	-----	-----
	04:00	11.2	0.00	-----	-----	-----	-----
	05:00	10.8	0.00	-----	-----	-----	-----
	06:00	10.4	0.00	-----	-----	-----	-----
	07:00	10.2	0.00	-----	-----	-----	-----
	08:00	11.0	0.00	-----	-----	-----	-----
	09:00	12.9	0.00	-----	-----	-----	-----
	10:00	13.8	0.00	-----	-----	-----	-----
	11:00	12.9	0.00	-----	-----	-----	-----
	12:00	12.1	0.00	-----	-----	-----	-----
11-15-91	13:00	11.4	0.00	-----	-----	-----	-----

I = Data was invalidated due to a biological interference