United States
Environmental Protection
Agency
Office of Radiation Programs

Eastern Environmental
Radiation Facility
1890 Federal Drive
Montgomery, AL 36109

EPA 520/5-88-021
October 1988

Radiation

EPA

A Long-Term Study of Radon and Airborne Particulates at Phosphogypsum Stacks in Central Florida

EPA 520/5-88-021

A STUDY OF RADON AND AIRBORNE PARTICULATES AT PHOSPHOGYPSUM STACKS IN CENTRAL FLORIDA

BY

T.R. Horton, R.L. Blanchard, and S.T. Windham

U.S. Environmental Protection Agency
Office of Radiation Programs
Eastern Environmental Radiation Facility
1890 Federal Drive
Montgomery, AL 36109

DISCLAIMER

Mention of any specific product or trade name in this report does not imply an endorsement or guarantee on the part of the Environmental Protection Agency.

CONTENTS

		Page
	List of Figures	vii
	List of Tables	ix
	Abstract	xi
	Acknowledgments	xiii
1.	INTRODUCTION	1-1
	1.1 Purpose	1-1
	1.2 The Process	1-2
	1.3 The Source	1-5
2.	SITE SELECTION AND STACK DESCRIPTION	2-1
	2.1 Site Selection	2-1
	2.2 Site and Stack Description	2-1
	2.2.1 Gardinier's phosphogypsum stack	2-4
	2.2.2 W.R. Grace's phosphogypsum stack	2-4
	2.2.3 Royster's phosphogypsum stack	2-7
	2.2.4 Conserv's phosphogypsum stack	2-7
	2.2.5 Estech's phosphogypsum stack	2-10
3.	STUDY DESIGN	3-1
	3.1 Measurement Objectives	3-1
	3.1.1 Radon Flux	3-1
	3.1.2 Radionuclide content of phosphogypsum samples	3-2

CONTENTS - Continued

Page

3.1.3 Moisture content of phosphogypsum samples 3-2

3.1.4 Airborne particulate samples 3-2

3.1.5 Airborne radon 3-3

3.1.6 Gamma-ray exposures 3-4

3.2 Methods 3-4

3.2.1 Radon Flux 3-4

3.2.2 Phosphogypsum sample collection and analyses 3-7

3.2.3 Moisture content determination of phosphogypsum samples 3-7

3.2.4 Airborne particulate sample collection 3-7

3.2.5 Airborne radon measurements 3-8

3.2.6 Gamma-ray exposure measurements 3-9

3.2.7 Background sample collection and measurements . . . 3-9

3.3 Sampling Program 3-9

3.3.1 General 3-9

3.3.2 Sampling program at the Gardinier site 3-10

3.3.3 Sampling program at the W.R. Grace site 3-14

3.3.4 Sampling program at the Royster site 3-18

3.3.5 Sampling program at the Conserv site 3-20

3.3.6 Sampling program at the Estech site 3-23

3.3.7 Background sampling program 3-25

3.4 Quality Assurance 3-29

3.4.1 Charcoal canisters (LAACC) 3-29

CONTENTS - Continued

Page

3.4.2 Moisture content of phosphogypsum 3-29

3.4.3 High-volume airborne particulate samples 3-30

3.4.4 Particle sizing samples 3-30

3.4.5 Sample representativeness and comparability 3-31

3.4.6 Sampling procedures 3-31

3.4.7 Sample custody 3-32

3.4.8 Calibration procedures and frequency 3-33

3.4.9 Analytical procedures 3-34

3.4.10 Internal quality control checks and frequency . . . 3-35

3.4.11 Data precision, accuracy, and completeness 3-36

4. RESULTS 4-1

4.1 Radon-222 Flux 4-1

4.2 Radionuclide Content of Phosphogypsum 4-7

4.3 Airborne Radioactive Particulate Concentrations and Particle Size 4-13

4.3.1 General 4-13

4.3.2 High-Volume Samples 4-13

4.3.3 Particle Size of Airborne Samples 4-18

4.4 Airborne Radon Concentrations 4-24

4.5 Gamma-Ray Exposures 4-32

4.6 Summary of Results 4-36

CONTENTS - Continued

		Page
5.	CONCLUSIONS	5-1
6.	REFERENCES	6-1

APPENDICES

A.	Individual radon flux and moisture content values for phosphogypsum stacks and background soils	A-1
B.	Radionuclide concentrations measured in high-volume air samples and particle size samples	B-1
C.	Radionuclide concentrations in background soil samples	C-1
D.	Outdoor radon concentrations	D-1
E.	Quality assurance results	E-1
F.	The average radon-222 flux measured during each sampling period on the phosphogypsum stacks	F-1

LIST OF FIGURES

		Page
1-1	Wet process for phosphoric acid manufacture in the United States	1-4
1-2	Geographic distribution of phosphate rock production in the United States	1-6
1-3	Location of phosphogypsum facilities in the United States	1-9
2-1	Locations of companies participating in field monitoring study	2-3
2-2	Site map of Gardinier, Inc.	2-5
2-3	Site map of W.R. Grace and Co.	2-6
2-4	Site map of Royster Co.	2-8
2-5	Site map of Conserv, Inc.	2-9
2-6	Site map of Estech General Chemicals Corporation	2-11
3-1	The Large Area Activated Charcoal Canister	3-5
3-2	Monitoring locations at Gardinier, Inc.	3-12
3-3	Monitoring locations at W.R. Grace's south stack	3-15
3-4	Monitoring locations at Royster Company	3-19
3-5	Monitoring locations at Conserv's west stack	3-21
3-6	Monitoring locations at Estech General Chemicals Corporation	3-24
3-7	Background monitoring locations	3-26

LIST OF TABLES

		Page
1.1	The principal phosphogypsum stacks in the United States	1-10
2.1	Description of the five participating stacks	2-2
3.1	A summary of the monitoring program at the five phosphogypsum sites	3-11
4.1	The average radon flux at each location on the phosphogypsum stacks	4-3
4.2	The annual average radon flux on each phosphogypsum stack . . .	4-5
4.3	The average moisture content of the phosphogypsum at each location on the Estech stack	4-6
4.4	Radium-226 in phosphogypsum samples	4-8
4.5	A summary of the radium-226 concentrations in phosphogypsum samples	4-10
4.6	Radioactivity in composite phosphogypsum samples	4-11
4.7	Average concentrations of the major radionuclides in the composite phosphogypsum samples	4-13
4.8	Specific radionuclide concentrations in air samples collected at the W.R. Grace stack and a background site . . .	4-16
4.9	Net radionuclide concentrations in air at the W.R. Grace stack	4-17
4.10	Radionuclide concentrations in particulates of different particle sizes, pCi/m^3	4-21

Page

4.11 The average percent of radionuclides in each particle size range 4-23

4.12 Corrected outdoor radon concentrations measured in air at individual sampling locations, pCi/L 4-26

4.13 A summary of the average outdoor radon concentrations in air, pCi/L 4-29

4.14 A comparison of the radon flux with the radon concentration in air at each stack 4-31

4.15 Gamma-ray exposure rate measurements at phosphogypsum sample locations 4-33

4.16 Average gamma-ray exposure rates measured over each phosphogypsum stack 4-35

4.17 A summary of measurements conducted during the one-year phosphogypsum study 4-36

4.18 Tabulation of selected parameters related to radon flux 4-38

4.19 A comparison of the average radon flux, Ra-226 concentrations, and gamma-ray exposure rates on the five phosphogypsum stacks 4-40

4.20 Average net concentrations of radionuclides in high-volume air samples 4-42

4.21 Average airborne radon concentrations near phosphogypsum stacks 4-46

ABSTRACT

The EPA is presently assessing the significance of radioactive emissions from phosphogypsum stacks to determine if they should be regulated under the Clean Air Act. As part of this assessment, a one-year study was conducted to measure the airborne radionuclide emissions from five phosphogypsum stacks in central Florida. This report provides a detailed description of this study.

Measurements were conducted over a 12-month period on four active and one inactive phosphogypsum stacks. The study included the following measurements: 1260 radon-222 flux, 90 ambient radon-222, and 50 gamma-ray exposure rates. Also, radionuclide analyses were performed on 33 airborne particulate samples, 9 airborne particle-size samples, and 50 phosphogypsum samples.

The annual average radon flux determined for the dry-loose material on top of active phosphogypsum stacks was 20 pCi/m^2-s, and is regarded as representative of stacks in the central Florida region. The annual average flux on the top surface of the inactive stack was 4 to 5 times smaller, due to a surface crust. The data suggest that to obtain a representative annual average radon flux on a phosphogypsum stack the total number of measurements made is more important than the period of time over which the measurements are made.

Information concerning the gamma-ray exposure rates on and near phosphogypsum stacks, the ambient radon-222 levels near stacks, and the significance of resuspended particulate matter from stacks is also provided. The relationships between the radon flux and the radionuclide content and moisture content of the phosphogypsum are discussed.

ACKNOWLEDGMENTS

The authors express their gratitude to Mike Gilley and his staff (Wesley Nall, Tom McNally, and Lee Forgey) at the Polk County Health Department, Winter Haven, Florida, for their dedication and excellence in conducting the day-to-day field activities involved in this study. Without their help this study would have been impossible. The authors also wish to thank Ted Houston and Armando Rodriguez of Conserv, Inc., J.R. Perrin of Estech, Inc., Steve Boswell of Gardinier, Inc., Randy Melton of W.R. Grace and Co., and Ted Schmalz of Royster Co. for their excellent cooperation in letting us conduct measurements on their plant sites.

The help provided by a number of reviewers of this report, especially Mr. Paul Magno (Office of Radiation Programs, Washington, D.C.), Dr. James Watson (University of North Carolina, Chapel Hill, N.C.), and Dr. Gordon Nifong (Florida Institute of Phosphate Research, Bartow, FL), is greatly appreciated. The dedication and patience displayed by Mardy Wilkes in typing the many drafts of this report are especially appreciated.

1. INTRODUCTION

1.1 Purpose

Phosphate rock contains elevated concentrations of U-238 and its decay products. In 1985, about 51 million metric tons of marketable phosphate rock were produced in the United States. Most of this phosphate rock is used in the production of fertilizers. Phosphogypsum is a by-product material produced in large amounts during the production of phosphoric acid. The phosphogypsum contains most of the radium-226 originally present in the phosphate rock and is stored in large stacks (piles) near the fertilizer facility. There are currently 62 phosphogypsum stacks in the United States covering more than 3,300 hectares.

Because phosphogypsum stacks release radionuclides, particularly radon-222, into the air, the EPA is presently assessing the significance of these emissions to determine if they should be regulated under Section 112 of the Clean Air Act. As a part of this assessment, a study was conducted to measure the radionuclide emissions from phosphogypsum stacks. This report describes the results of a year-long study of the radionuclide emissions from 5 phosphogypsum stacks in central Florida.

1.2 The Process

The most prevalent use of phosphate rock is for the production of phosphoric acid, accounting for about 80 percent of the U.S. ore production. In 1985 there were 29 facilities in the United States producing phosphoric acid from phosphate rock by the wet process in which the rock is acidulated to form the acid. The average wet process plant can produce about 700 metric tons of phosphoric acid per day. Most of the phosphoric acid is used in the production of agricultural fertilizers.

Figure 1-1 is a diagram of the wet process for manufacturing phosphoric acid. The production involves four primary operations: raw material feed preparation, phosphate rock digestion, filtration, and concentration. In most installations the phosphate ore is dried in direct-fired rotary kilns and ground to a fineness of less than 150 μm for improved reactivity during acidulation. The key feature in the plant is the acidulator (digester), the reaction vessel in which ground phosphate rock is digested with sulfuric acid (H_2SO_4) to produce orthophosphoric acid (28 percent P_2O_5) and gypsum. The primary reaction is:

$$Ca_3(PO_4)_2 + 3H_2SO_4 + 2H_2O \rightarrow \underset{\text{Phosphoric Acid}}{2H_3PO_4} + \underset{\text{gypsum}}{3CaSO_4 \cdot 2H_2O}.$$

Sulfuric acid used in the wet process is either manufactured on site or piped from a nearby sulfuric acid manufacturer. The slurry from the digester, which consists of calcium sulfate (gypsum) and phosphoric acid, is pumped to a vacuum filter for separation of gypsum solids from the liquid (28 percent P_2O_5) phosphoric acid. The filter cake is dried by suction, the filter pan is inverted, and the cake is then washed from the filter. The phosphoric acid from the filtration stage, which contains 28 percent P_2O_5, is concentrated to 54 percent P_2O_5 (75 percent H_3PO_4) by vacuum evaporation of the water. The concentrated phosphoric acid may be blended with the lower concentration acid for use in a variety of products.

The gypsum (calcium sulfate) is the principal by-product from wet process phosphoric acid production. The gypsum is transferred as a slurry to on-site disposal areas, which are referred to as gypsum stacks. The gypsum stacks are usually constructed directly on virgin or mined-out land with little or no preparation of the land surface. The gypsum slurry is pumped to the top of the stack, where it forms a small impoundment commonly referred to as a gypsum pond. Gypsum is dredged from the pond on top of the stack and used to increase the height of the dike surrounding the pond.

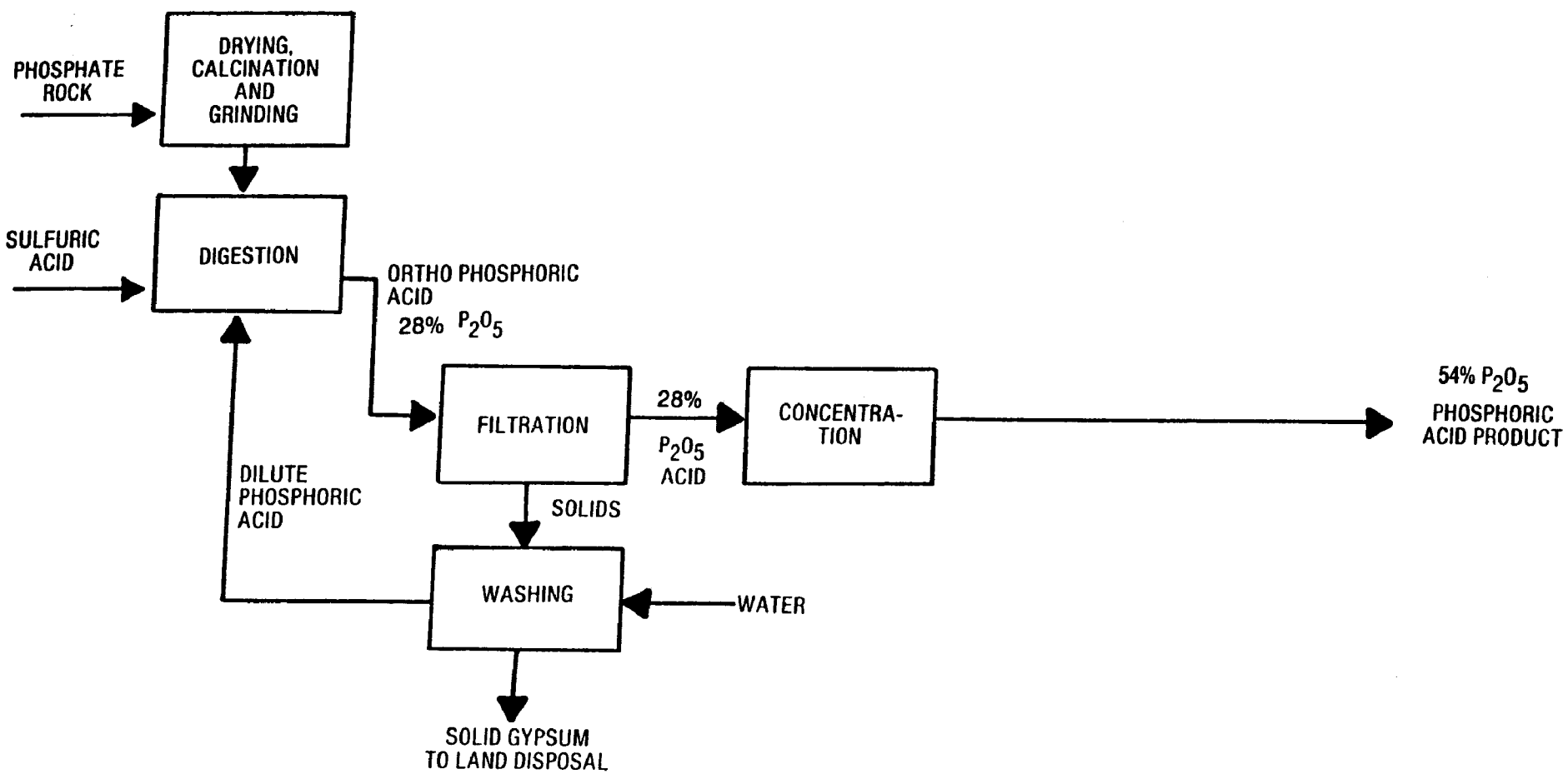

Figure 1-1. Wet process for phosphoric acid manufacture in the United States (Pe83).

1.3 The Source

In 1985, approximately 175 million metric tons of phosphate rock were mined in the United States, which yielded 51 million metric tons of marketable ore (BOM85). Principal phosphate rock mining states and their percent of U.S. production are Florida (80 percent); Idaho (7 percent); North Carolina (6 percent); Tennessee (3 percent); Utah (2 percent); and minor amounts from Alabama and Wyoming, as shown in Figure 1-2.

Phosphate rock deposits contain appreciable quantities of uranium and its decay products. The uranium concentration in phosphate rock ranges from about 20 to 200 ppm*, which is 10 to 100 times higher than the uranium concentration in typical rocks and soils (2 ppm). The principal radionuclides in phosphate rock are: uranium-238, uranium-234, thorium-230, radium-226, radon-222, lead-210, and polonium-210. When phosphate rock is processed, the radionuclides can be released into the environment. In the acidulation process there is a selective separation and concentration of radionuclides. Most of the radium-226, about 80 percent, follows the phosphogypsum while about 85 percent of the uranium and 70 percent of the thorium are found in the phosphoric acid. These radionuclides, particularly radium-226, are deposited along with the phosphogypsum onto the stacks of by-product material and are possible sources of airborne radioactivity.

---

*1 part-per-million (ppm) of uranium-238 = 0.746 dpm per gram.

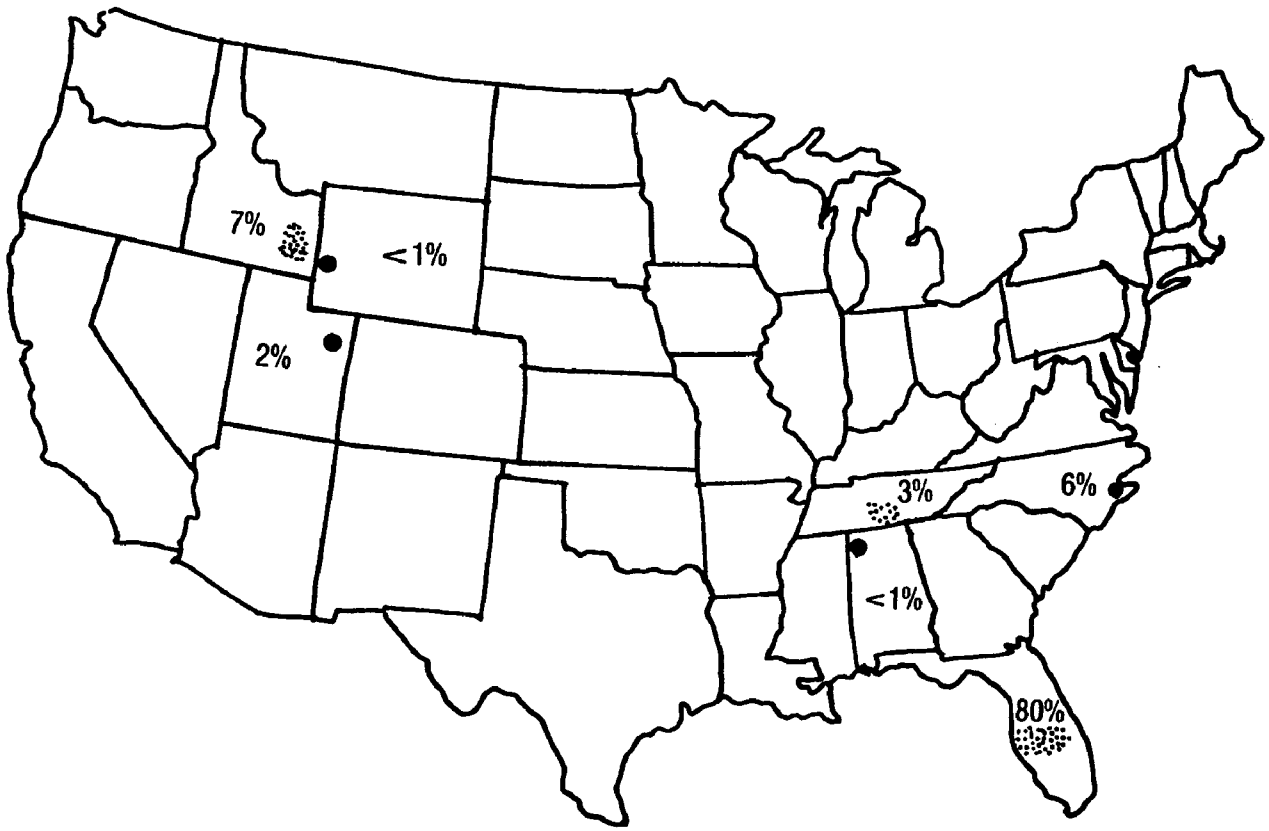

Figure 1-2. Geographic distribution of phosphate rock production in the United States (Pe83).

Radon-222, the decay product of radium-226, is a gaseous element that diffuses into the air from the radium-226 in the gypsum stacks. Also, potential exists for the radionuclides in gypsum to be resuspended into the air by winds and vehicular traffic that produce dust from the stacks. These are the two principal mechanisms for airborne releases of radioactivity from phosphogypsum stacks. The amount of radon emanating from a gypsum stack ("the source term") is proportional to the stack area, the radium-226 concentration in the waste material, and to an emanation coefficient depends upon a number of variables, the most important being the moisture content of the gypsum. In addition, a hard crust forms on inactive stacks that tends to reduce the potential for airborne particulates and causes a reduction in the radon flux.

Gypsum stacks range in size from 2 to almost 300 hectares*, and heights range from 3 to about 60 meters. The location and number of phosphogypsum facilities in the United States are shown in Figure 1-3. Each facility contains one or more phosphogypsum stacks. Although there are 62 phosphogypsum stacks in the United States, the EPA has centered its assessment on the largest 58 stacks, ignoring four because of size or a present lack of information. Table 1.1 lists the principal phosphogypsum stacks and the total base area of these stacks in each state. The 58 gypsum stacks have a combined base area of about 3,370 ha, of which 1,630 ha (about 50 percent) are located in Florida (PEI85a). Because Florida has more than three times the phosphogypsum of any other state, is

---

*1 hectare (ha) = 10,000 square meters.

presently producing most of the gypsum in the United States, and has a large regional population density near gypsum facilities, the phosphogypsum stacks in Florida were selected for this study.

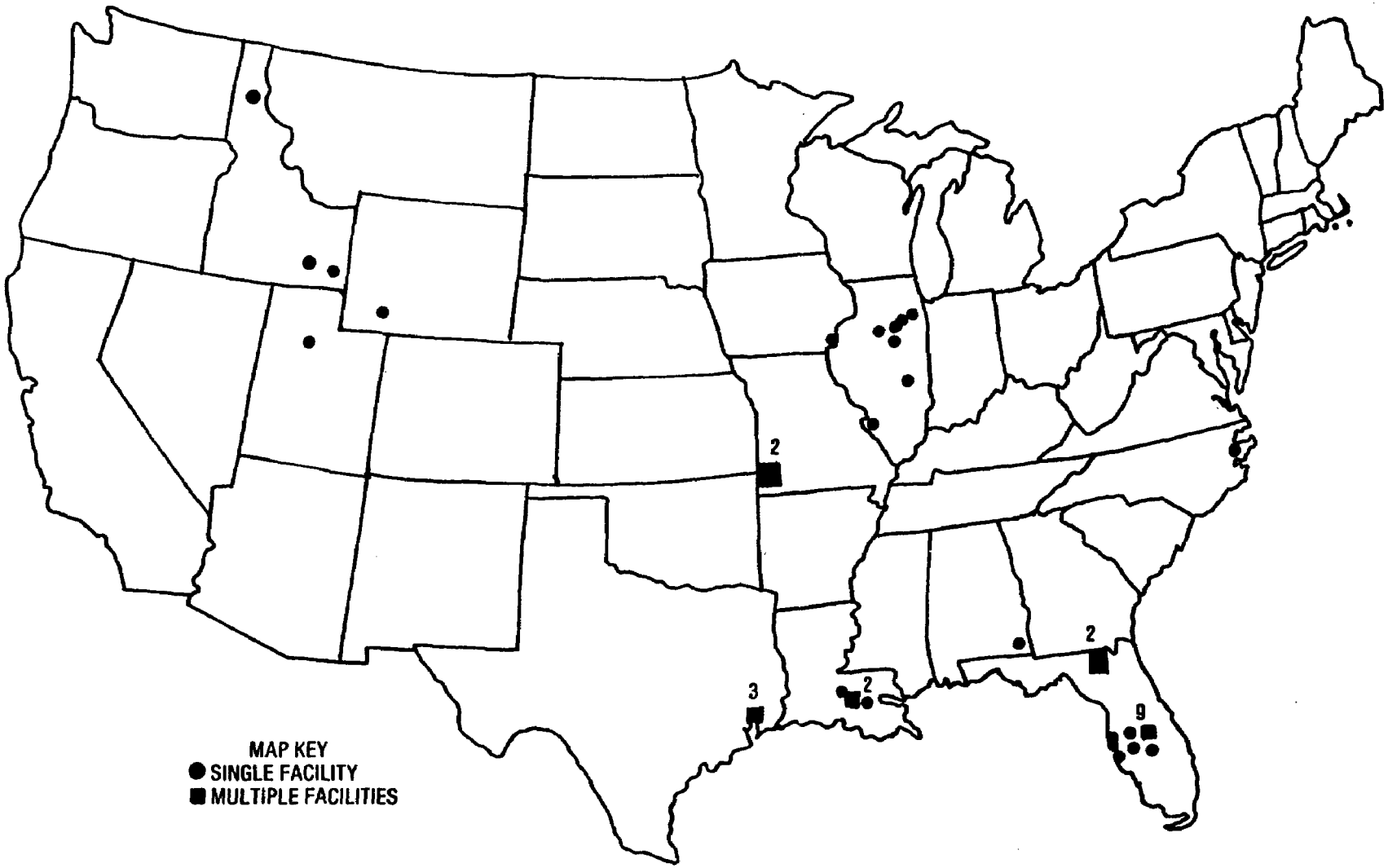

Figure 1-3. Location of phosphogypsum facilities in the United States.

Table 1.1 The principal phosphogypsum stacks in the United States

State	No. of Stacks	Status	Total Area of Stacks in Each State (ha)*
Arkansas	1	Inactive	9
Florida	17	Operating	1522
	3	Inactive	110
Idaho	2	Operating	117
	1	Idle	24
Illinois	2	Operating	117
	5	Inactive	73
	1	Idle	32
Iowa	3	Inactive	64
Louisiana	4	Operating	508
	3	Idle	35
Mississippi	1	Operating	101
Missouri	3	Inactive	48
North Carolina	3	Operating	146
Texas	1	Operating	61
	2	Inactive	35
	4	Idle	66
Utah	1	Operating	121
Wyoming	1	Operating	182

*1 ha = 10,000m^2
Note: Idle stacks are those that are presently inactive but will likely be reactivated in the future. There are no plans to reactivate those classified as inactive or closed.

2. SITE SELECTION AND STACK DESCRIPTION

2.1 Site Selection

The factors considered in selecting the phosphogypsum stacks in central Florida as the sites for the field monitoring study were the following:

1) The phosphate industry is larger in central Florida than in any other region or state.
2) The region contains the preponderate quantity of phosphogypsum, in both operating and inactive stacks.
3) Pertinent data obtained from previous studies of the phosphate industry in the region were readily available.
4) Concurrent studies of a related nature were being conducted in the region.
5) The phosphate region in Florida has a greater population density than most other phosphate mining regions, providing the potential for a larger population exposure to radon and particulate effluents.

2.2 Site and Stack Description

The five sites that participated in the field monitoring study were Gardinier, Inc., W.R. Grace and Company, Royster Company, Conserv, Inc., and Estech General Chemicals Corporation. All sites operated active

phosphogypsum stacks except Estech. Table 2.1 lists the five sites, identifies the stacks monitored, and gives the base area, height, and quantity of gypsum contained for each stack. The locations of these sites are also shown in Figure 2-1. A detailed description of each site participating in the monitoring study is presented below.

Table 2.1 Description of the five participating stacks

Company Name	Stack Monitored	Location	Area (ha)*	Height (meters)	Quantity of Gypsum (10^6 metric tons)
Gardinier, Inc.	Gypsum stack	East Tampa, FL	138	54	84.4
W.R. Grace and Company	South stack	Bartow, FL	164	12	37.4
Royster Co.	North extension stack	Mulberry, FL	16	9	Unknown
Conserv, Inc.	West stack	Mulberry, FL	31	27	8.6
Estech General Chemicals Corp.	Gypsum stack	Bartow, FL	40	9	4.5

*Area of the stack base. 1 hectare (ha) = 10,000 square meters.

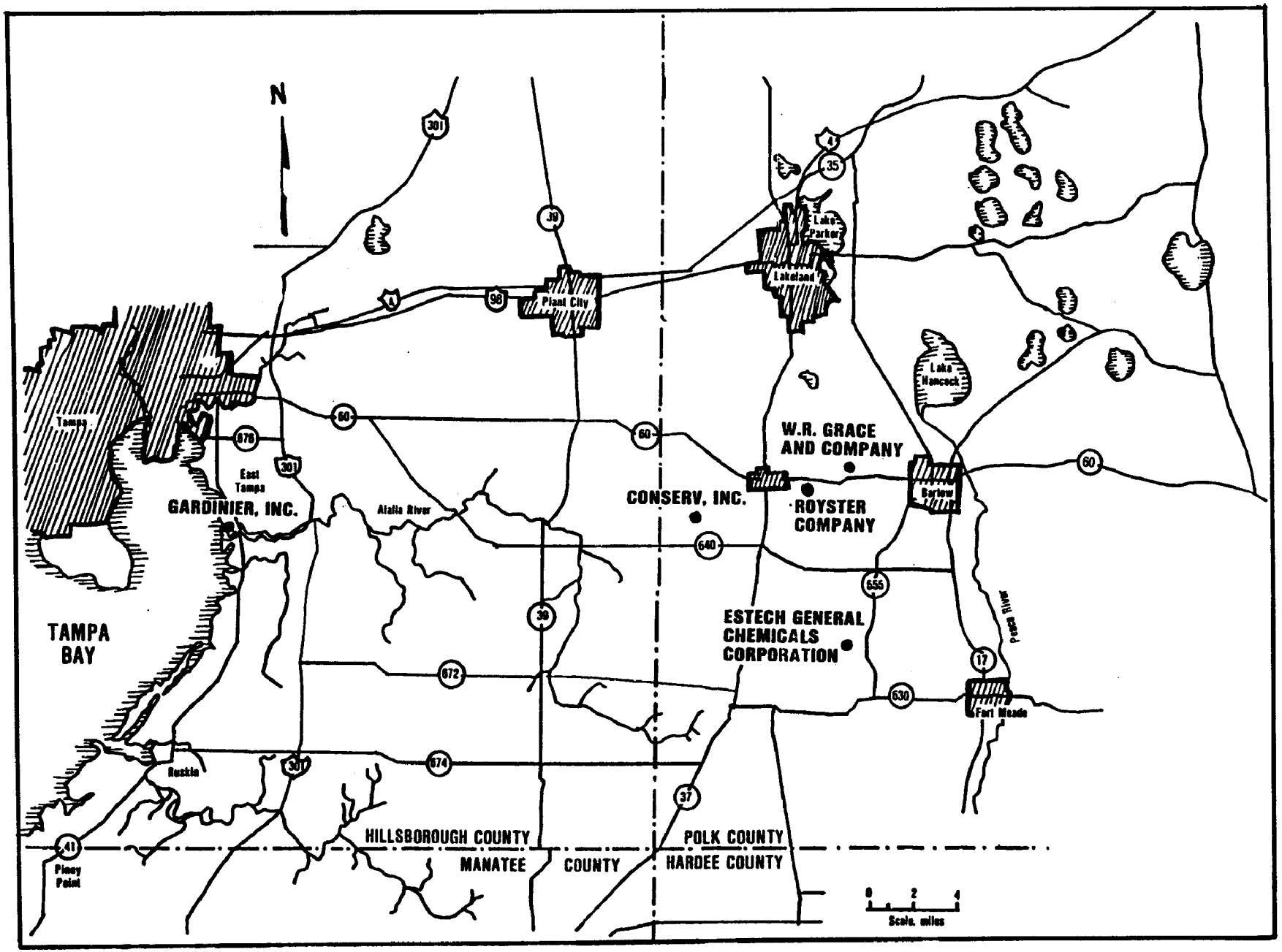

Figure 2-1. Locations of companies participating in field monitoring study.

2.2.1 Gardinier's Phosphogypsum Stack

The Gardinier site is located in East Tampa, Hillsborough County, Florida, approximately 8 miles east of the MacDill Air Force Base and 12 miles southeast of Tampa International Airport. Gardinier, Inc., operates only one gypsum stack, which is located immediately east of Hillsborough Bay and west of U.S. Route 41 (see Figure 2-2). The stack is presently about 55 meters high and its base covers 138 ha. The top of the gypsum stack is presently about 36 ha. The sides of the stack are either vegetated or in the process of being vegetated, and water normally covers the top surface, except for the perimeter dike and cross dams. The company plans to operate the stack to a height of about 60 meters, at which time the gypsum slurry will be piped across State Route 41 to a new gypsum stack that is not yet constructed.

2.2.2 W.R. Grace's Phosphogypsum Stack

The W.R. Grace site is located about 4 miles west of Bartow, Florida. The active south phosphogypsum stack, where the monitoring was conducted, is located southeast of the plant and immediately south of State Route 60 (see Figure 2-3). The stack is about 12 meters high and its base covers an area of 164 ha. The top of the gypsum stack is about 145 ha, which is segmented into 15 cells of varying sizes. The top of the stack is normally covered with water, except at certain times of the year the gypsum surface may be dry or only damp. The sides of the gypsum stack are not vegetated.

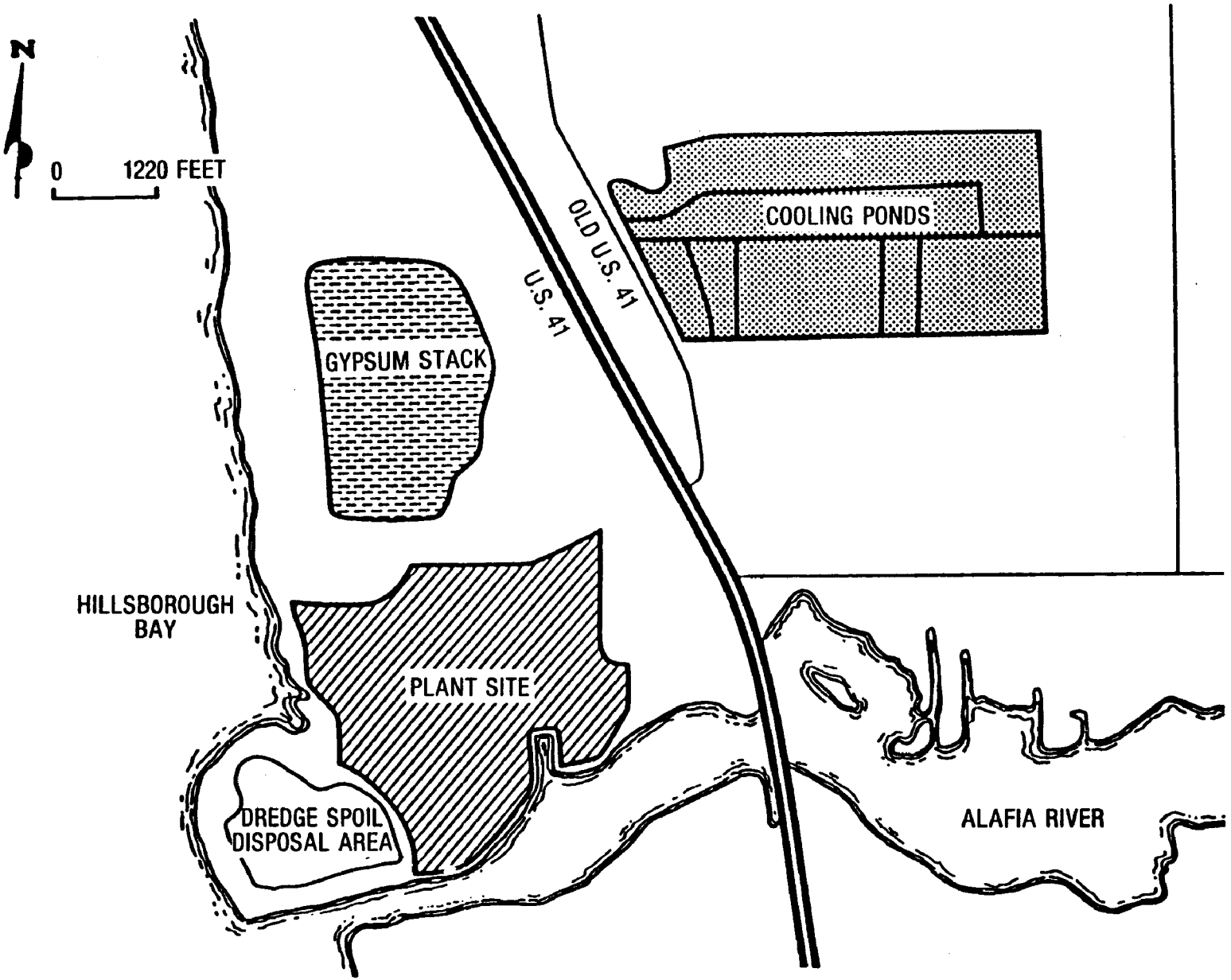

Figure 2-2. Site map of Gardinier, Inc.

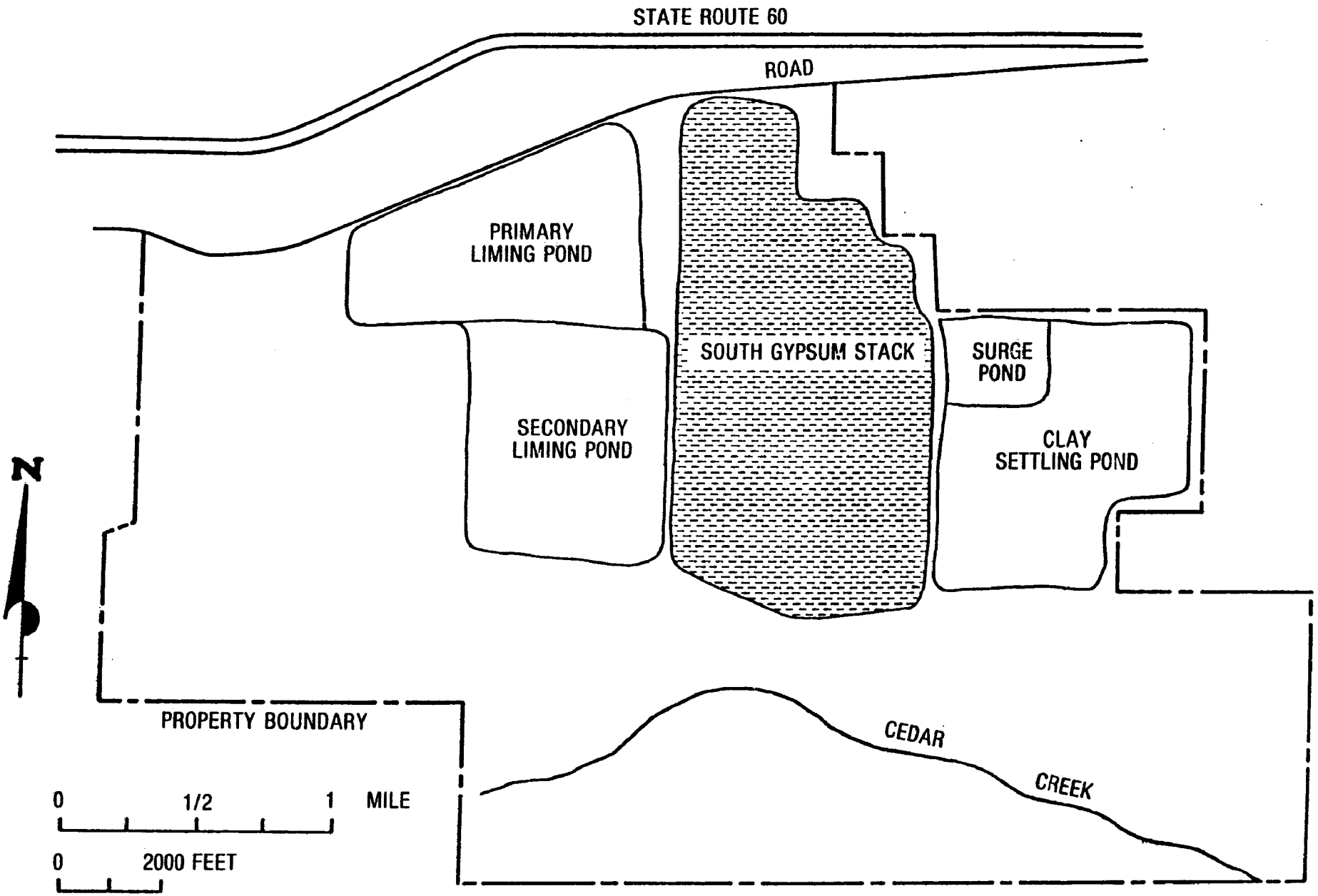

Figure 2-3. Site map of W.R. Grace and Co.

W.R. Grace also operates a somewhat smaller north stack, but it is infrequently used and was not included in the field monitoring study.

2.2.3 Royster's Phosphogypsum Stack

The Royster site is located about 1 1/2 miles east of Mulberry, Florida, on the south side of State Route 60. The north stack and north extension stack are located directly north of the plant in between the plant and State Route 60 (see Figure 2-4). The north extension stack is currently about 9 meters high and its base covers an area of about 16 ha. Only the north extension stack is active, although gypsum slurry flows via a drainage ditch across the north stack to the north extension. The top of the north extension stack, having only one cross dam, is normally covered with water. There is no vegetation on the sides of either the north stack or the north extension stack.

A south stack also exists at the Royster site, however, it was not included as a part of the field monitoring study.

2.2.4 Conserv's Phosphogypsum Stack

The Conserv site is located approximately four miles southwest of Mulberry, Polk County, Florida. Conserv operates two gypsum stacks on this site, which are designated as the east and west stacks (see Figure 2-5). Presently, the east and west stacks are 9 and 27 meters

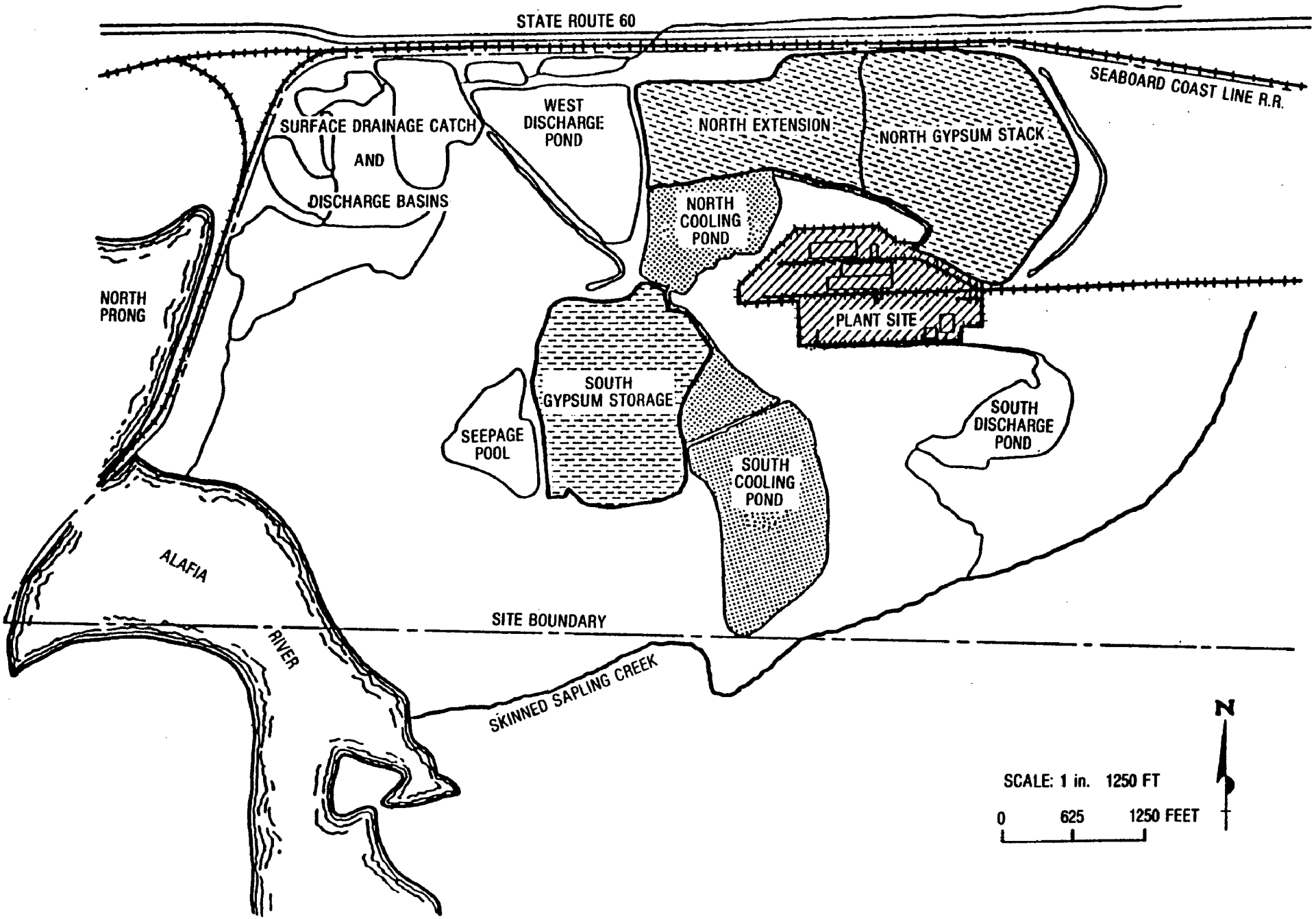

Figure 2-4 Site map of Royster Co

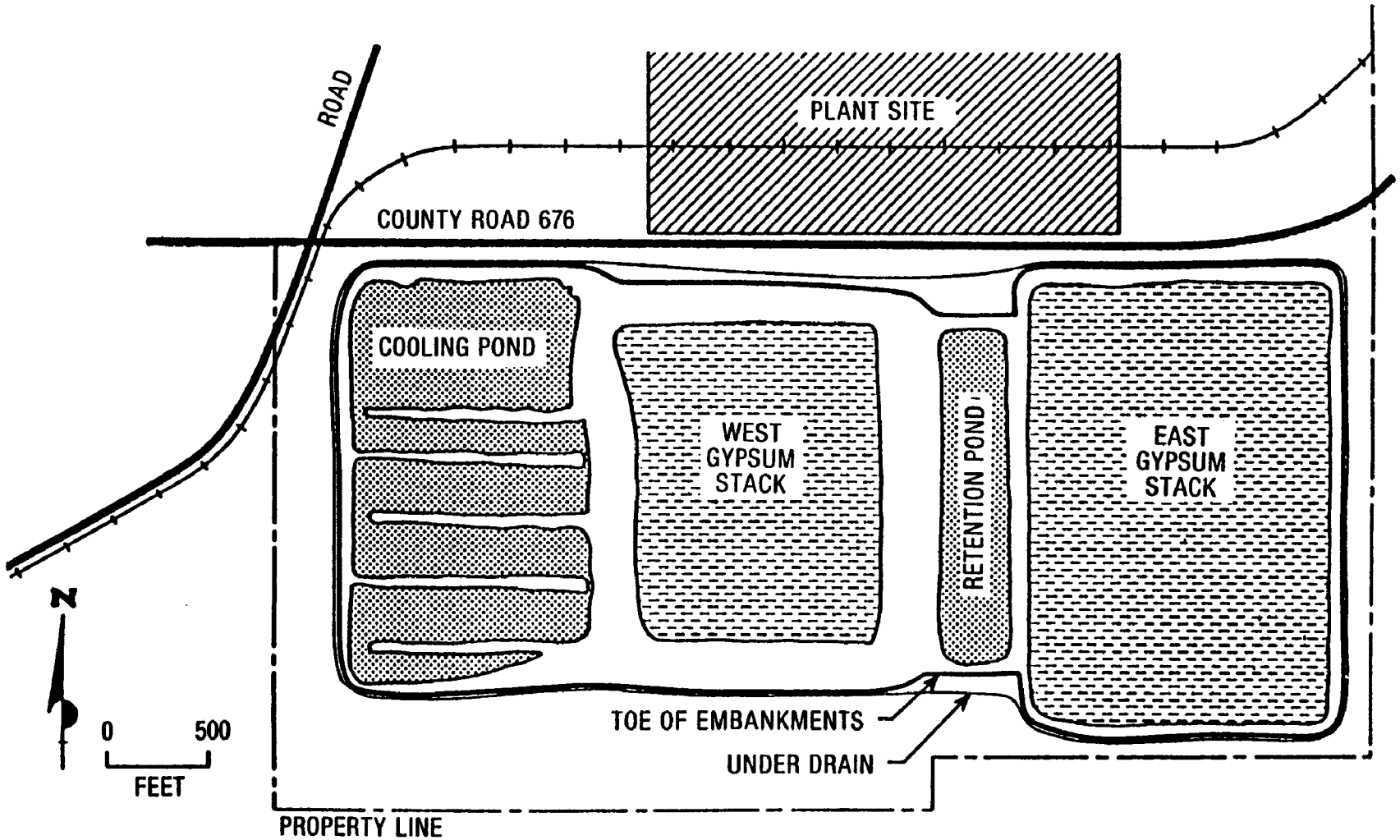

Figure 2-5. Site map of Conserv, Inc.

high, and their bases cover areas of 32 and 31 hectares, respectively. While dense vegetation covers the sides of the east stack, vegetation on the sides of the west stack is either scarce or nonexistent. Monitoring was conducted for this study only at the west stack.

Conserv operates the stacks on a rotation schedule, that is, variable with time. The top surface of the west gypsum pile is normally covered with water while receiving the gypsum slurry discharge. When the discharge is diverted from the west to the east stack, the surface water remaining will evaporate or seep away. As a result, the top surface of the stack will become dry enough to dredge and build up dikes for receipt of future discharges.

2.2.5 Estech's Phosphogypsum Stack

The Estech site is located approximately 8 miles south-southwest of Bartow, Florida. The Estech site contains one inactive gypsum stack that lies just south of the plant and off of State Route 555. The height of the inactive stack varies from about 3 meters to 9 meters and occupies an area of about 40 ha at its base (see Figure 2-6). The stack has been inactive since 1968, during which time it has naturally acquired a patchy vegetation cover on all surfaces except the access road. Periodically a front-end loader will work the eastern end of the stack for buyers of the phosphogypsum.

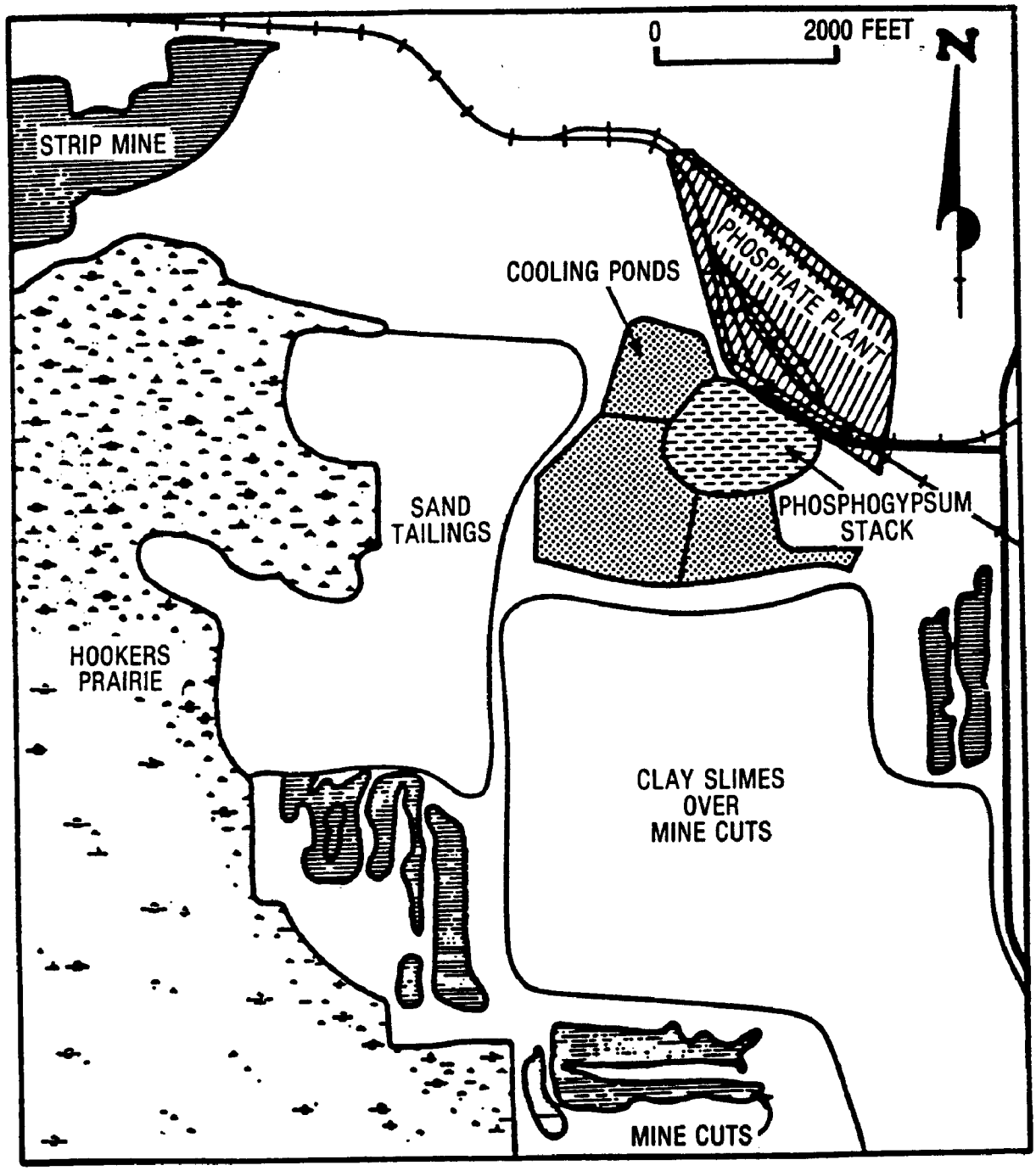

Figure 2-6. Site map of Estech General Chemicals Corporation.

3. STUDY DESIGN

3.1 Measurement Objectives

The following measurements were performed to obtain the data pertinent to the study objectives.

3.1.1 Radon Flux

The radon flux is the rate at which radon emanates from the surface of the gypsum stack. The flux measurements yield the picocuries of radon emanating per square meter per second. The radon flux is used to estimate the annual radon emission rate from the stack.

Measurements of radon flux were made to obtain the following information:

1) the average annual radon flux over the area of a stack and the variation that exists between stacks,
2) the variation of the radon flux with time (seasonal variation),
3) the difference in the radon flux of operating and inactive stacks,
4) the variation of the radon flux as a function of the radium-226 concentration in the waste material, and
5) the variation of the radon flux caused by differences in the moisture content of the gypsum material.

3.1.2 Radionuclide Content of Phosphogypsum Samples

Naturally occurring radionuclides are known to exist in elevated concentrations in phosphogypsum (Gu75, Ho79). The more important of these radionuclides are isotopes of uranium and thorium, radium-226, polonium-210, and lead-210. Knowledge of the concentrations of these radionuclides in the surface layer of the gypsum stacks is important because they represent the source of the radon and the radioactive airborne particulate emissions.

3.1.3 Moisture Content of Phosphogypsum Samples

It is well known that the moisture content of the phosphogypsum has a large effect on the radon flux. In general, the radon flux may be expected to decrease with increasing moisture in the gypsum, if all other variables are constant. Thus, the moisture content of the gypsum was measured at each site of the radon flux measurement in order to determine if a relationship between radon flux and moisture content could be observed.

3.1.4 Airborne Particulate Samples

Dust from phosphogypsum stacks may be produced by winds and vehicular traffic on the stacks. Because phosphogypsum contains elevated levels of naturally occurring radionuclides (see Section 3.1.2), the dust represents

an airborne source of radioactivity. In order to determine the significance of this airborne source of radionuclides, total suspended particulates were collected in upwind and downwind directions of two stacks. The particulates collected were analyzed for specific radionuclides which were then related to an airborne concentration.

Particle sizing was performed on some of the total suspended particulate samples. The size of the dust particles is relevant because it relates to the distance the dust may be transported and to the fraction of the dust that is respirable.

3.1.5 Airborne Radon

Airborne radon concentrations, measured as pCi/L, were obtained above and around the phosphogypsum stacks for the purpose of: 1) determining if an increase in airborne concentration due to the radium-226 in the gypsum was detectable above background levels; 2) determining the size of the increase; and 3) determining, if possible, any relationship between the increased airborne radon concentration and the radon flux and/or the radium-226 concentration in the surface layer of the gypsum stack.

3.1.6 Gamma-ray Exposures

Gamma-ray exposures on gypsum stacks may be expected to exceed background levels because higher concentrations of naturally occurring radionuclides exist in phosphogypsum. Since gamma-ray exposure levels might present a qualitative measure of the relative abundance of radionuclides existing in the gypsum at measurement locations, gamma-ray exposure measurements, as μR/hr, were included in the study program to: 1) determine an average exposure rate on phosphogypsum stacks; 2) determine if a qualitative relationship exists between the gamma-ray exposures above the surface and the radionuclide, principally radium-226, concentrations in the surface gypsum; and 3) observe any spatial distribution of exposure over the surface of a stack due to the heterogeneous distribution of radionuclides in the gypsum.

3.2 Methods

3.2.1 Radon Flux

To determine the radon flux, a specially designed charcoal canister called the "Large Area Activated Charcoal Canister (LAACC)" is positioned directly on the surface of the gypsum stack selected for the flux determination (see Figure 3-1). The LAACC is 10 inches in diameter and contains about 180 grams of granular activated charcoal. The radon

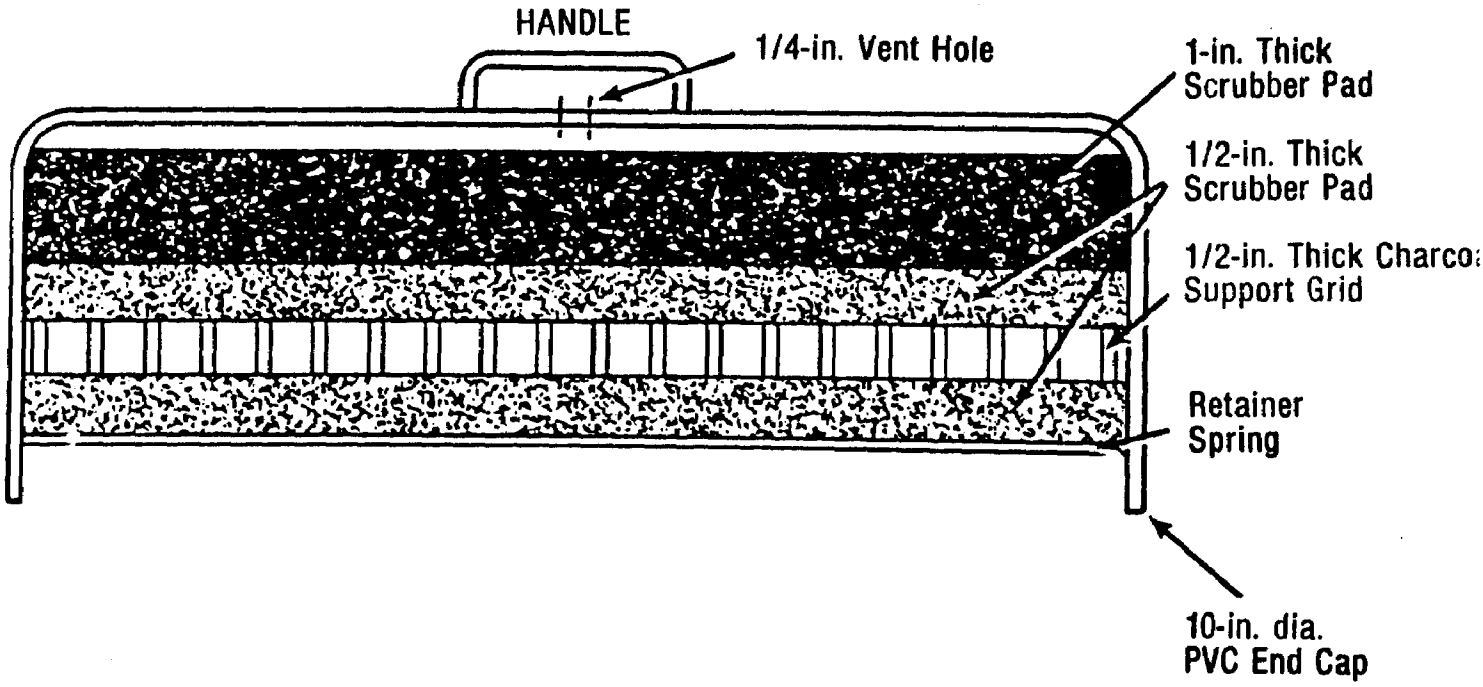

Figure 3-1. The Large Area Activated Charcoal Canister.

diffuses from the gypsum into the canister and is adsorbed onto the charcoal where it decays to its progenies. The amount of radon adsorbed on the activated charcoal was quantified by gamma-ray spectroscopy of the charcoal using a NaI(Tl) crystal and multichannel analyzer. The 609 KeV peak of bismuth-214 was measured to determine the radon activity on the charcoal. The radon flux was calculated from the radon activity, the area of the collector, the time of exposure (usually 24 hours), and the radon decay correction. The decay corrections were kept small by analyzing the charcoal within two days of exposure.

This method of radon flux measurement assumes two basic conditions. First, it must be assumed that the charcoal is 100 percent efficient in collecting radon. For short periods of time, less than 36 hours, this assumption is considered valid for all seasons of the year (Ha83). Temperature has a large effect on the radon collection efficiency, and larger collection times may not result in a quantitative recovery. Thus, a 24-hour exposure time was conservatively chosen. It was also assumed that the radon flux being measured was constant during the exposure period. Although this condition was rarely, if ever, met, the error introduced is believed to be relatively small.

This method has an accuracy of greater than ± 10 percent, a precision of ± 10 percent, and a sensitivity of 0.2 pCi/m^2-s.

3.2.2 Phosphogypsum Sample Collection and Analyses

Each sample was obtained by removing the top 15 cm of surface phosphogypsum over an area approximating the area and location covered by the LAACC. The sample was removed using a JMC soil sampling auger and placed in a 1-liter polyethylene widemouthed bottle. Samples were sent to the Eastern Environmental Radiation Facility where they were homogenized and analyzed for radium-226. The 10 samples from each stack were then composited and the five composite samples analyzed for uranium-238, uranium-235, uranium-234, thorium-232, thorium-230, thorium-228, thorium-227, radium-226, radium-228, polonium-210, and lead-210 by published procedures (Li84).

3.2.3 Moisture Content Determination of Phosphogypsum Samples

A surface sample of phosphogypsum was collected from an area adjacent to the LAACC, sealed immediately in a plastic bag, and returned to the Polk County Health Department for a moisture content determination. Samples were oven dried for 16 hours at a temperature of 60±5°C and the moisture content determined using the recommended ASTM D2216-80 method.

3.2.4 Airborne Particulate Sample Collection

Total suspended particulate samples were collected for a period of one week at selected locations having available power supplies using high-volume samplers. The high-volume samplers were operated as

recommended by the Environmental Protection Agency (PEI86). At the end of each week the exposed sample filters were sent to the Eastern Environmental Radiation Facility where they were composited into monthly samples for radiochemical analysis.

Samples for particle sizing were collected for a period of one day using the Andersen particle sizing head with the ASTM D2009 procedure. After the collection period, filters from the head were sent to the Eastern Environmental Radiation Facility for radiochemical analysis.

Both total suspended particulate filters and particle sizing filters were analyzed for uranium-238, uranium-234, thorium-232, thorium-230, thorium-228, radium-226, and occasionally radium-228, by published procedures (Li84). The particle sizing filters were also analyzed for polonium-210 and lead-210.

3.2.5 Airborne Radon Measurements

Type F TRACK ETCH^R detectors (supplied by Terradex Corporation, Walnut Creek, CA) were used to measure the airborne radon concentration 1 meter above the ground surface on and around the phosphogypsum stacks. At each location to be measured, three detectors were mounted to the inside of an inverted 2-gallon plastic bucket that afforded protection from the weather. The detectors were exposed for about four months, at

which time they were retrieved and returned to the Eastern Environmental Radiation Facility (for quality assurance purposes) who, in turn, forwarded them to the Terradex Corporation for processing.

3.2.6 Gamma-ray Exposure Measurements

Gamma-ray exposure measurements were made 1 meter above the ground surface using a Model 12S Ludlum Scintillometer. The hand-held instrument measures only the gamma-ray exposure, using a NaI(Tl) crystal, and reports the pulse rate directly in μR/hr. Each day the scintillometers were standardized using a pressurized ionization chamber (PIC).

3.2.7 Background Sample Collection and Measurements

All background samples and measurements were obtained using the same equipment, procedures, and quality assurance as the source samples.

3.3. Sampling Program

3.3.1 General

Environmental sampling for radon flux, ambient airborne radon concentrations, radionuclide composition of phosphogypsum and airborne particulates, particle size distribution of airborne particulates, moisture content of surface gypsum, and gamma-ray exposures were performed

between July 22, 1985 and July 18, 1986. Table 3.1 summarizes the sampling conducted at each site during this period. A more detailed and extensive monitoring study was conducted at the Gardinier and W.R. Grace facilities. A detailed description of the monitoring program at each site is given below.

3.3.2 Sampling Program at the Gardinier Site

Large area charcoal canisters were placed at 10 locations along the perimeter dike (see Figure 3-2). Locations were selected that would provide a representative sample without interfering with plant operations. The canisters were exposed at each location for a 24-hour period each week from 22 July 1985-4 February 1986, and thereafter for a 24-hour period monthly to June 24, 1986. Sampling was delayed when heavy rain was expected during the 24-hour sampling period. Monitoring was conducted as described in Section 3.2.1.

A surface gypsum sample was collected at each of the 10 canister locations during the week of July 22, 1985. Samples were collected and analyzed as described in Section 3.2.2.

Throughout the one-year monitoring study, as each charcoal canister was retrieved, a sample of the surface gypsum was collected from the area adjacent to the canister. These samples were returned to the laboratory and measured for their moisture content. The methods of collection and analysis are described in Section 3.2.3.

Table 3.1 A summary of the monitoring program at the five phosphogypsum sites

Site	Total number of samples or measurements obtained					
	Radon flux	Radon in air	Gypsum	Airborne particulates	Particle size	Gamma-ray exposures
Gardinier	339(10)	31(12)	10(10)	59(2)	4(2)	10(10)
W.R. Grace	531(10)	32(13)	10(10)	40(2)	4(2)	10(10)
Royster	129(10)	8 (4)	10(10)	0	0	10(10)
Conserv	129(10)	8 (4)	10(10)	0	0	10(10)
Estech	130(10)	12 (5)	10(10)	0	0	10(10)

Notes:

(1) The number of sampling locations are given in parenthesis. Background measurements/samples are not included.
(2) Each radon in air measurement includes 3 Track Etch detectors.
(3) The number of soil moisture measurements equals the number of radon flux measurements.

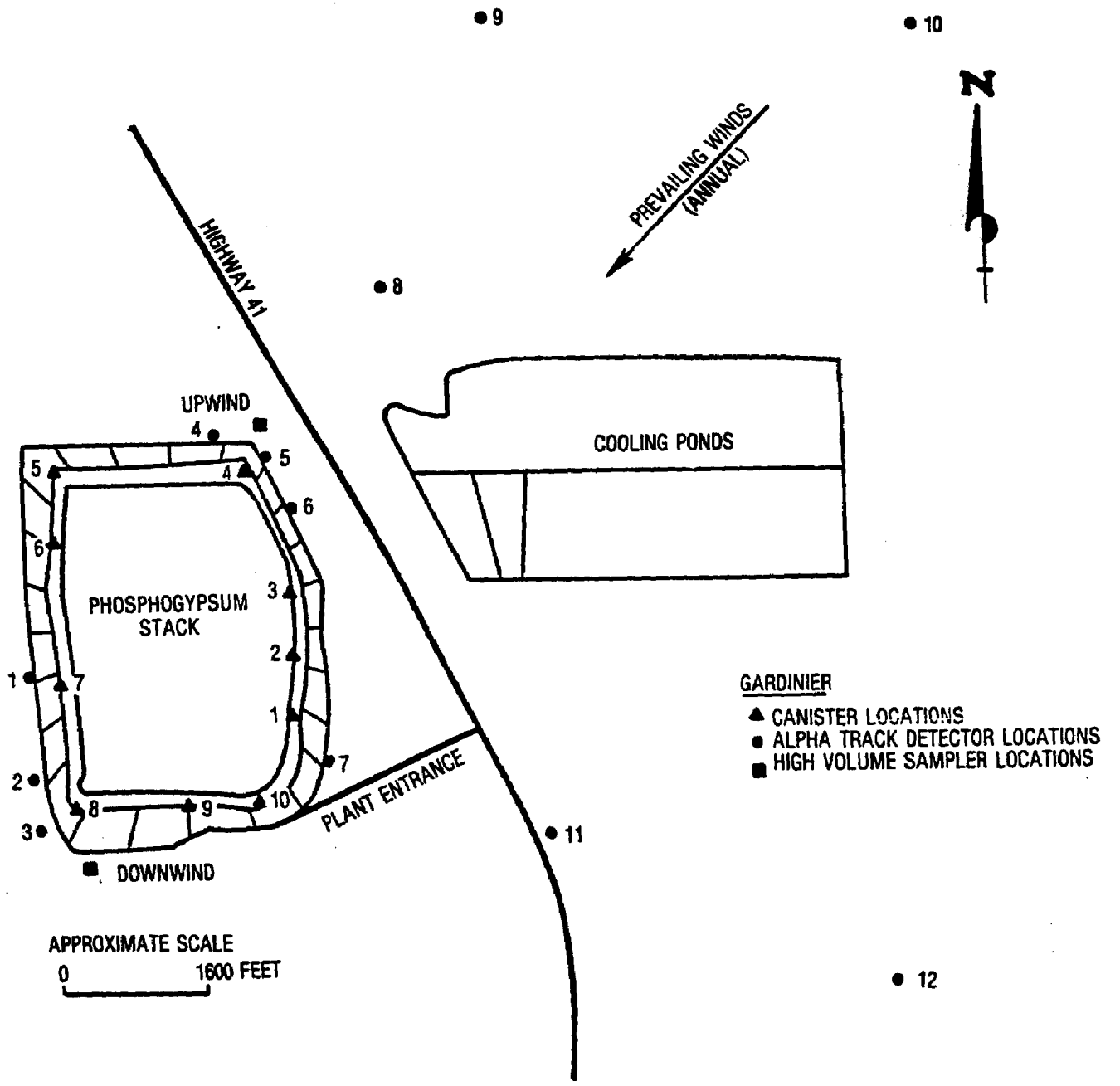

Figure 3-2. Monitoring locations at Gardinier, Inc.

The upwind and downwind locations chosen for sampling airborne particulates are shown in Figure 3-2. The upwind sampler was located about 150 meters (500 feet) northeast of the stack at the lime treatment station, and the downwind sampler was located about 180 meters (600 feet) southwest of the stack. However, both samplers were moved midway through the monitoring period due to excessive fugitive dust emissions from haul road traffic. The northeast (upwind) sampler was relocated on August 26, 1985, to the top of the inactive lime treatment station about 37 meters south of the original location and positioned about 5 meters above ground surface. The southwest (downwind) sampler was relocated on December 4, 1985, to a location 15 meters north of the original location and positioned about 5.5 meters above the ground surface. The prevailing wind direction in the vicinity of the site was determined by reviewing the annual frequency distribution of wind directions derived from data collected from 1967 to 1970 and 1973 to 1979 at nearby MacDill Air Force Base. The prevailing wind direction in the vicinity of Gardinier on an annual basis is from the northeast. Airborne particulate sampling began on July 26, 1985, and was terminated on February 3, 1986, because it was determined that the downwind sampler was collecting particulates mainly from the plant and not from the stack. The method of collection and the analyses performed are described in Section 3.2.4.

Alpha track detectors were exposed at 12 locations on the Gardinier site (see Figure 3-2). Seven sampling locations were along the base perimeter in the principal wind directions. Detectors were exposed at

five additional locations in an easterly direction from the stack at about one- and two- stack diameters from the stack centroid. Detectors were exposed for about four-month cycles over the study period, resulting in three measurement periods, 22 July 1985-4 December 1985; 2 December 1985-3 April 1986; and 2 April 1986-23 July 1986. The methods of measurement are described in Section 3.2.5.

Gamma-ray exposure measurements were performed 1 meter above ground surface during the week of July 22, 1985, at the same stack locations where surface phosphogypsum samples had been collected. Measurements were made as described in Section 3.2.6.

3.3.3 Sampling Program at the W.R. Grace Site

Large area charcoal canisters were placed at 9 locations along the perimeter dike and at one location on a cross dam near the center of the stack (see Figure 3-3). Locations were selected that would provide a representative sample without interferring with plant operations. The canisters were exposed at each location for a 24-hour period each week throughout the monitoring study, 24 July 1985-15 July 1986. Sampling was delayed when heavy rain was expected to occur during the 24-hour sampling period. Near the end of the study, fifteen additional measurements were made at the one- and two- stack diameter alpha-track detector locations. Monitoring was conducted as described in Section 3.2.1.

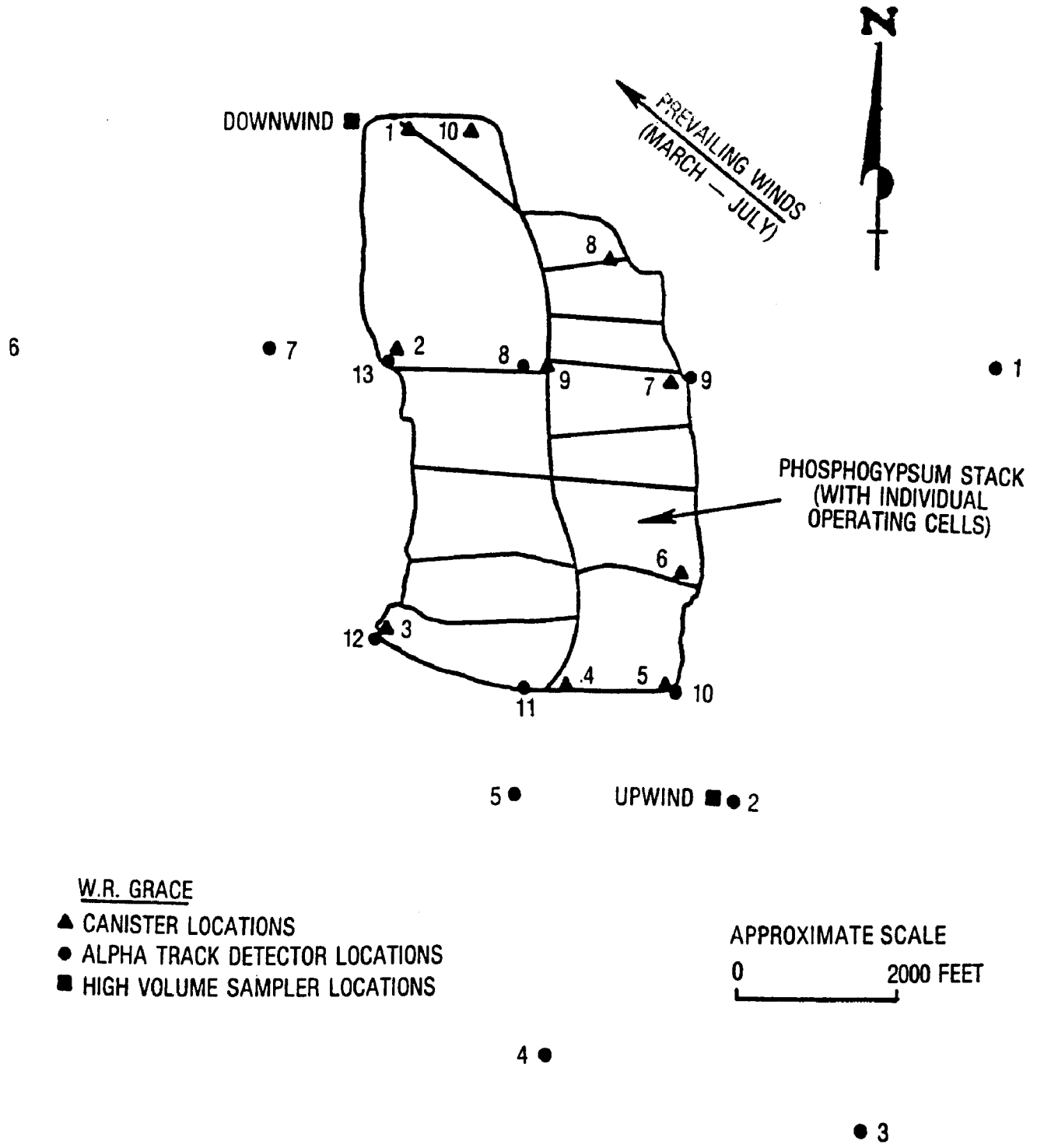

Figure 3-3. Monitoring locations at W.R. Grace's south stack.

A surface gypsum sample was collected at each of the 10 canister locations during the week of July 22, 1985. Samples were collected and analyzed as described in Section 3.2.2.

Throughout the one-year monitoring study, as each charcoal canister was retrieved, a sample of the surface gypsum was collected from the area adjacent to the canister. These samples were returned to the laboratory and measured for their moisture content. The methods of collection and analysis are described in Section 3.2.3.

W.R. Grace was selected to replace Gardinier as the site for the high-volume air particulate sampling location because the south stack at the W.R. Grace site is totally isolated from the plant, eliminating the problem of interference from plant and roadway dust that was so prevalent at the Gardinier site. Also, an ideal upwind/downwind relationship was established and power was readily available. The upwind and downwind locations selected for sampling airborne particulates are shown in Figure 3-3. The upwind sampler was located about 460 meters (1500 feet) southeast of the stack and the downwind sampler was located about 115 meters (375 feet) northwest of the stack at the top of the lime treatment station site. Meteorological data from both MacDill Air Force Base and Orlando International Airport were used to determine the prevailing wind direction from March 1986 through July 1986, the period air particulate sampling was conducted at W.R. Grace. These data indicated that the most

probable wind direction at the site for this period was from the southeast. Airborne particulate sampling began at the W.R. Grace site on March 7, 1986, and ended on July 17, 1986. The method of collection and the analyses performed are described in Section 3.2.4.

Particle sizing samples were collected for four 24-hour periods at the same locations as the high-volume samplers. Two samples were collected at the upwind sampler location and two at the downwind sampler location. Samples were collected for a 24-hour period beginning on April 21, 1986, and July 17, 1986. The method of collection and the analyses performed are described in Section 3.2.4.

Alpha track detectors were exposed at 13 locations on the W.R. Grace site (see Figure 3-3). Five measurement locations were along the base perimeter of the stack, one was near the center of the stack on a cross dam, and seven were about one- and two-stack diameters from the stack centroid. Detectors were exposed for about four-month cycles over the study period 22 July 1985-23 July 1986, resulting in three measurement periods: 22 July 1985-4 December 1985; 2 December 1985-3 April 1986; and 2 April 1986-23 July 1986. The methods of measurement are described in Section 3.2.5.

Gamma-ray exposure measurements were performed 1 meter above the ground surface during the week of July 22, 1985, at the same stack locations where surface phosphogypsum samples had been collected. During

the latter stages of the study, seven additional measurements were made at the one- and two-stack diameter alpha-track detector locations. Measurements were made as described in Section 3.2.6.

3.3.4 Sampling Program at the Royster Site

Large area charcoal canisters were placed at 10 locations along the perimeter dike of the North Extension Stack (see Figure 3-4). Locations were selected that would provide a representative sample without interfering with plant operations. The canisters were exposed at each location for a 24-hour period each month throughout the monitoring study, 25 July 1985-1 July 1986. Sampling was delayed when heavy rain was expected to occur during the 24-hour sampling period. Monitoring was conducted as described in Section 3.2.1.

A surface gypsum sample was collected at each of the 10 charcoal canister locations during the week of July 22, 1985. Samples were collected and analyzed as described in Section 3.2.2.

Throughout the one-year monitoring study, as each charcoal canister was retrieved, a sample of the surface gypsum was collected from the area adjacent to the canister. These samples were returned to the laboratory and measured for their moisture content. The methods of collection and analysis are described in Section 3.2.3.

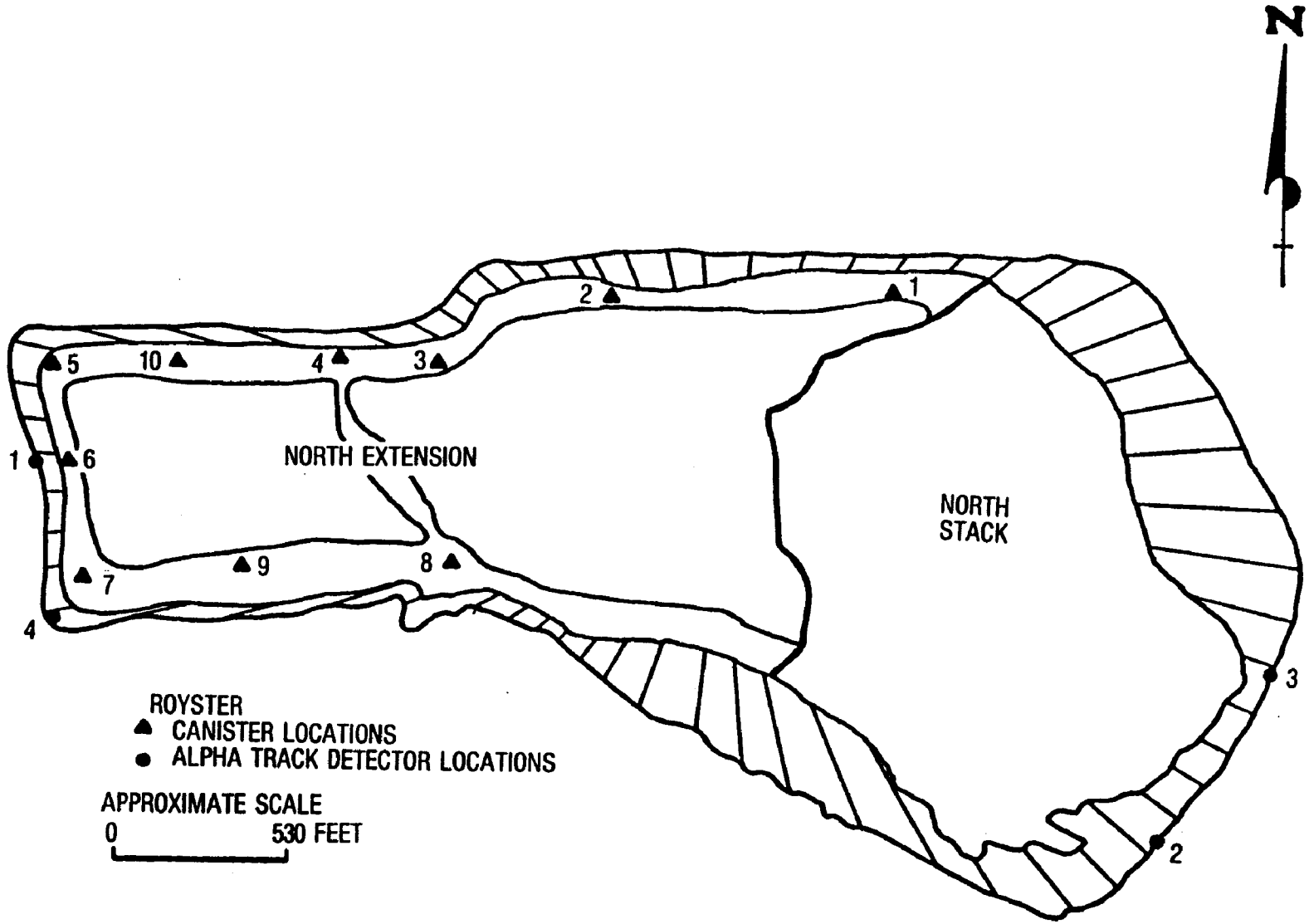

Figure 3-4. Monitoring locations at Royster Company.

Alpha track detectors were exposed at four locations on the base perimeter of the stack. Two measurement locations were at the west end of the North Extension Stack and two were at the southeast side of the North Stack (see Figure 3-4). Detectors were exposed for about four-month cycles over the study period of 22 July 1985-23 July 1986, resulting in three measurement periods: 22 July 1985-4 December 1985; 2 December 1985-3 April 1986; and 2 April 1986-23 July 1986. The methods of measurement are described in Section 3.2.5.

Gamma-ray exposure measurements were performed 1 meter above the ground surface during the week of July 22, 1985, at the same stack locations where surface phosphogypsum samples had been collected. Measurements were made as described in Section 3.2.6.

3.3.5 Sampling Program at the Conserv Site

Large area charcoal canisters were placed at 10 locations along the perimeter dike of the West Stack at the Conserv facility (see Figure 3-5). Locations were selected that would provide a representative sample without interfering with plant operations. The canisters were exposed at each location for a 24-hour period each month throughout the monitoring study, 24 July 1985-8 July 1986. Sampling was delayed when heavy rain was expected to occur during the 24-hour sampling period. Monitoring was conducted as described in Section 3.2.1.

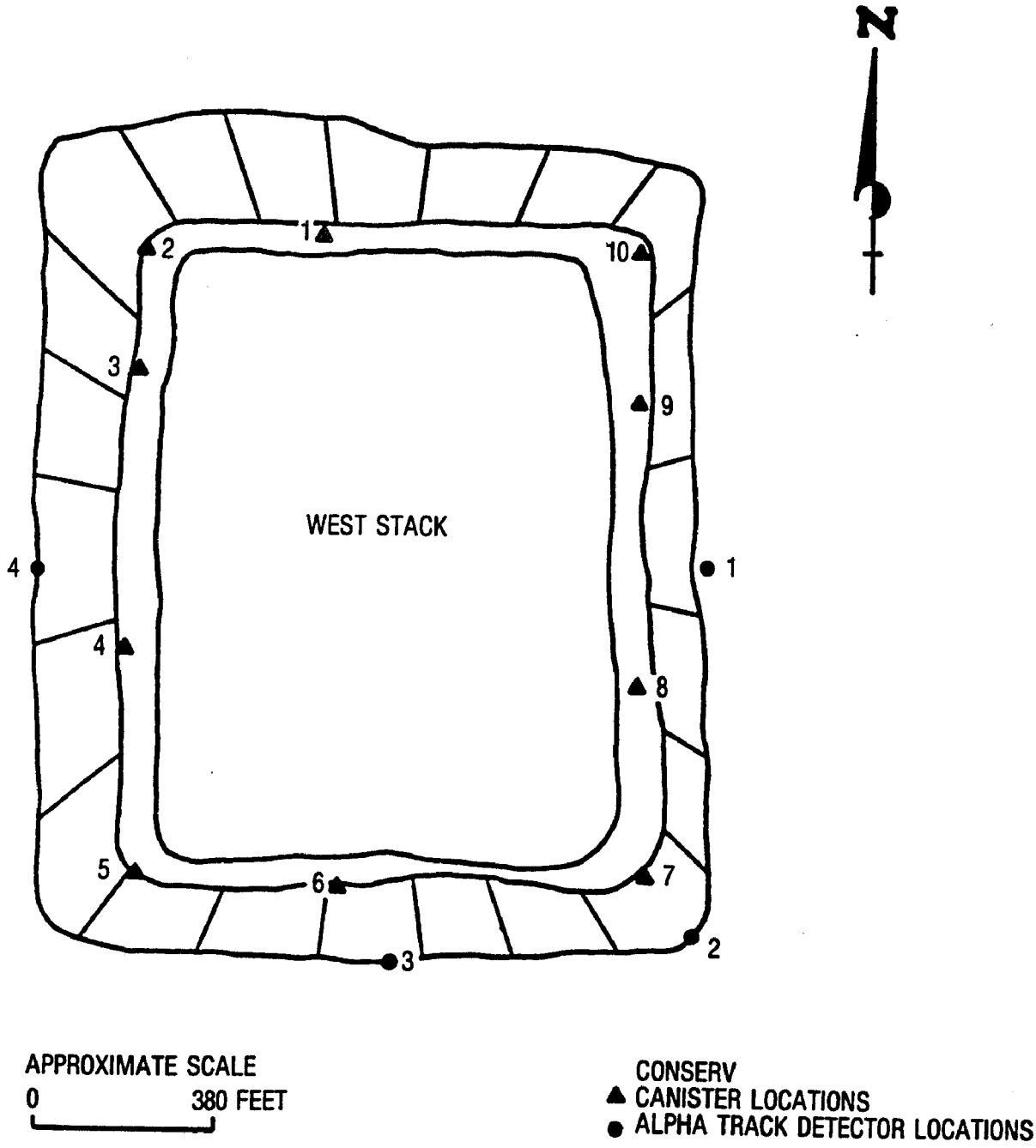

Figure 3-5. Monitoring locations at Conserv's west stack.

A surface gypsum sample was collected at each of the 10 charcoal canister locations during the week of July 22, 1985. Samples were collected and analyzed as described in Section 3.2.2.

Throughout the one-year monitoring study, as each charcoal canister was retrieved, a sample of the surface gypsum was collected from the area adjacent to the canister. These samples were returned to the laboratory and measured for their moisture content. The methods of collection and analysis are described in Section 3.2.3.

Alpha track detectors were exposed at four locations on the base perimeter of the West Stack (see Figure 3-5). Locations included one each along the east, west, south, and southeast sides of the stack. Detectors were exposed for about four month cycles over the study period, 22 July 1985-23 July 1986, resulting in three measurement periods; 22 July 1985-4 December 1985; 2 December 1985-3 April 1986; and 2 April 1986-23 July 1986. The methods of measurement are described in Section 3.2.5.

Gamma-ray exposure measurements were performed 1 meter above the ground surface during the week of July 22, 1985, at the same stack locations where surface phosphogypsum samples had been collected. Measurements were made as described in Section 3.2.6.

3.3.6 Sampling Program at the Estech Site

Large area charcoal canisters were placed at 10 locations randomly distributed across the surface of the inactive stack (see Figure 3-6). The canisters were exposed at each location for a 24-hour period each month during the monitoring period, 25 July 1985-15 July 1986. Sampling was delayed when heavy rain was expected to occur during the 24-hour sampling period. Monitoring was conducted as described in Section 3.2.1.

A surface gypsum sample was collected at each of the 10 charcoal canister locations during the week of July 22, 1985. Samples were collected and analyzed as described in Section 3.2.2.

Throughout the one-year monitoring study, as each charcoal canister was retrieved, a sample of the surface gypsum was collected from the area adjacent to the canister. These samples were returned to the laboratory and measured for their moisture content. The methods of collection and analysis are described in Section 3.2.3.

Alpha track detectors were exposed at five locations on the stack; four locations were selected on the base perimeter of the stack and one at the center (see Figure 3-6). Detectors were exposed for about four-month cycles over the study period, 22 July 1985-23 July 1986, resulting in

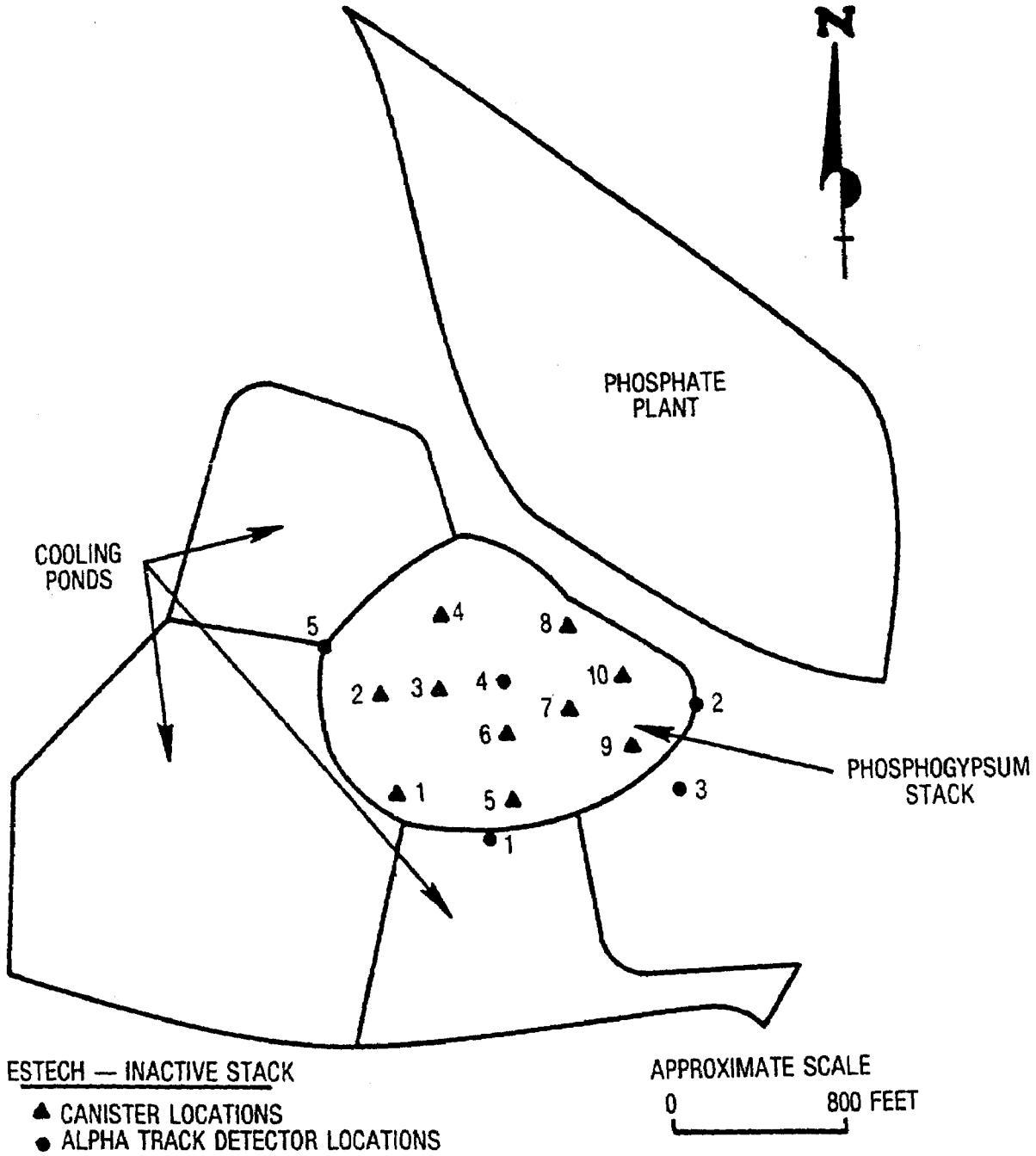

Figure 3-6. Monitoring locations at Estech General Chemicals Corporation.

three measurement periods; 22 July 1985-4 December 1985; 2 December 1985-3 April 1986; and 2 April 1986-23 July 1986. The methods of measurement are described in Section 3.2.5.

Gamma-ray exposure measurements were performed 1 meter above the ground surface during the week of July 22, 1985, at the same stack locations where surface phosphogypsum samples had been collected. Measurements were made as described in Section 3.2.6.

3.3.7 Background Sampling Program

All background samples and measurements were made using the same type equipment, procedures, and quality assurance as the source samples (see Sections 3.2 and 3.4). The background locations are shown in Figure 3-7. Prefixes GB and PB refer to Gardinier and Polk County background locations. Background determinations for radon flux, radionuclides in soil, and airborne radon concentrations were made at each location. Airborne particulate background measurements were made at location PB01T in Winter Haven, Florida.

Radon flux and soil moisture measurements. Thirteen radon flux measurements were made approximately monthly at one location in Winter Haven, Polk County, Florida, an area unrelated to the phosphate industry. Sixteen additional background radon flux measurements were made periodically during the study period at four different locations in each of Polk and Hillsborough Counties, Florida. In January 1986, single radon

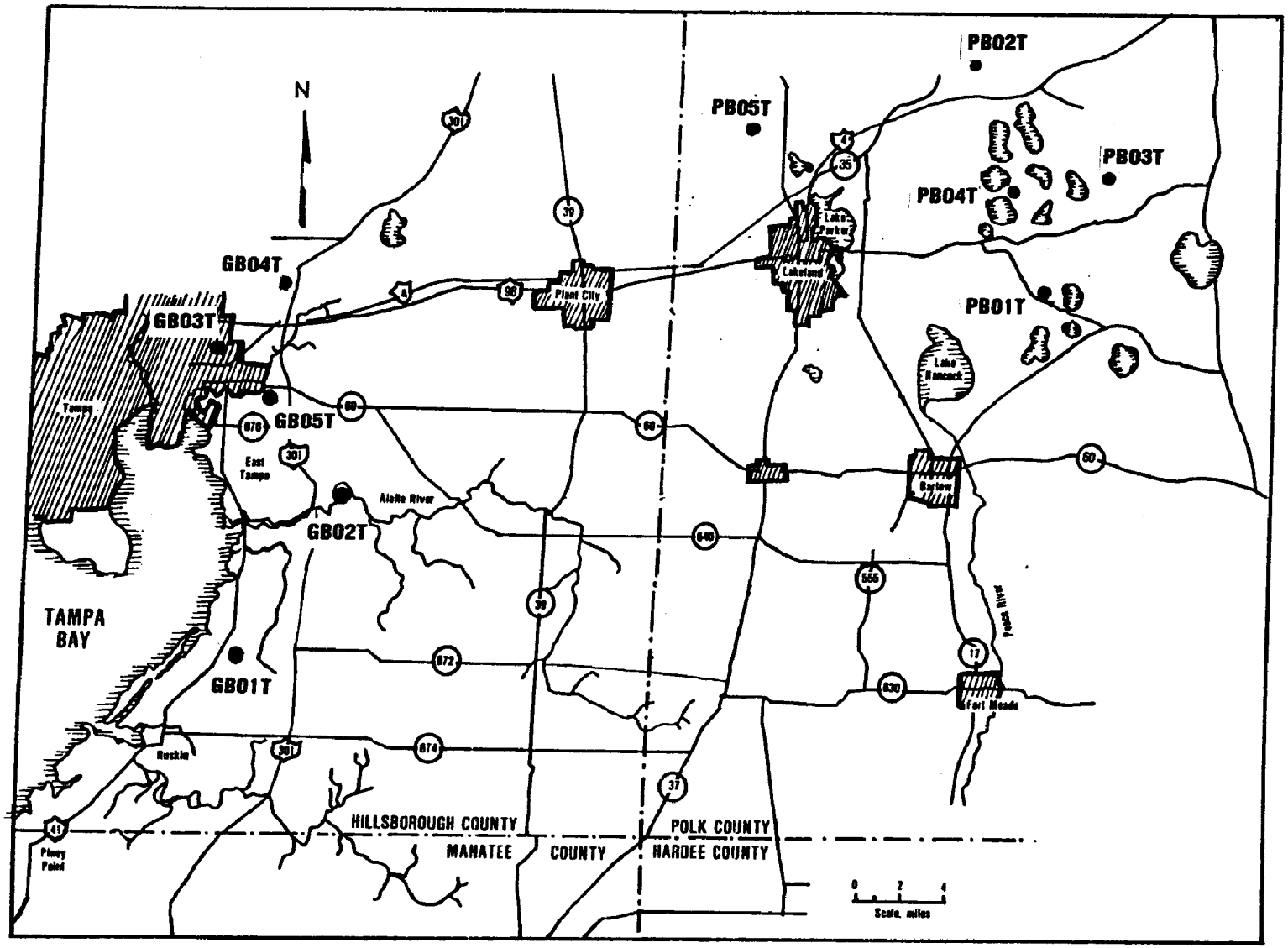

Figure 3-7. Background monitoring locations.

flux measurements were made at six locations in Montgomery County, Alabama. A total of 35 background radon flux measurements were made during the study period.

The moisture contents were determined for eleven soil samples obtained during the study period at the monthly background radon flux measurement site in Polk County, Florida. The soil for this measurement was obtained directly adjacent to the charcoal canister at the completion of the radon flux measurement.

Radionuclide content of soil samples. Background soil samples were collected on December 4, 1985, at all locations in central Florida that were used for background radon flux measurements: five locations in Polk County and four locations in Hillsborough County. These locations were unrelated to areas associated with the phosphate industry. The background soil samples were collected in the same manner and analyzed for the same radionuclides as were the phosphogypsum samples.

Airborne particulate and particle sizing samples. Background airborne particulate samples were collected continuously during the study period. The high-volume sampler was located at the monthly background radon flux measurement site in Polk County, Florida. This location was not influenced by airborne particles originating from any phosphogypsum stack. Filters were changed weekly and treated in the same manner as those obtained near the phosphogypsum stacks (see Section 3.2.4).

One particle sizing sample was collected as a background sample near the end of the study period at the same site where the high-volume sampler was located.

Airborne radon measurements. The radon concentration in above-ground air was measured using three alpha track detectors at each of nine locations that were judged to be outside the influence of the phosphogypsum stacks (about 8 km from any stack). Five locations were around the Polk County phosphogypsum stacks, and four locations surrounded the Gardinier stack in Hillsborough County. Detectors were exposed for a period of four months, allowing three measurement periods during the year-long study. During the first measurement period, detectors were lost at two locations near the Gardinier stack giving a total of 25 background measurements in the central Florida region.

Gamma-ray exposure measurements. Due to the low sensitivity of the Ludlum scintillometer, no background measurements were made. Background measurements have been taken in Polk County by Polk County Health Department personnel using a pressurized ionization chamber. These measurements were taken outside the influence of the phosphate industry and phosphogypsum stacks. These results will be described in a later section of this report.

3.4 Quality Assurance

The procedures utilized in this study to assure the quality of the data generated are described in detail by PEI Associates, Inc. (PEI85b) and the USEPA (EERF82). In general, the PEI procedures relate to the field measurements and sampling, while the EERF procedures were implemented to assure proper laboratory management and analyses of the samples collected. Only a brief description of these procedures are given below. The reader is directed to the two reports cited above if greater detail is required.

3.4.1 Charcoal Canisters (LAACC)

A standard charcoal canister, specially prepared by the EPA containing 0.0991 g of Ra-226 (112 nCi), was counted daily to detect changes in counting system performance (PEI85b, Ha85). A blank activated charcoal canister, prepared from each new batch of charcoal received, was also counted daily. Ten percent of the exposed charcoal canisters were analyzed twice to detect leaking containers and check the reproducibility of the counting technique.

3.4.2 Moisture Content of Phosphogypsum

Phosphogypsum samples were collected adjacent to the large-area charcoal canisters at the completion of each 24-hour exposure period. Requirements for the precision and accuracy of Test Method D2216 that was

used to determine the moisture content has not been developed by ASTM, however, at least 90 percent of all samples collected were required to yield what were considered useable data.

3.4.3 High-Volume Airborne Particulate Samples

An initial flow rate was recorded at the beginning of each sampling period when a new filter was installed. After five initial flow rates had been recorded, the average of these values constituted the "established initial average flow rate." (A control chart was maintained of the initial flow rates.) If an initial flow rate exceeded ± 20 percent of the established initial average flow rate, corrective action was taken by the operator.

After every six months of operation, the Eastern Environmental Radiation Facility provided the operator a replacement calibrated orifice and magnehelics for installation on each sampler. At least 80 percent of all samples collected were required to yield what were considered useable data.

3.4.4 Particle Sizing Samples

Initial and final sampler flow rates were required to differ by less than ± 10 percent. Since only nine particle sizing samples were obtained, all were required to yield useable data.

3.4.5 Sample Representativeness and Comparability

A concerted effort was made to ensure that all sample measurements were representative of the media and conditions being measured. Soil samples for moisture determination were collected directly adjacent to the charcoal canisters. Selection of the charcoal canister locations was based on the EPA report, Radon Flux Measurements on Gardinier and Royster Phosphogypsum Piles Near Tampa and Mulberry, Florida (Ha85). High volume and particle sizing samplers were operated at flow rates recommended by the manufacturer to ensure the collection of representative samples. High-volume samplers were positioned using the nearest and most complete meteorological data.

All results were reported in standard units appropriate to the method. Soil moisture content was reported as percent moisture, radon flux calculations were reported as picocuries per square meter-second (pCi/m^2-s), high-volume and particle sizing sampler flow rates were reported as actual cubic feet per minute (acfm), and alpha track measurements for radon-222 were reported as tracks per square millimeter ($tracks/mm^2$) and also as picocuries of radon-222 per liter (pCi/L).

3.4.6 Sampling Procedures

Sampling procedures for the collection of phosphogypsum samples and for the use of charcoal canisters, alpha track detectors, high-volume samplers, high-volume particle sizing samplers, and the scintillometer are

discussed in detail in Section 3.2. During the monitoring study, the Polk County Health Department maintained log books of field activities. Log books include all applicable information associated with sample collections and measurements. The following table lists information obtained.

Information	Charcoal Canisters	Hi-Vol Samplers	Alpha-Track Detectors	Scintillometer	Gypsum Samples
Site	X	X	X	X	X
Name of Stack	X	X	X	X	X
Sample Location	X	X	X	X	X
Instrument/ Sampler ID	X	X	X	X	
Sample ID	X	X	X		X
Date and Time of Collection				X	X
Date and Time On and Off	X	X	X		
Observations/ Comments	X	X	X	X	X

3.4.7 Sample Custody

Strict custodial control of all samples collected in the field was maintained at all times in accordance with the chain-of-custody field procedures detailed in Section 2, Appendix 2 of the PEI Associates, Inc. Quality Assurance Project Plan for this study (PEI85b). A control record documents all custody changes that occurred between the field and laboratory personnel. Once samples had been received at the Eastern Environmental Radiation Facility, EERF SOP No. 6 (EERF82) procedures were followed.

3.4.8 Calibration Procedures and Frequency

Equipment that required calibration for this study includes the high-volume samplers, high-volume particle sizing samplers, large-area activated charcoal canisters and the associated radioactivity counting equipment, and the scintillometers.

High-Volume Samplers. High-volume samplers were calibrated at the EPA-EERF Air Calibration Facility in Montgomery, Alabama, using a Roots Meter. The orifice and magnehelic pressure gauge was calibrated as a unit at five flow rates over the range of 15 to 40 m^3/hr. Calibration data were recorded and a calibration curve plotted as m^3/hr versus pressure (in. of H_2O). Calibration data were collected at least semiannually, or whenever a weekly reading indicated a problem, i.e., when an initial flow rate exceeded $\pm$ 20 percent of the established initial average flow rate.

High-Volume Particle Sizing Samplers. High-volume samplers equipped with Andersen particle sizing heads were calibrated at the EPA-EERF Air Calibration Facility using a Roots Meter. The calibration was conducted as described above for the high-volume samplers. However, the particle sizing samplers were calibrated to operate at 20 cfm using a variable voltage transformer, and the timers were calibrated using a stopwatch.

Large Area Activated Charcoal Canisters (LAACC). A detailed description of the calibration and assay procedures for these charcoal canisters is given in Appendix 1 of the PEI Associates Quality Assurance Project Plan (PEI85b). In brief, the radioactivity of two standard charcoal sources, each containing 112 nCi of radium-226 uniformily distributed through 180 g of activated charcoal, was measured. An efficiency factor was then computed by dividing the average measured radioactivity of the two standard charcoal sources minus the background in cpm by the known radioactivity of the charcoal sources in dpm. Quantitative retention of all radon entering the canister is assumed. The same two 112 nCi charcoal sources were counted at the beginning and at the end of each day's counting as a check of the radioactivity counting equipment. A background count using unexposed charcoal is made at the beginning and at the end of each counting day to check for inadvertent contamination of the detector or other changes affecting the background.

Scintillometer. The scintillometer was calibrated and checked for accuracy each day by using a pressurized ionization chamber (PIC).

3.4.9 Analytical Procedures

The Polk County Health Department was responsible for measuring the gamma-ray activity of the charcoal canisters and for determining the moisture content of collected phosphogypsum samples. The gamma-ray analyses of the charcoal canisters were performed according to the

detailed procedures given in Appendix 1 of the PEI Associates Quality Assurance Project Plan (PEI85b). Moisture content of the phosphogypsum samples were determined by the ASTM D2216-80 Method, Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures.

All samples subjected to radiochemical analyses were sent to the Eastern Environmental Radiation Facility, EPA, Montgomery, Alabama. All samples were analyzed according to the EERF Radiochemistry Procedures Manual (Li84).

3.4.10 Internal Quality Control Checks and Frequency

Internal quality control checks were conducted on the following measurements: radon flux, soil moisture, radon in air (alpha-track detectors), and radionuclide analyses.

The charcoal from every tenth exposed canister was recounted as were samples that deviated from a predetermined pattern of counts. Five percent of the samples analyzed were either blanks (charcoal having no radioactivity added) or samples spiked with known quantities of radium-226. Also, five percent of the samples collected were replicates. Replicate samples were collected either by placing canisters side by side, or by making successive measurements on the exact same location.

Every tenth phosphogypsum sample analyzed for moisture content was subjected to a duplicate analysis. Every tenth sample analyzed for its radionuclide content was also resubmitted for a duplicate analysis. Blank samples (samples of the same matrix but containing no added radioactivity) were periodically submitted to the analytical laboratory. Spiked samples (samples of the same matrix containing a known radionuclide content) comprised ten percent of the analyses performed.

After exposure, all alpha track detectors were returned to the Eastern Environmental Radiation Facility. There, detectors that had been exposed to known radon-222 concentrations were integrated into each batch of samples and then forwarded to the Terradex Corporation for analyses.

3.4.11 Data Precision, Accuracy, and Completeness

The precision, accuracy, and percent of completeness of measurements and analyses are tabulated below.

Parameter	Precision (Percent)	Accuracy (Percent)	Completeness (Percent)
Radon Flux	10[a]	10[a]	99
Moisture Content	20	ND	99
Alpha-Track Detectors	50	25 at 4 pCi/L	88
Gamma-Ray Exposures	10 at 30 μR/hr	15 at 30 μR/hr	100
Radiochemical Analyses			
U-238/U-234	25/25	8/8	100
Th-230	25	10	91
Ra-226	25	8	94
Pb-210/Po-210	ND/25	ND/ND	100

[a]For values greater than 1.0 pCi/m^2-s.
ND-Not determined.

4. RESULTS

4.1 Radon-222 Flux

The results of all 1239 radon-222 flux measurements made on the dry top surface areas of the five phosphogypsum stacks during the year-long study are listed in Appendix A. The annual average flux determined for each of the ten measurement locations on the phosphogypsum stacks are given in Table 4.1. The standard deviation, the range of values observed, and the number of measurements made at each location are included in the table. Large variations between individual measurements, often exceeding factors of 100, are observed over the 12-month period at each location on the active stacks (see minimum-maximum values). Variation with time is expected due to differences in gypsum moisture content, temperature, and barometric pressure (St84, Ga86); however, because gypsum was continually added to the surfaces of the active stacks between measurements, the Ra-226 content of the surface gypsum, as well as, the density and porosity of the gypsum were also different in most cases for each measurement.

The results given in Table 4.1 are summarized in Table 4.2. The differences in the mean flux values at the ten locations are small, as reflected by relatively small standard deviations that ranged from 14 percent at the Royster stack to 48 percent at the Conserv stack. The larger standard deviations of the mean flux values determined for the

Conserv stack (48 percent) and the W.R. Grace stack (38 percent) can be attributed to one measurement location on each stack, C06 and GR06, respectively. The last column of Table 4.2 shows that the annual average flux values for the different locations on a stack fall within a rather narrow range. Again, the larger range of values observed for the locations on the Conserv and W.R. Grace stacks are due largely to the results at one location. Generally, the annual average flux values at different locations on a stack were well within a factor of two.

The annual average flux at the ten locations on the Estech stack is about 4.5 times less than the average flux of the four active stacks, 4.4 and 20.5 pCi/m^2-s, respectively. This observation agrees with an earlier reported reduction in radon-222 flux of four between active and inactive stacks (Ha85). This reduction is the result of a thick crust that forms on inactive stacks that inhibits the diffusion of radon gas from the stack surface. However, the annual average flux values for the four active stacks are similar, all falling within 20 percent of the mean value. This would indicate that the Florida phosphogypsum stacks are of similar composition and properties.

The large range observed in the measured values of radon flux at an active site with time is not surprising considering that most parameters that affect radon emanation, radium content, moisture content, density, porosity, temperature, and pressure, changed to some degree from one sampling period to the next. A comparison of the average radon-222 flux

Table 4.1 The average radon flux at each location on the phosphogypsum stacks

Location[a]	Radon Flux, pCi/m^2 - sec				
	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Values
		Gardinier Stack			
G01	21	13	0.64	63	34
G02	20	14	2.5	63	33
G03	18	12	1.0	57	34
G04	18	11	0.31	54	33
G05	18	9	1.8	44	34
G06	27	19	1.2	75	34
G07	20	12	0.19	54	33
G08	15	11	1.3	39	33
G09	16	8	2.9	39	34
G10	26	21	1.7	99	34
		W.R. Grace Stack			
GR01	21	14	1.1	65	52
GR02	11	5	2.1	23	52
GR03	15	6	3.5	35	51
GR04	17	7	4.8	39	52
GR05	22	8	7.6	43	52
GR06	5	5	0.22	22	52
GR07	23	29	2.8	210	52
GR08	13	6	0.27	32	52
GR09	14	10	1.8	65	52
GR10	17	12	0.26	54	52
		Royster Stack			
R01	22	15	0.59	42	12
R02	24	21	1.7	81	13
R03	19	19	1.7	61	13
R04	18	13	2.6	42	13
R05	17	8	3.2	37	13
R06	24	13	3.5	44	13
R07	24	16	5.9	50	13
R08	27	18	8.4	67	13
R09	20	8	8.1	38	11
R10	20	12	3.0	41	12

Table 4.1 The average radon flux at each location on the phosphogypsum stacks - Continued

Location[a]	Radon Flux, pCi/m^2 - sec				
	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Values
		Conserv Stack			
C01	18	7	9.9	33	13
C02	22	15	2.7	61	13
C03	19	12	2.4	46	13
C04	20	10	7.5	41	13
C05	20	10	4.5	33	12
C06	58	100	3.9	340	13
C07	29	12	15.	59	13
C08	19	8	5.8	31	12
C09	21	9	5.8	35	13
C10	25	18	11.	82	13
		Estech Stack			
E01	4.0	1.6	0.67	5.4	13
E02	4.5	1.4	2.3	7.0	13
E03	1.7	1.4	0.57	6.0	13
E04	5.5	2.3	2.0	9.4	13
E05	5.2	2.3	2.0	8.7	13
E06	4.1	1.1	2.2	5.8	13
E07	3.7	1.6	1.0	7.9	13
E08	3.2	1.2	1.2	5.5	13
E09	7.4	3.8	1.8	14.1	13
E10	4.6	3.4	1.2	14.5	13

[a]See Section 3.3 for a description of the sampling locations.

Table 4.2 The annual average radon flux on each phosphogypsum stack

Stack[a]	Radon Flux pCi/m^2 - sec	
	Mean[b]	Range[c]
Gardinier	20 ± 4	15 - 27
W.R. Grace	16 ± 6	5 - 23
Royster	21 ± 3	17 - 27
Conserv	25 ± 12	18 - 58
Estech	4.4 ± 1.5	1.7 - 7.4

[a] All stacks were active except the Estech stack.
[b] ± values are the standard deviations of the means.
[c] Range of mean annual flux values determined for the 10 locations on the stacks.

measured at the 10 locations on each stack for each period shows a significant variation of radon-222 flux over the surface of a stack with time, but there is no apparent regular or consistent variation with time (see Appendix F). Neither is there an apparent seasonal variation related to rainfall or temperature. However, any seasonal variation may have been obscured by the changing source terms and other parameters that resulted from the addition of phosphogypsum to the stack surfaces between measurements.

Variations between individual flux measurements do not appear as large on the inactive Estech stack where the stack surface was undisturbed during the year-long measurement period. However, no definite correlation is observed when the moisture content (Table 4.3) is compared with the corresponding radon flux (Table 4.1) for this stack.

In summary, annual average radon emissions were determined for the five phosphogypsum stacks studied. The locations selected for measurement were representative of dry gypsum on the stack top surface, but may over-estimate the average flux of the stack because no consideration was made for the crusted sides. Also, the average flux on the inactive phosphogypsum stack was significantly lower, about 4.5 times, than that measured on the active stacks. However, the uncontrolled nature of the many variables that affect radon flux prevented a determination of their influence on the results.

Table 4.3 The average moisture content of the phosphogypsum at each location on the Estech stack

Location	Percent Moisture Content				
	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Values
E01	11	2	8.4	13.9	13
E02	12	3	7.0	19.2	13
E03	20	6	8.3	35.9	13
E04	10	6	3.8	27.6	13
E05	14	4	8.3	21.1	13
E06	11	4	2.9	16.6	13
E07	12	3	5.3	15.2	13
E08	12	2	7.8	15.6	13
E09	14	1	12.7	17.3	13
E10	7	6	0.3	20.7	13
All locations	12	5	0.3	35.9	130

4.2 Radionuclide Content of Phosphogypsum

The radium-226 concentrations measured in ten phosphogypsum samples collected from each of the five stacks are listed in Table 4.4. Samples were obtained at the same ten locations where radon flux measurements were performed. Phosphogypsum samples were collected only once, at the beginning of the study (see Section 3.3). Because phosphogypsum was continually added to the active stacks during the year-long study, these concentrations relate only to the surface phosphogypsum at the time of collection. However, these data are useful in obtaining information on the radionuclide content of phosphogypsum and how concentrations may vary over the surface of a stack and from one stack to another.

In general, the radium-226 concentrations in the phosphogypsum samples from all stacks were similar. Of the 50 samples analyzed, 41 (82 percent) contained Ra-226 in the range of 20 pCi/g to 40 pCi/g. Six samples had concentrations exceeding 40 pCi/g while only three samples contained less than 20 pCi/g. Fifty-six percent of the samples contained Ra-226 in the range of 25 pCi/g to 35 pCi/g. Except for samples on the Gardinier stack in which the concentrations were very uniform, 31.0 pCi/g to 36.5 pCi/g, concentrations varied on a stack by factors of two to three.

Table 4.4 Radium-226 in phosphogypsum samples

Site/Location	Date of Collection	Ra-226, pCi/g dry weight
Gardinier/G01	07/23/85	33.8
Gardinier/G02	07/23/85	31.4
Gardinier/G03	07/23/85	33.3
Gardinier/G04	07/23/85	33.9
Gardinier/G05	07/23/85	31.0
Gardinier/G06	07/23/85	36.5
Gardinier/G07	07/23/85	32.4
Gardinier/G08	07/23/85	33.3
Gardinier/G09	07/23/85	31.2
Gardinier/G10	07/23/85	32.2
Grace/GR01	07/25/85	26.4
Grace/GR02	07/25/85	26.7
Grace/GR03	07/25/85	45.6
Grace/GR04	07/25/85	19.4
Grace/GR05	07/25/85	48.2
Grace/GR06	07/25/85	28.9
Grace/GR07	07/25/85	30.5
Grace/GR08	07/25/85	28.3
Grace/GR09	07/25/85	22.6
Grace/GR10	07/25/85	27.6
Royster/R01	07/26/85	23.0
Royster/R02	07/26/85	21.0
Royster/R03	07/26/85	47.9
Royster/R04	07/26/85	33.4
Royster/R05	07/26/85	31.1
Royster/R06	07/26/85	49.2
Royster/R07	07/26/85	22.9
Royster/R08	07/26/85	27.1
Royster/R09	07/26/85	15.8
Royster/R10	07/26/85	31.6
Conserv/C01	07/25/85	22.5
Conserv/C02	07/25/85	24.7
Conserv/C03	07/25/85	24.0
Conserv/C04	07/25/85	23.6
Conserv/C05	07/25/85	28.9
Conserv/C06	07/25/85	81.1
Conserv/C07	07/25/85	47.9
Conserv/C08	07/25/85	35.1
Conserv/C09	07/25/85	26.9
Conserv/C10	07/25/85	24.4

Table 4.4 Radium-226 in phosphogypsum samples - Continued

Site/Location	Date of Collection	Ra-226, pCi/g dry weight
Estech/E01	07/26/85	26.1
Estech/E02	07/26/85	24.3
Estech/E03	07/26/85	25.1
Estech/E04	07/26/85	18.8
Estech/E05	07/26/85	30.3
Estech/E06	07/26/85	26.4
Estech/E07	07/26/85	23.6
Estech/E08	07/26/85	22.1
Estech/E09	07/26/85	21.5
Estech/E10	07/26/85	30.8

The radium-226 concentrations determined in phosphogypsum samples from each stack are summarized in Table 4.5. The mean Ra-226 concentrations for each stack is given with the standard deviation of the mean. The range of concentrations are listed in the last column. Except for a few values, these data reflect uniform concentrations over a stack and from one active stack to another. The average concentrations of Ra-226 on the active stacks all fall within a small range, 30 to 34 pCi/g. The average concentration of the inactive Estech stack is somewhat lower, 25±4 pCi/g. The mean Ra-226 concentration of all four active stacks is 32±2 pCi/g.

A composite phosphogypsum sample was prepared from the ten samples collected on each stack and analyzed for the naturally occurring radionuclides. The results of these analyses are listed in Table 4.6.

Background concentrations, listed on the bottom line of the table, are the average concentrations of the nine soil samples listed in Appendix C that had been collected in areas of Florida that were unrelated to the phosphate industry (see Section 3.3.7).

A comparison of the Ra-226 concentrations determined in the composite samples (Table 4.6) with the mean concentrations determined for the individual samples (Table 4.5) shows close agreement for the Conserv, Gardinier, and W.R. Grace samples. Concentrations in the Estech and Royster samples differed significantly, by 47 percent and 30 percent, respectively. As it is very difficult to ensure homogeneity of solid mixtures, an explanation of these differences may be that the samples from the Estech and Royster stacks were not uniformly mixed in the composite samples.

Table 4.5 A summary of the radium-226 concentrations in phosphogypsum samples

Stack	pCi/g dry	
	Mean[a]	Range
Gardinier	33 ± 2	31 - 37
W.R. Grace	30 ∓ 9	19 - 48
Royster	30 ∓ 11	16 - 49
Conserv	34 ∓ 18	23 - 81
Estech	25 ∓ 4	19 - 31

[a]Mean concentration with the standard deviation of samples from the 10 locations.

Table 4.6 Radioactivity in composite phosphogypsum samples

Location	--- Concentration, pCi/g dry weight ---					
	Ra-226	U-234	U-238	Th-230	Po-210	Pb-210
Conserv	33.2	2.7	3.1	4.2	28.0	34.3
Estech	17.4	2.3	2.4	4.9	21.9	32.6
Gardinier	32.7	4.9	5.2	6.7	26.6	38.2
Grace	29.7	3.6	2.7	6.5	27.7	37.1
Royster	22.6	2.9	2.5	3.1	29.4	38.7
Background[a]	0.5	0.3	0.3	0.3	0.5	0.7

[a] See Appendix C.

Notes: (1) The average 2σ uncertainties (percent) associated with these concentrations are: Ra-226 (1.3), U-234 (16), U-238 (16), Th-230 (12), Po-210 (9.5), Pb-210 (20).

(2) The concentrations of Ra-228, Th-227, Th-228, and Th-232 were small and insignificant (less than 1 pCi/g) in all samples.

The radionuclide content of composite samples from the different stacks varied by factors of two or less. Some variation may be attributed to the inhomogeneous composition of the composite sample and, in some cases, to large uncertainties in the analytical results.

These data also show a considerable fractionation of radionuclides occurring during the chemical process of producing phosphoric acid from the phosphate rock. It has been reported that about 80 percent of the Ra-226 follows the phosphogypsum while about 86 percent of the uranium and

70 percent of the thorium are found in the phosphoric acid (Gu75). Thus, the Ra-226/U-238 and Th-230/U-238 activity ratios should be about 5.7 and 2.1, respectively, if, as reported (Gu75), secular equilibrium exists in the phosphate rock prior to chemical treatment. These data indicate similar but somewhat different ratios. The average activity ratios of the major radionuclides in the composite phosphogypsum samples are as follows.

Ra-226/U-238 = 9.2	Pb-210/Ra-226 = 1.4
Th-230/U-238 = 1.7	Po-210/Pb-210 = 0.74
Pb-210/U-238 = 12	U-234/U-238 = 1.1

The average concentrations of the principal radionuclides measured in the composite phosphogypsum samples from the four active stacks are listed in Table 4.7. Included in the table are the radionuclide concentrations measured in the composite sample from the Estech stack and, for comparison, the average concentrations measured in the background soil samples. The radionuclide concentrations in the phosphogypsum exceeded by many times the background concentrations. Uranium concentrations exceed background by about 11 times, thorium by 17 times, and radium by 60 times. Although these concentrations are many times background, they are less than those associated with uranium mill tailings by a factor of a hundred or more (EPA86).

Table 4.7 Average concentrations of the major radionuclides in the composite phosphogypsum samples

	Concentrations, pCi/g dry weight					
Samples	Ra-226	U-234	U-238	Th-230	Po-210	Pb-210
Active stacks	30 ± 5	3.5 ± 1.0	3.4 ± 1.2	5.1 ± 1.8	28 ± 1	37 ± 2
Estech stack	17	2.3	2.4	4.9	22	33
Background soil	0.5	0.3	0.3	0.3	0.5	0.7

Note - ± values are the standard deviations of the mean.

4.3 Airborne Radioactive Particulate Concentrations and Particle Size

4.3.1 General

To determine the significance of radioactive particles in air from phosphogypsum stacks, airborne particulate concentration and particle size measurements were made in the vicinity of two phosphogypsum stacks. Also, weekly background samples were collected continuously over a 12-month period in Winter Haven, Polk County, Florida, where no phosphate rock exists. The sampling methods are explained in Section 3.2.4.

4.3.2 High-Volume Samples

Airborne particulate samples were initially collected in downwind and upwind directions of the Gardinier stack using High Volume air samplers (see Section 3.3.2). However, after a six-month sampling period this

location was abandoned because most of the dust that was collected had originated from nearby haul roads or the phosphate plant and was not related to fugitive dust from the stack. Although it is not possible to interpret the results obtained for these samples with respect to air particulates from the phosphogypsum stack, they are included in Appendix B, Tables B.7 to B.10.

The High Volume air samplers were relocated in March 1986 to the W.R. Grace south stack in Bartow, Florida. The samplers were positioned 460 m southeast (upwind) and 115 m northwest (downwind) from the stack edge and were operated continuously for a four month period (see Section 3.3.3). Filters, replaced weekly, were combined into monthly samples and analyzed for their natural radionuclide content.

The results of the radionuclide analyses of the airborne particulate samples collected at the W.R. Grace site are presented in Appendix B, Tables B.3 to B.6. The results of the radionuclide analyses of the background samples collected in Winter Haven, Florida, are given in Appendix B, Tables B.1 and B.2. The gross concentrations of the four principal radionuclides measured in the airborne particulate samples are listed in Table 4.8 along with the mass of material collected and the total air volume sampled during each monthly period. In order to correct

these concentrations for the background contributions, the gross concentrations are converted to specific concentrations by using the equation given in footnote (d) of Table 4.8. The specific radionuclide concentrations are listed in the last four columns of Table 4.8. The net airborne radionuclide concentrations, listed in Table 4.9, were computed by subtracting the background contributions, Table 4.8, and converting the net specific activities to concentrations in terms of pCi/m^3 using the equation given in footnote (c) of Table 4.9. The concentrations of Po-210 and Pb-210 were not measured in the high-volume air samples because the filters were ashed prior to the analyses.

The airborne radionuclide concentrations are all quite small, in the range of a few hundred attocuries per cubic meter, and only about three times the measured background concentrations. In general, the average monthly concentrations varied by less than a factor of three during the four-month sampling period.

The concentration of radionuclides in the airborne particulates collected at the northwest location averaged 50 to 70 percent higher than those collected at the southeast location (see the average net concentrations listed at the bottom of Table 4.9). Higher concentrations at the northwest location might be expected because the sampler at that

Table 4.8 Specific radionuclide concentrations in air samples collected at the W.R. Grace stack and a background site

Sampling Period	Location[a]	Volume Sampled (m^3)	Net Mass Collected[b] (gms)	Gross Concentrations, pCi/m^3[c]				Specific Concentrations, pCi/g[d]			
				Th-230	U-234	Ra-226	U-238	Th-230	U-234	Ra-226	U-238
3/07-3/31/86	SE	29,100	0.2651	1.32E-4	1.24E-4	1.54E-4	1.20E-4	14.49	13.61	16.90	13.17
3/03-3/31/86	BKG	35,400	0.2421	2.39E-5	1.96E-5	2.60E-5	1.76E-5	3.49	2.87	3.80	2.57
3/31-4/28/86	SE	31,400	0.4106	1.46E-4	1.57E-4	1.66E-4	1.40E-4	11.17	12.01	12.69	10.71
3/31-4/28/86	NW	31,100	0.5196	2.61E-4	2.52E-4	2.87E-4	2.46E-4	15.62	15.08	17.18	14.72
3/31-4/28/86	BKG	32,700	0.3875	3.67E-5	4.20E-5	5.81E-5	5.44E-5	3.10	3.54	4.90	4.56
4/28-5/27/86	SE	32,800	0.4381	1.62E-4	1.92E-4	2.26E-4	1.89E-4	12.13	14.37	16.92	14.15
4/28-5/27/86	NW	26,100	0.4599	2.70E-4	2.74E-4	2.49E-4	2.64E-4	15.32	15.55	14.13	14.76
4/28-5/27/86	BKG	35,300	0.4162	3.53E-5	3.18E-5	4.82E-5	2.92E-5	2.99	2.70	4.09	2.46
5/27-6/23/86	SE	27,000	0.2333	1.51E-4	1.19E-4	1.30E-4	1.13E-4	17.48	13.77	15.04	13.08
5/27-6/23/86	NW	31,000	0.3081	1.22E-4	1.45E-4	3.90E-4	1.33E-4	12.28	14.59	39.24	13.08
5/27-6/23/86	BKG	33,300	0.1898	2.99E-5	2.71E-5	6.10E-5	2.31E-5	5.25	4.75	10.70	4.05
6/23-7/17/86	SE	29,000	0.4520	1.73E-4	1.38E-4	2.10E-4	1.38E-4	11.10	8.85	13.47	8.85
6/23-7/17/86	NW	27,600	0.4661	1.60E-4	1.52E-4	1.90E-4	1.57E-4	9.47	9.00	11.25	9.30
6/23-7/17/86	BKG	22,500	0.3432	5.16E-5	1.88E-5	7.90E-5	3.45E-5	3.38	1.23	5.18	2.26

[a] High volume air samplers were located 460 m southeast (SE) of the stack, 115 m northwest (NW) of the stack, and at a background location (BKG) in Winter Haven, Florida.

[b] Net mass collected = total mass - filter ash mass (0.09336 g per 4 filters)

[c] Concentrations from Appendix B - Tables B.1 (Background), B.3 (SE corner), and B.4 (NW corner).

[d] $\frac{(pCi/m^3)\ (\text{Volume sampled, } m^3)}{(\text{Net mass on filter, g})}$

Table 4.9 Net radionuclide concentrations in air at the W.R. Grace stack

Sampling Period	Location[a]	Net Specific Concentrations, pCi/g[b]				Net Airborne Particulate Concentrations, pCi/m^3[c]			
		Th-230	U-234	Ra-226	U-238	Th-230	U-234	Ra-226	U-238
3/07-3/31/86	SE	11.00	10.74	13.10	10.60	1.00E-4	9.78E-5	1.19E-4	9.66E-5
3/31-4/28/86	SE	8.07	8.47	7.79	6.15	1.06E-4	1.11E-4	1.02E-4	8.04E-5
3/31-4/28/86	NW	12.52	11.54	12.28	10.16	2.09E-4	1.93E-4	2.05E-4	1.70E-4
4/28-5/27/86	SE	9.14	11.67	12.83	11.69	1.22E-4	1.56E-4	1.71E-4	1.56E-4
4/28-5/27/86	NW	12.33	12.85	10.04	12.30	2.17E-4	2.26E-4	1.77E-4	2.17E-4
5/27-6/23/86	SE	12.23	9.02	4.34	9.03	1.06E-4	7.79E-5	3.75E-5	7.80E-5
5/27-6/23/86	NW	7.03	9.84	28.54	9.03	6.99E-5	9.78E-5	2.84E-4	8.97E-5
6/23-7/17/86	SE	7.72	7.62	8.29	6.59	1.20E-4	1.19E-4	1.29E-4	1.03E-4
6/23-7/17/86	NW	6.09	7.77	6.07	7.04	1.03E-4	1.31E-4	1.03E-4	1.19E-4
Average Net Concentrations	SE					1.1E-4	1.1E-4	1.1E-4	1.0E-4
	NW					1.5E-4	1.6E-4	1.9E-4	1.5E-4

[a] High volume air samplers were located 460 m southeast (SE) and 115 m northwest (NW) of the stack.

[b] Net pCi/g = (gross pCi/g - bkg pCi/g)

[c] $$\text{Net pCi/m}^3 = \frac{\text{(net pCi/g) (net mass on filter, g)}}{\text{(volume sampled, m}^3\text{)}}$$

location was much closer to the stack, 115 m versus 460 m, and it was in a predominantly downwind direction from the phosphogypsum stack. However, the source of a large proportion of the material collected by the High-Volume samplers appears to be other than the phosphogypsum stack. The ratios of the radionuclide concentrations collected from the air do not reflect phosphogypsum. For example, the Ra-226/U-238 concentration ratio measured in the composite phosphogypsum sample from the W.R. Grace stack was 11 (see Table 4.6), which is much larger than the same ratio of concentrations observed in the airborne particulate samples, less than 2 (see Table 4.9). The same observation is made concerning the Th-230/U-238 concentration ratios. This agrees with the observation that although by-product material on the phosphogypsum stack is over 50 percent sulfate, particles collected only a few hundred meters from the stack generally contain less than 10 percent sulfate (Ni88). Thus, a significant amount of the material collected by the air samplers was from a source other than the phosphogypsum stack, illustrating the extreme difficulty of relating airborne samples collected at a predetermined location to a particular source over a long period of time.

4.3.3 Particle Size of Airborne Samples

The size of airborne radioactive particles is an important factor that must be considered when estimating the potential radiation dose equivalent due to inhalation of particulates. Particle size measurements were made as described in Section 3.2.4. Sampling was initially conducted

at the Gardinier stack (see Appendix B, Tables B.22 to B.29), but was terminated there and relocated at the W.R. Grace stack for the same reasons as given above for the High-Volume sampling.

At the W.R. Grace stack, 24-hour particle size samples were collected twice (4/21/86 and 7/17/86) at each of the two High-Volume sampler locations, 460 m southeast and 115 m northwest of the stack. The particles were separated into 5 ranges of size, and the material collected in each range was analyzed separately for its radionuclide content. The results of these measurements are given in Appendix B, Tables B.13 to B.16. One background particle sizing sample was collected at the background location in Winter Haven, Florida, and the results of this sample are given in Appendix B, Table B.11.

Blank filters for each stage were analyzed for their radionuclide content and the results are listed in Appendix B, Table B.21. Subtracting these concentrations from the gross concentrations yielded the net radionuclide concentrations for each stage of the four samples that are listed in Appendix B, Tables B.17 to B.20. The quantities of airborne material collected in each stage were very small, leading to large uncertainties in the results. The concentrations in the blank filters often exceeded the sample concentrations resulting in many less-than values. This was particularly true of the backup filter, which collected all particles having diameters of < 1.1 μm.

The concentrations of the principal radionuclides associated with each of the 5 particle size ranges are listed in Table 4.10. The total concentrations for all particle size ranges are listed in the last column. In this summation, less-than values were assumed equal to the concentrations. Thus, most total concentrations listed in this column are maximum values. These uncertainties limit the usefulness of the particle size data. The concentration of most radionuclides observed in the particle size samples collected at the W.R. Grace stack are not significantly greater than those measured in the background samples listed last in Table 4.10. For example, the average Po-210 concentration, 8.4E-3 pCi/m^3, is the same as the concentration measured in the background sample, 9.5E-3 pCi/m^3, considering the 18 percent uncertainty in these values.

The percent of the radionuclides appearing in each particle size range is given in Table 4.11. Only the sets of data having positive values for all five particle size ranges were used to determine the percentages. These samples are identified by asterisks in Table 4.10. In the second column of Table 4.11 are listed the number of samples for which concentration values were positive for all particle size ranges. Due to the small sample number, no distinction is made between sampling location nor sampling time in computing these average percentages.

The particle size distribution associated with Po-210 is different than that of the other three radionuclides. Very little Po-210 is associated with the larger sized particles and nearly all (about 80

Table 4.10 Radionuclide concentrations in particulates of different particle sizes, pCi/m^3

Radionuclide	Particle Size Ranges, μm > 7	3.3-7.0	2.0-3.3	1.1-2.0	< 1.1	Total for all particle sizes
			Southeast Corner, 4/21/86[a]			
Ra-226	NA	NA	2.1E-4	NA	1.2E-4	> 3.3E-4
U-234	2.3E-4	< 1E-4	< 8E-5	< 6E-5	4.8E-4	< 9.5E-4
U-238	7.0E-5	1.5E-4	3.2E-5	< 9E-5	2.1E-4	< 5.5E-4
Th-230	1.4E-4	< 6E-5	1.4E-5	5.8E-5	< 3E-4	< 5.7E-4
Pb-210	< 3E-3	< 2E-3	< 3E-3	5.1E-4	1.8E-2	< 2.7E-2
Po-210*	3.2E-4	1.9E-4	2.0E-4	3.9E-4	3.3E-3	4.4E-3
			Southeast Corner, 7/17/86[b]			
Ra-226	8.6E-5	1.2E-4	8.6E-5	NA	2.7E-4	> 5.6E-4
U-234	2.0E-4	< 1E-4	3.2E-5	< 9E-5	1.4E-5	< 4.4E-4
U-238*	2.6E-4	7.0E-5	6.2E-5	8.1E-5	7.4E-5	5.5E-4
Th-230	8.7E-5	< 1E-4	8.7E-5	5.6E-5	< 3E-4	< 6.3E-4
Pb-210	< 3E-3	< 3E-3	4.1E-4	< 3E-3	1.4E-2	< 2.3E-2
Po-210*	2.4E-4	2.7E-4	3.1E-4	4.9E-4	6.1E-3	7.4E-3
			Northwest Corner, 4/21/86[c]			
Ra-226	NA	NA	NA	NA	5.9E-4	> 5.9E-4
U-234	1.9E-4	< 2E-4	9.7E-5	< 9E-5	3.4E-4	< 9.2E-4
U-238*	2.7E-4	1.4E-4	1.1E-4	1.5E-4	1.5E-4	8.2E-4
Th-230*	2.3E-4	9.6E-5	6.5E-5	5.8E-5	3.8E-4	8.3E-4
Pb-210	< 3E-3	< 3E-3	4.6E-3	1.9E-4	1.8E-2	< 2.9E-2
Po-210*	3.1E-4	1.7E-4	3.9E-4	4.7E-4	1.5E-2	1.6E-2
			Northwest Corner, 7/17/86[d]			
Ra-226*	2.1E-4	2.4E-4	8.3E-5	1.2E-4	1.4E-4	7.9E-4
U-234	8.5E-5	3.7E-5	1.8E-6	< 9E-5	< 3E-4	< 5.1E-4
U-238	1.4E-4	6.6E-5	1.9E-5	4.6E-5	< 3E-4	< 5.7E-4
Th-230	7.2E-5	< 9E-5	2.7E-5	1.0E-5	8.2E-5	< 2.8E-4
Pb-210	< 1E-3	< 3E-3	4.5E-3	1.7E-3	1.3E-2	< 2.3E-2
Po-210*	2.1E-4	2.4E-4	1.7E-4	2.6E-4	5.0E-3	5.9E-3

Table 4.10 Radionuclide concentrations in particulates of different particle sizes, pCi/m^3 - Continued

Radionuclide	Particle Size Ranges, μm > 7	3.3-7.0	2.0-3.3	1.1-2.0	< 1.1	Total for all particle sizes
			Background, 7/14/86[e]			
Ra-226	7.7E-5	2.2E-4	7.7E-5	1.1E-4	< 1E-4	< 5.8E-4
U-234	3.3E-5	< 1E-4	< 8E-5	< 1E-4	< 3E-4	< 6.1E-4
U-238	4.5E-5	5.7E-5	< 6E-5	4.7E-5	< 3E-4	< 5.1E-4
Th-230	< 3E-4	2.7E-4	1.9E-4	2.1E-4	< 3E-4	< 1.3E-3
Pb-210	3.0E-5	< 3E-3	3.0E-3	1.3E-3	8.4E-3	< 1.6E-2
Po-210*	2.3E-4	4.3E-4	5.6E-4	8.6E-4	7.4E-3	9.5E-3

[a]From Appendix B, Table B.17.
[b]From Appendix B, Table B.18.
[c]From Appendix B, Table B.19.
[d]From Appendix B, Table B.20.
[e]From Appendix B, Table B.12.

Note: Approximate 2σ uncertainties in net particle size concentrations are: Ra-226=16 percent; U-238=33 percent; U-234=35 percent; Th-230=36 percent; Pb-210=64 percent; and Po-210=18 percent.

*Samples used to prepare Table 4.11.

percent) is combined with the small (< 1.1 μm) respirable sized particles. This closely resembles the particle size distribution of background Po-210. Most of the Ra-226 and U-238 are associated with the larger sized particles. More than 50 percent of the radioactivity is with particles greater than 3.3 μm in diameter, while only about 20 percent is combined with the smaller (< 1.1 μm) respirable sized particles. These data resemble the distribution observed for particles measured downwind from a wet process phosphate plant in which more than 40 percent of the radioactivity was associated with particles having diameters greater than

3.3 μm and only about 20 percent of the radioactivity was with the smaller (< 1.1 μm) sized particles (PA78). It should be emphasized, however, that the phosphogypsum stack was not the principal source of the particulates collected; thus, these data reflect the air quality for that area and are not specific to phosphogypsum.

In summary, the small quantities of particulates collected and their low radionuclide content indicate that airborne emissions from phosphogypsum stacks are not significant. This supports the conclusion that airborne particulates are observed infrequently from phosphogypsum stacks because of the high moisture content in the gypsum on active stacks and the crust that exists on inactive stacks. Thus, most dust produced is due to vehicular traffic on and around the stack and very little, if any, by wind erosion.

Table 4.11 The average percent of radionuclides in each particle size range

Radionuclide	No. of Samples	Particle Size Ranges, μm				
		> 7	3.3-7.0	2.0-3.3	1.1-2.0	< 1.1
Ra-226	1	27	30	10	15	18
U-238	2	40	15	12	17	16
Th-230	1	28	11	8	7	46
Po-210	4	4	3	4	6	83
Po-210, Bkg	1	2	5	6	9	78
Total Alpha emitters[a]	4	32	18	10	13	27

[a]Excluding Po-210.

4.4 Airborne Radon Concentrations

Radon-222 concentrations in air were obtained one meter above ground surface at each phosphogypsum stack using alpha-track detectors (see Section 3.3). In addition, background concentrations were measured at 9 locations located at least 8 km from any phosphogypsum stack. Measurements were made continuously during the 1-year study using three 4-month exposure periods; 22 July 1985-4 December 1985; 2 December 1985-3 April 1986; and 2 April 1986-23 July 1986. The methods for these measurements are described in Section 3.2.5.

It was not feasible to place the alpha track detectors on top of the active stacks for extended periods of time because of the continuous activity of adding phosphogypsum to the stacks. To ensure detector safety, exposure locations believed to be representative of the stack surface were selected along the perimeter roads at the base of the stacks. The Estech and W.R. Grace stacks did accommodate an additional measurement location near the center of the stacks. In addition, detectors were also placed at distances of approximately one- and two-stack diameters from the Gardinier and W.R. Grace stacks.

Although the study was designed to obtain exposures for 3 detectors at each location for each four-month period (see Section 3.1.5), this was realized for only about 70 percent of the measurements. Even though care was exercised in selecting measurement locations that were removed from

plant activity and traffic, one, two, and sometimes all three detectors were found to be damaged or missing at the end of the sampling period. The results for detectors showing any damage were discarded. Thus, the results of some measurements are based on only one or two detectors. Of the 116 measurements accomplished, 96 are based on the results of three detectors, 16 on two detectors, and 4 on only one detector. Data for 25 measurements were lost because all three detectors at a site were either damaged or missing.

The results of all individual alpha track detectors exposed in the study are listed in Appendix D, Table D.1. The results for each set of detectors that were exposed together were averaged and the average value adjusted according to a series of calibration measurements (see Appendix D, Tables D.2 and D.3). The average corrected radon concentrations determined for each location are listed in Table 4.12 and are summarized in Table 4.13. There is no indication that concentrations were consistently higher during any one sampling period. Concentrations at a perimeter site generally varied between periods by a factor of two or less. The average radon concentrations in air at different locations along the base perimeter of a stack also do not vary significantly (see last column, Table 4.12). An analysis of the concentrations at these sampling locations with respect to the direction of the prevailing winds in the area of the stack fail to reveal any consistent correlation. This indicates a significant contribution of radon to the detectors from sources other than the phosphogypsum stacks. Also, higher radon

Table 4.12 Corrected outdoor radon concentrations measured in air at individual sampling locations, pCi/L[a]

Sampling Location[b]		First Period[c]	Second Period[d]	Third Period[e]	Annual Average Concentration[h]
			Gardinier Stack		
G01	SP	0.53	0.31	0.22	0.35 ± 0.16
G02	SP	0.61	0.35	0.36	0.44 ± 0.15
G03	SP	1.79	0.28	0.31	0.79 ± 0.86
G04	SP	0.52	0.40	0.44	0.45 ± 0.06
G05	SP	0.78	0.48	0.40	0.55 ± 0.20
G06	SP	1.60	0.56	0.41	0.86 ± 0.61
G07	SP	(f)	0.35	(f)	0.35
G08	1-SD	(f)	0.18	0.16	0.17 ± 0.01
G09	2-SD	0.26	0.23	0.19	0.23 ± 0.04
G10	2-SD	(f)	0.26	0.17	0.22 ± 0.06
G11	1-SD	0.24	0.21	0.16	0.20 ± 0.07
G12	2-SD	(f)	0.18	0.17	0.18 ± 0.01
			W.R. Grace Stack		
GR01	2-SD	0.08	0.68	(f)	0.38 ± 0.42
GR02	1-SD	5.48	(f)	1.78	3.6 ± 2.6
GR03	2-SD	0.69	0.42	0.33	0.48 ± 0.19
GR04	2-SD	1.02	0.58	0.50	0.70 ± 0.28
GR05	1-SD	0.59	0.72	0.59	0.63 ± 0.07
GR06	2-SD	0.60	0.43	(f)	0.52 ± 0.12
GR07	1-SD	0.63	0.51	0.50	0.55 ± 0.07
GR08	C	(f)	0.29	(f)	0.29
GR09	SP	0.73	0.44	0.45	0.54 ± 0.33
GR10	SP	1.00	0.60	0.56	0.72 ± 0.24
GR11	SP	2.20	1.10	1.40	1.6 ± 0.6
GR12	SP	1.12	(f)	0.66	0.89 ± 0.33
GR13	SP	0.51	0.35	(f)	0.43 ± 0.11
			Royster Stack		
R01	SP	0.55	0.50	(f)	0.52 ± 0.04
R02	SP	0.36	0.41	1.16	0.64 ± 0.44
R03	SP	0.29	0.36	(f)	0.32 ± 0.05
R04	SP	(f)	0.47	(f)	0.47
			Conserv Stack		
C01	SP	0.55	(f)	0.97	0.76 ± 0.30
C02	SP	0.83	0.69	1.16	0.89 ± 0.24
C03	SP	0.61	0.65	(f)	0.63 ± 0.03
C04	SP	(f)	0.36	(f)	0.36

Table 4.12 Corrected outdoor radon concentrations measured in air at individual sampling locations, pCi/L[a] - Continued

Sampling Location[b]		First Period[c]	Second Period[d]	Third Period[e]	Annual Average Concentration[h]
			Estech Stack		
E01	SP	0.44	0.55	(f)	0.50 ± 0.08
E02	SP	0.62	0.55	0.87	0.68 ± 0.17
E03	SP	(f)	0.77	0.61	0.69 ± 0.11
E04	C	0.65	1.02	(f)	0.84 ± 0.26
E05	SP	1.10	0.78	0.79	0.89 ± 0.18
			Background		
PB01		0.12	0.17	0.13	0.14 ± 0.03
PB02		0.15	0.16	0.15	0.15 ± 0.01
PB03		0.12	0.16	0.16	0.15 ± 0.02
PB04		0.19	0.21	0.16	0.19 ± 0.03
PB05		0.21	0.19	0.19	0.20 ± 0.01
GB01		(f)	0.64	0.37	0.50 ± 0.20
GB02		(f)	(g)	(g)	(g)
GB03		0.14	0.28	0.45	0.29 ± 0.16
GB04		0.15	0.17	0.20	0.17 ± 0.03
GB05		(g)	0.21	0.30	0.26 ± 0.06

[a] Average corrected exposure measured on three detectors.

[b] Sampling locations: SP-stack perimeter, 1 SD-a distance of one stack diameter, 2 SD-a distance of two stack diameters, C-near center of stack. Background: PB-Polk County and GB-Hillsborough County, FL.

[c] First period measurements were made from 7/22/85 to 12/4/85. The correction factor for this period was 1.25 (see Appendix D, Table D.2).

[d] Second period measurements were made from 12/2/85 to 4/3/86. The correction factor for this period was 1.02 (see Appendix D, Table D.3).

[e] Third period measurements were made from 4/2/86 to 7/23/86. The correction factor for this period was 0.67 (see Appendix D, Table D.3).

[f] All three detectors were either lost or damaged.

[g] No measurements made.

[h] ± values are standard deviations of the mean.

concentrations were not observed at the locations near the center of the Estech and W.R. Grace stacks, as might be expected. The low concentration observed at the center of the W.R. Grace stack is attributed to water covering the stack surface in the vicinity of the detectors.

The results of the distant measurements at the Gardinier stack were all similar, as was the case at the W.R. Grace stack, except for one site, GR02, where a large difference was observed. The background concentrations, especially those measured in Polk County, Florida, were very consistent during the 12-month period.

The average annual radon concentrations in air at each phosphogypsum stack are summarized in Table 4.13. The Gardinier stack is located in Hillsborough County, FL, while the other four stacks are in Polk County, FL. The background radon concentrations were consistently higher in Hillsborough County for unknown reasons. The concentrations at the one- and two-stack diameter locations at Gardinier, 0.20 pCi/L, were 45 percent lower than the average Hillsborough County background. Using the lower value of 0.20 pCi/L for the background at the Gardinier stack and the average Polk County background, 0.16 pCi/L, at the other four stacks results in the following net radon concentrations at the base perimeters of the phosphogypsum stacks.

Gardinier stack-0.4 pCi/L	Conserv stack-0.6 pCi/L
W.R. Grace stack-0.7 pCi/L	Estech stack-0.6 pCi/L
Royster stack-0.4 pCi/L	

Table 4.13 A summary of the average outdoor radon concentrations in air, pCi/L

Stack	First Period	Second Period	Third Period	Annual Average Concentration
Gardinier				
Stack perimeter	0.97 ± 0.57	0.39 ± 0.10	0.36 ± 0.08	0.56 ± 0.41
1-stack diameter	0.24	0.20 ± 0.02	0.16 ± 0.00	0.19 ± 0.03
2-stack diameters	0.26	0.22 ± 0.04	0.18 ± 0.01	0.21 ± 0.04
W.R. Grace				
Stack perimeter	1.1 ± 0.7	0.62 ± 0.33	0.77 ± 0.43	0.86 ± 0.51
Center of stack	(a)	0.29	(a)	0.29
1-stack diameter	2.3 ± 2.8	0.62 ± 0.15	0.96 ± 0.71	1.4 ± 1.7
2-stack diameters	0.60 ± 0.39	0.53 ± 0.13	0.42 ± 0.12	0.53 ± 0.25
Royster				
Stack perimeter	0.40 ± 0.13	0.44 ± 0.06	1.16	0.51 ± 0.28
Conserv				
Stack perimeter	0.66 ± 0.15	0.57 ± 0.18	1.06 ± 0.13	0.73 ± 0.25
Estech				
Stack perimeter	0.70 ± 0.30	0.73 ± 0.20	0.76 ± 0.13	0.71 ± 0.19
Center of stack	0.65	1.02	(a)	0.84 ± 0.26
Background				
Polk County	0.16 ± 0.04	0.18 ± 0.02	0.16 ± 0.02	0.16 ± 0.03
Hillsborough County	0.14 ± 0.01	0.32 ± 0.21	0.33 ± 0.11	0.29 ± 0.16

(a) No measurements obtained at this location.
Note: ± values are standard deviations of the mean.

The net concentrations are all similar and exceed the background levels by 3 to 5 times. However, the concentrations at the W.R. Grace stack do reflect some anomalies when the concentrations at the distant locations are considered. The radon concentrations at the 1-stack diameter locations (about 500 m) are about twice that observed at the base perimeter locations, while the concentrations at the 2-stack diameter locations (about 1500 m) are about 3 times background (see Section 3.3.3 for sampling locations). These high concentrations are explained by the fact that the W.R. Grace stack is surrounded by reclaimed mined-out land. Thus, high radon concentrations in areas around the W.R. Grace stack are to be expected. For example, concentrations as high as 5.5 pCi/L were observed at measurement location GR02 (see Table 4.12), which is about 500 m southeast (upwind) of the stack (see Section 3.3.3). Thus, the source of the radon measured at these distant locations is not the phosphogypsum stack but rather radium-226 in the soil in the immediate vicinity of the detectors.

Table 4.14 shows the comparison of the average radon concentrations with the average flux determined for each stack. The results in this table indicate that no relationship exists between the radon flux on a stack and the radon concentration in air at the base perimeter of a stack. This is especially obvious considering the results at the Estech stack, which has the lowest flux but one of the highest radon concentrations. The area surrounding the Estech stack, like that at the W.R. Grace stack, contains mined-out land, and this is the most likely cause of the high radon concentrations observed on the perimeter of the stack.

It is clear from these data that the radon concentrations measured at the base perimeter of a stack have no relationship to the radon flux on that stack, but are the result of radon emanating from the soil in close proximity to the detector locations. Contributing to the failure to observe a correlation between radon flux and concentration is: (a) the time of measurement, 24 hours versus 4 months, and (b) the area of the radon source measured with the charcoal canister, 0.05 m^2, versus an unknown area monitored by the alpha-track detector of many square meters.

Table 4.14 A comparison of the radon flux with the radon concentration in air at each stack

Stack	Mean Radon Flux, $pCi/m^2\text{-}s$[a]	Mean Radon Concentration, pCi/L[b]
Gardinier	20	0.56
W.R. Grace	16	0.86
Royster	22	0.51
Conserv	25	0.73
Estech	4.4	0.71

[a]From Table 4.2.
[b]From Table 4.13.

4.5 Gamma-Ray Exposures

Gamma-ray exposure measurements were obtained one meter above ground level at each location on the phosphogypsum stacks where radon flux measurements and phosphogypsum samples were obtained (see Sections 3.1.6 and 3.3). These measurements were made only once, during the first week of the study when the phosphogypsum samples were collected. Background exposure measurements were obtained in a region of Polk County, Florida, outside the influence of the phosphate industry and any phosphogypsum stack (see Section 3.3.7). Background exposure rates, measured with pressurized ionization chambers, ranged from 4 to 6 μR/hr (Na86).

The gamma-ray exposure rates measured at each of the 10 sampling locations on the five phosphogypsum stacks are given in Table 4.15. Except for only a few measurements, the exposure rates were very consistent over the surface of the stacks, varying by only about 30 percent over the entire surface. Exposures were particularly consistent over the Estech and Gardinier stacks where exposures differed by only 5 μR/hr and 6 μR/hr, respectively. In general, no correlation is observed between the gamma-ray exposure rates and the radon flux measured at these locations at the same time (see Appendix A). A comparison of the exposure rates with the Ra-226 concentrations in phosphogypsum collected at the same time and location also shows no direct correlation.

Table 4.15 Gamma-ray exposure rate measurements at phosphogypsum sample locations

Site/Location[a]	Date of Measurement	Exposure Rate at 1 Meter, μR/hr
Gardinier/G01	07/23/85	30
Gardinier/G02	07/23/85	30
Gardinier/G03	07/23/85	29
Gardinier/G04	07/23/85	33
Gardinier/G05	07/23/85	28
Gardinier/G06	07/23/85	32
Gardinier/G07	07/23/85	30
Gardinier/G08	07/23/85	31
Gardinier/G09	07/23/85	2[illegible]
Gardinier/G10	07/23/85	29
Grace/GR01	07/25/85	40
Grace/GR02	07/25/85	32
Grace/GR03	07/25/85	41
Grace/GR04	07/25/85	36
Grace/GR05	07/25/85	30
Grace/GR06	07/25/85	32
Grace/GR07	07/25/85	34
Grace/GR08	07/25/85	33
Grace/GR09	07/25/85	34
Grace/GR10	07/25/85	48
Royster/R01	07/26/85	34
Royster/R02	07/26/85	28
Royster/R03	07/26/85	33
Royster/R04	07/26/85	32
Royster/R05	07/26/85	34
Royster/R06	07/26/85	38
Royster/R07	07/26/85	36
Royster/R08	07/26/85	33
Royster/R09	07/26/85	32
Royster/R10	07/26/85	32

Table 4.15 Gamma-ray exposure rate measurements at phosphogypsum sample locations - Continued

Site/Location[a]	Date of Measurement	Exposure Rate at 1 Meter, μR/hr
Conserv/C01	07/25/85	26
Conserv/C02	07/25/85	27
Conserv/C03	07/25/85	27
Conserv/C04	07/25/85	28
Conserv/C05	07/25/85	37
Conserv/C06	07/25/85	50
Conserv/C07	07/25/85	50
Conserv/C08	07/25/85	30
Conserv/C09	07/25/85	28
Conserv/C10	07/25/85	27
Estech/E01	07/26/85	34
Estech/E02	07/26/85	32
Estech/E03	07/26/85	32
Estech/E04	07/26/85	32
Estech/E05	07/26/85	34
Estech/E06	07/26/85	32
Estech/E07	07/26/85	34
Estech/E08	07/26/85	30
Estech/E09	07/26/85	32
Estech/E10	07/26/85	35

[a]Locations of sampling sites are given in Section 3.3.

The gamma-ray exposure rates are summarized for each stack in Table 4.16. There is very little difference in the average exposure rates measured on the five phosphogypsum stacks. The average exposure rate for all five stacks is 33 μR/hr. The average exposure rate on the W.R. Grace stack exceeded this value by about 10 percent, while the exposure on the Gardinier stack averaged about 10 percent lower than the average for all

five stacks. If 5 μR/hr is used as the background exposure rate in that region of Florida (Na86), the exposure rates on the phosphogypsum stacks exceed the background level by about 6 or 7 times. This reflects the higher radionuclide content of the phosphogypsum in which radium-226, for example, exceeds its background concentration by about 11 times (see Section 4.2).

Table 4.16 Average gamma-ray exposure rates measured over each phosphogypsum stack

Stack	Average Exposure rate, μR/hr[a]	Range of exposures, μR/hr
Gardinier	30 ± 2	27 - 33
W.R. Grace	36 ∓ 5	30 - 48
Royster	33 ∓ 3	28 - 38
Conserv	33 ∓ 9	26 - 50
Estech	33 ∓ 2	30 - 35

[a]Average consists of 10 measurements. The ± values are standard deviations of the means.
Note: Background exposure rates in Polk County, Florida, have a typical range of 4 to 6 μR/hr (Na86).

4.6 Summary of Results

A year-long study of radon-222 and airborne particulates was conducted at five phosphogypsum stacks in central Florida. Four of the stacks studied were active and one was inactive during the study period. A description of the five participating stacks is presented in Table 2.1. Measurements made during the 12-month study are listed in Table 4.17. Also listed are the numbers of measurements conducted and the section of the report where the results for those measurements are described.

Table 4.17 A summary of measurements conducted during the one-year phosphogypsum study

Measurement[a]	Number of Measurements	Section Describing Results
Radon flux	1,258	4.1
Moisture content of phosphogypsum	1,258	4.1
Radionuclides in phosphogypsum	50	4.2
Radionuclides in airborne particulates	99	4.3
Particle sizes of airborne particulates	8	4.3
Ambient radon-222	91	4.4
Gamma-ray exposures	50	4.5

[a]Measurements were conducted during the period 22 July 1985-18 July 1986.

Radon Flux and Associated Measurements

Listed in Table 4.18 are the results of measurements of radon flux, moisture content of the phosphogypsum, radium-226 content of the phosphogypsum, and the gamma-ray exposure rates that were obtained

simultaneously at each location on the five stacks. This was the only instance that all measurements were taken at the same time. However, no direct correlations were observed between any of these parameters.

Although large differences in the radon flux were observed at different times at the same location, the differences were not consistent to any particular time of the year. Any correlation involving time that might have existed would have very likely been obliterated by the continual addition of fresh phosphogypsum to the stacks. Even though the same locations were measured repeatedly throughout the year, the Ra-226 content, density, porosity, and moisture content of the phosphogypsum changed between measurements. Thus, due to the routine operations on the active stacks, the source term was continually changing throughout the year.

The annual average radon flux, Ra-226 concentrations in the phosphogypsum, and gamma-ray exposure rates determined for each stack are listed in Table 4.19. Considering the active stacks, the average values do not differ significantly for the four stacks. The average radon fluxes varied from 16 to 25 pCi/m^2-s, the Ra-226 concentrations from 30 to 34 pCi/g, and the gamma-ray exposure rates from 30 to 36 μR/hr. This would indicate that although local variations exist on the stacks, overall the stacks are quite similar in composition and physical properties. Also, the average radon fluxes determined for the Gardinier and Royster

Table 4.18 Tabulation of selected parameters related to radon flux

Site/Location	Date of Collection	Ra-226, pCi/g	Percent Moisture	Radon Flux, pCi/m^2 sec	Exposure Rate at 1 meter, μR/hr
Gardinier/G01	07/23/85	33.8	11.1	14.9	30
Gardinier/G02	07/23/85	31.4	15.2	2.5	30
Gardinier/G03	07/23/85	33.3	15.5	23.6	29
Gardinier/G04	07/23/85	33.9	10.4	9.9	33
Gardinier/G05	07/23/85	31.0	16.4	31.6	28
Gardinier/G06	07/23/85	36.5	13.3	17.2	32
Gardinier/G07	07/23/85	32.4	17.1	36.2	30
Gardinier/G08	07/23/85	33.3	17.0	35.3	31
Gardinier/G09	07/23/85	31.2	14.2	15.5	27
Gardinier/G10	07/23/85	32.2	15.7	99.1	29
Grace/GR01	07/25/85	26.4	13.2	3.4	40
Grace/GR02	07/25/85	26.7	17.2	2.8	32
Grace/GR03	07/25/85	45.6	11.1	17.9	41
Grace/GR04	07/25/85	19.4	9.3	12.5	36
Grace/GR05	07/25/85	48.2	12.1	7.6	30
Grace/GR06	07/25/85	28.9	17.3	2.8	32
Grace/GR07	07/25/85	30.5	12.1	14.5	34
Grace/GR08	07/25/85	28.3	11.8	13.3	33
Grace/GR09	07/25/85	22.6	5.5	18.6	34
Grace/GR10	07/25/85	27.6	8.4	7.7	48
Royster/R01	07/26/85	23.0	10.5	31.4	34
Royster/R02	07/26/85	21.0	9.6	22.2	28
Royster/R03	07/26/85	47.9	12.8	55.9	33
Royster/R04	07/26/85	33.4	10.9	42.0	32
Royster/R05	07/26/85	31.1	12.3	20.0	34
Royster/R06	07/26/85	49.2	15.2	41.4	38
Royster/R07	07/26/85	22.9	13.6	41.1	36
Royster/R08	07/26/85	27.1	11.7	27.0	33
Royster/R09	07/26/85	15.8	14.0	18.7	32
Royster/R10	07/26/85	31.6	13.7	32.5	32
Conserv/C01	07/25/85	22.5	18.5	18.2	26
Conserv/C02	07/25/85	24.7	22.4	41.4	27
Conserv/C03	07/25/85	24.0	15.2	45.6	27
Conserv/C04	07/25/85	23.6	17.1	41.5	28
Conserv/C05	07/25/85	28.9	19.6	33.5	37
Conserv/C06	07/25/85	81.1	11.4	341.9	50
Conserv/C07	07/25/85	47.9	11.2	34.1	50
Conserv/C08	07/25/85	35.1	25.6	No result	30
Conserv/C09	07/25/85	26.9	18.9	34.6	28
Conserv/C10	07/25/85	24.4	21.2	20.2	27

Table 4.18 Tabulation of selected parameters related to radon flux - Continued

Site/Location	Date of Collection	Ra-226, pCi/g	Percent Moisture	Radon Flux, pCi/m^2 sec	Exposure Rate at 1 meter, μR/hr
Estech/E01	07/26/85	26.1	11.8	5.4	34
Estech/E02	07/26/85	24.3	13.4	4.7	32
Estech/E03	07/26/85	25.1	8.3	2.1	32
Estech/E04	07/26/85	18.8	14.5	2.0	32
Estech/E05	07/26/85	30.3	8.3	4.0	34
Estech/E06	07/26/85	26.4	9.4	4.1	32
Estech/E07	07/26/85	23.6	5.3	2.8	34
Estech/E08	07/26/85	22.1	14.1	5.5	30
Estech/E09	07/26/85	21.5	16.4	5.1	32
Estech/E10	07/26/85	30.8	2.2	2.3	35

stacks are not significantly different from those determined during surveys of four days and five days, respectively, in April-May 1985 (Ha85). The average radon flux measured at 211 locations on the Gardinier stack between April 30 and May 3, 1985, was 19 pCi/m^2-s. The average radon flux determined for 62 locations on the active part of the Royster stack on May 9, 1985, was 17 pCi/m^2-s. The agreement between these results and those of the present study are exceptionally good considering the very short measurement periods of the earlier survey and that different locations on the stack were monitored during the two studies.

These results imply that making measurements over a lengthy period is not as important as measuring a sufficient number of locations on a stack. Computing the cumulative averages of radon flux measurements made during the 1-year and 4-day studies indicates that approximately 100 samples, irrespective of sampling period, are adequate to obtain the average radon flux of a phosphogypsum stack.

The average radon flux measured on the inactive Estech stack is 4.7 times less than that determined for the active stacks. This agrees with the results of an earlier study on the Royster stack that indicated a four-fold decrease in the radon flux when a stack becomes inactive (Ha85). The cause of this decrease is the formation of a crust that forms on the surface of a stack when it becomes inactive. The thickness of the crust increases with time, which reduces the radon emanation from the surface and essentially eliminates resuspension of material by the wind.

Table 4.19 A comparison of the average radon flux, Ra-226 concentrations, and gamma-ray exposure rates on the five phosphogypsum stacks

Stack	Average Radon Flux, pCi/m^2-s	Average Ra-226 Concentration, pCi/g	Average Exposure Rate, μR/hr
Gardinier	20 ± 6	33 ± 2	30 ± 2
W.R. Grace	16 ± 5	30 ± 9	36 ± 5
Royster	22 ± 8	30 ± 11	33 ± 3
Conserv	25 ± 15	34 ± 18	33 ± 9
Estech (Inactive)	4.4 ± 1.4	25 ± 4	33 ± 2

Note: ± values are standard deviations of the means.

Radionuclide Content of Phosphogypsum

The analyses of phosphogypsum samples collected from 10 locations on each stack reflected a rather uniform distribution of Ra-226 over the five stacks (see Tables 4.4 and 4.5). The average concentrations of Ra-226 on the active stacks all fall within a small range, 30 to 34 pCi/g with an

average of 32 ± 2 pCi/g. About 70 percent of the concentrations were within 25 percent of the average concentration. The average concentration of Ra-226 in phosphogypsum from the inactive Estech stack was somewhat lower, 25 ± 4 pCi/g.

The radionuclide concentrations measured in samples of phosphogypsum composited from 10 locations on each stack are listed in Table 4.6. In general, concentrations of the principal radionuclides measured in the composite samples from the different stacks are similar and reflect the same radioactive disequilibrium. Some variation is attributed to the inhomogeneous composition of the composited samples.

The average concentrations of the principal radionuclides measured in the composite phosphogypsum samples were given in Table 4.7. Also listed in this table for a comparison are the average concentrations of radionuclides measured in ten background soil samples from Polk and Hillsborough Counties of Florida. Concentrations of radionuclides in phosphogypsum are significantly greater than the background levels, from 11 (U-238) to 60 times (Ra-226).

Since radioactivity in phosphate rock generally exists in radioactive equilibrium, the disequilibrium observed in the phosphogypsum is due primarily to the fractionation of the radionuclides during chemical processing of the ore. Most of the Ra-226, Po-210, and Pb-210 follow the phosphogypsum, while 80 to 90 percent of the uranium and thorium remain with the phosphoric acid.

High-Volume Air Samples and Particle Size

High-volume air samples were collected 460 m southeast (upwind) and 115 m northwest (downwind) of the W.R. Grace stack where they operated continuously for 4 months. Background samples were collected simultaneously at a private residence in Winter Haven, Florida. Filters were replaced weekly, composited into monthly samples, and analyzed for their radionuclide content. Concentrations measured were adjusted for radioactivity in the background samples, as described in Section 4.3.2. Concentrations of Po-210 and Pb-210 could not be measured because the filters were ashed prior to analyses. The average net concentrations of the principal radionuclides measured are listed in Table 4.20. Background concentrations are included for comparison.

Table 4.20 Average net concentrations of radionuclides in high-volume air samples[a]

Location	Concentrations, aCi/m^3			
	U-238	U-234	Th-230	Ra-226
Southeast	100	110	110	110
Northwest	150	160	150	190
Background	32	28	35	54

[a]Sampling period-March 10, 1986 to July 17, 1986.

Concentrations of radionuclides in airborne particulate samples collected at the southeast location are small and similar, about 100 aCi/m^3, and only 2 to 4 times background. Higher concentrations

were observed at the northwest location, 150 to 190 aCi/m^3 and exceeded background by 4 to 6 times. Concentrations at the northwest location were 50 to 70 percent higher than concentrations at the southeast location, due in part to the shorter distance to the stack, 115 m versus 460 m, a close proximity to the stack access road, and that it was in a predominant downwind direction from the stack. The source of a large fraction of the material collected by the high-volume samplers appears to be a source other than the phosphogypsum stack, probably, in large part, vehicular dust from the stack access road. The ratios of the radionuclide concentrations collected from the air do not reflect phosphogypsum. Secular equilibrium existed in air samples collected at the southeast location. Samples collected at the northwest location have activity ratios of 1.3 for both Ra-226/U-238 and Ra-226/Th-230, whereas these ratios in phosphogypsum from the W.R. Grace stack were 11 and 5, respectively. Thus, most of the material collected by the air samplers was from a source other than the phosphogypsum stack. This illustrates the extreme difficulty of relating airborne samples to a particular source when collected at a predetermined location over a long period of time.

Two 24-hour particle size samples were collected at each of the two high-volume sampling locations near the W.R. Grace stack, and one background particle size sample was obtained at the sampling location in Winter Haven, Florida. The particles were separated into five ranges of size, and the material collected in each range was analyzed separately for its radionuclide content. The radionuclide content of the blank filters of each stage was determined and subtracted from the gross concentrations

measured in the stack samples. Because the radioactivity in the blank filters often exceeded that of the sample, many of the data obtained have limited value. A positive result for a radionuclide concentration in all five stages of a sample was obtained in only 9 out of 30 sets of analyses (see Table 4.10).

The average percent of radionuclides in each particle size range for those sets of data having positive values for all ranges of particle size was given in Table 4.11. The particle size distribution of Po-210 is entirely different from that of the other radionuclides and closely resembles the distribution of the background sample. Nearly all of the Po-210 is associated with the smallest particle size range, while only 7 percent is with particles having diameters greater than 3.3 μm. This is not unusual and has been attributed to Rn-222 progeny attaching primarily to small particles. More than 50 percent of the Ra-226 and U-238 is associated with the larger sized particles while less than 20 percent is combined with the small and more respirable sized particles. However, the total picocuries of radionuclides collected by the Anderson samplers at the stack were not significantly different from that collected by the background sampler. Thus, like the high-volume samples, it is probable that most of the material collected for particle sizing had not originated from the phosphogypsum stack.

Airborne Radon Concentrations

Radon-222 concentrations in air were obtained one meter above the ground surface at each phosphogypsum stack using alpha-track detectors. Background concentrations were measured at nine locations that were at least 8 km from any phosphogypsum stack. Measurements were made continuously during the study using three 4-month exposure periods. Because of the continuous operations being conducted by plant personnel on the active stacks, it was not possible to place the detectors on the top surface of the stacks. Rather, the detectors were placed around the perimeter at the base of the stacks with a larger number in a predominant downwind direction.

Listed in Table 4.21 are the average radon concentrations measured at the five phosphogypsum stacks. The average radon concentrations measured at the base of the stacks are small and exceed the background concentrations by only 3 to 5 times. The concentrations varied by as much as a factor of 8 over the year, but the difference could not be related to the prevailing wind direction or to the season of the year. Also, the results at the Estech stack illustrate the total lack of a correlation with radon flux, as the average radon concentration is similar to that at the other stacks but the radon flux was 4 to 5 times smaller.

Table 4.21 Average airborne radon concentrations near phosphogypsum stacks

Source	Radon Concentrations on Stack Perimeter, pCi/l	
	Average Concentrations	Range of Concentrations
Phosphogypsum Stacks		
Gardinier	0.56	0.22-1.79
W.R. Grace	0.86	0.35-2.20
Royster	0.51	0.29-1.16
Conserv	0.73	0.36-1.16
Estech	0.71	0.44-1.10

Gamma-ray Exposure Rates

One set of gamma-ray exposure rate measurements were obtained one meter above the ground surface at locations on the phosphogypsum stacks where radon flux and phosphogypsum sampling were performed. Background exposure measurements, made in a region of Polk County, Florida, outside the influence of the phosphate industry, ranged from 4 to 6 μR/hr.

The average gamma-ray exposure rates obtained from 10 measurements on each phosphogypsum stack were given in Table 4.16. The ranges of exposures observed are included. The exposure rates over a stack are quite constant, varying by no more than a factor of two, and not significantly different on the various stacks. These exposure rates are not large, but exceed the background exposure rate, 5 μR/hr, by about 6 times.

5.0 CONCLUSIONS

A year-long study of radon-222 and airborne particulates was conducted at five phosphogypsum stacks in central Florida. Four of the stacks studied were active and one was inactive. The results of measurements made during this study provide the basis for the following conclusions.

1. The annual average radon flux measured in dry areas on the top of four active phosphogypsum stacks was 20 pCi/m^2-s. This is 100 times the average background flux, 0.2 pCi/m^2-s, measured in central Florida.

2. The results indicate that the radon flux from inactive stacks is nearly 5 times less than from active stacks due to the natural formation of a crust over the top surface of the stack. This is a natural process of decontamination that will remain secure unless the surface is disturbed.

3. The results indicate that approximately 100 radon flux measurements conducted at 10 or more sites, irrespective of sampling period, will provide a representative radon source term for phosphogypsum stacks.

4. Essentially no correlations were observed between the radon flux and the moisture content of the phosphogypsum, the Ra-226 concentrations of the phosphogypsum, airborne radon concentrations, and gamma-ray exposure rates.

5. The radionuclide concentrations in phosphogypsum exceed background levels by more than an order-of-magnitude. In phosphogypsum, the average radium-226 concentration was 30 pCi/g, about 10 times that of uranium-238/234.

6. Very low airborne radioactive particulate concentrations were measured near the phosphogypsum stacks. The particulates collected originated primarily from sources other than the phosphogypsum stack. The absence of measurable quantities of radionuclides from the phosphogypsum stack is due to a crust that exists on the inactive areas and the high moisture content in the active areas of the stacks.

7. Radon-222 concentrations measured around the base perimeter of the phosphogypsum stacks were low, constant, and apparently primarily from sources other than the phosphogypsum stacks. Concentrations ranged from 0.4 to about 1 pCi/L with an average of less than 1 pCi/L.

8. Gamma-ray exposure rates measured across the stack surfaces were relatively small, about 30 μR/hr, and constant, varying by less than a factor of two. This exposure rate is about 6 times the regional background exposure rate of 5 μR/hr.

6.0 REFERENCES

BOM85 U.S. Bureau of Mines, 1985, Minerals Yearbook.

EERF82 Eastern Environmental Radiation Facility, USEPA, 1982, Quality Assurance Plan and Standard Operating Procedures.

EPA86 U.S. Environmental Protection Agency, 1986, Proposed Standard for Radon-222 Emissions from Licensed Uranium Mill Tailings, U.S. Environmental Protection Agency Report, EPA 520/1-86-001.

Ga86 Gan, T.H., Mason, G.C., Wise, K.N., Whittlestone, S., and Wyllie, H.A., 1986, "Desorption of Rn-222 by Moisture and Heat," Health Physics 50, No. 3, p. 407-410.

Gu75 Guimond, R.J. and Windham, S.T., 1975, Radioactivity Distribution in Phosphate Products, By-Products, Effluents and Wastes, U.S. Environmental Protection Agency, Office of Radiation Programs, Technical Note ORP/CSD-75-3.

Ha83 Hartley, J.N., Gee, G.W., Baker, E.G., and Freeman, H.D., 1983, 1981 Radon Barrier Field Test at Grand Junction Uranium Mill Tailings Pile, Pacific Northwest Laboratory Report, PNL-4539, Richland, Washington.

Ha85 Hartley, J.N., and Freeman, H.D., 1985, 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.

Ho79 Horton, T.R., 1979, A Preliminary Radiological Assessment of Radon Exhalation From Phosphate Gypsum Piles and Inactive Uranium Mill Tailings Piles, U.S. Environmental Protection Agency Report, EPA 520/5-79-004.

Li84 Lieberman, R., 1984, Eastern Environmental Radiation Facility Radiochemistry Procedures Manual, U.S. Environmental Protection Agency Report, EPA 520/5-84-006.

Na86 Nall, Wesley, Polk County Health Department, Winter Haven, Florida, Personal Communication, November 1986.

Ni88 Nifong, G.D., Florida Institute of Phosphate Research, Bartow, Florida, Written Communication, January 22, 1988.

Pa78 Partridge, J.E., Horton, T.R., Sensintaffar, E.L., and Boysen, G.A., 1978, Radiation Dose Estimates Due to Air Particulate Emissions From Selected Phosphate Industry Operations, U.S. Environmental Protection Agency, Office of Radiation Programs, Technical Note ORP/EERF-78-1.

Pe83 PEDCo Environmental, Inc., 1983, Evaluation of Waste Management for Phosphate Processing-Interim Report on Characterization of Phosphate Processing Wastes and Selection of Management Practices and Sites to be Monitored, EPA contractor report-Contract No. 68-03-3036, Work Assignment No. SAP07, Cincinnati, Ohio.

PEI85a PEI Associates, Inc., 1985, Data Describing Phosphogypsum Piles, Work Assignment No. 10 under Contract No. 68-02-3878, for the U.S. Environmental Protection Agency.

PEI85b PEI Associates, Inc., 1985, Quality Assurance Project Plan - Radionuclide Air Sampling At Florida Phosphogypsum Piles, Work Assignment No. 13 under Contract No. 68-02-3878, for the U.S. Environmental Protection Agency.

PEI86 PEI Associates, Inc., 1986, Radionuclide Air Sampling at Florida Phosphogypsum Stacks, Work Assignment No. 25 under Contract No. 68-02-3878, for the U.S. Environmental Protection Agency.

St84 Stranden, E., Kolstad, A.K., and Lind, B., 1984, "Radon Exhalation: Moisture and Temperature Dependence," Health Physics 47, No. 3, p. 480-484.

APPENDIX A

Individual radon flux and moisture content values for phosphogypsum stacks and background soils.

Table A.1
Radon flux and moisture content in background soils

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GB01	2/ 3/86	2/ 4/86	.211	16.53	99.0
GB01	4/ 2/86	4/ 3/86	.079	40.25	99.0
GB03	12/ 3/85	12/ 4/85	.353	18.98	99.0
GB03	4/ 2/86	4/ 3/86	.333	10.98	99.0
GB04	12/ 3/85	12/ 4/85	.295	22.25	99.0
GB04	4/ 2/86	4/ 3/86	.289	12.34	99.0
GB05	2/ 3/86	2/ 4/86	.078	45.80	99.0
GB05	4/ 2/86	4/ 3/86	.062	51.98	99.0
MG01	1/31/86	2/ 1/86	.595	9.47	99.0
MG02	1/31/86	2/ 1/86	.485	11.22	99.0
MG03	1/31/86	2/ 1/86	.154	30.77	99.0
MG04	1/31/86	2/ 1/86	.563	9.81	99.0
MG05	1/31/86	2/ 1/86	.194	24.83	99.0
MG06	1/31/86	2/ 1/86	.297	16.68	99.0
PB01	8/20/85	8/22/85	.110	17.12	99.0
PB01	9/30/85	10/ 2/85	.078	24.00	5.2
PB01	10/21/85	10/22/85	.103	30.37	4.1
PB01	11/18/85	11/19/85	.505	7.86	2.8
PB01	12/16/85	12/17/85	.100	32.06	6.0
PB01	1/20/86	1/21/86	.103	29.50	5.4
PB01	2/17/86	2/18/86	.128	24.29	9.3
PB01	3/24/86	3/25/86	.112	28.02	5.9
PB01	4/ 2/86	4/ 3/86	.128	25.15	99.0
PB01	4/14/86	4/15/86	.135	23.33	3.5
PB01	5/12/86	5/13/86	.111	29.65	2.9
PB01	6/16/86	6/17/86	.219	15.14	9.1
PB01	7/ 7/86	7/ 8/86	.111	28.86	5.7
PB02	12/ 3/85	12/ 4/85	.223	28.61	99.0
PB02	4/ 2/86	4/ 3/86	.205	16.43	99.0
PB03	12/ 3/85	12/ 4/85	.292	22.50	99.0
PB03	4/ 2/86	4/ 3/86	.191	17.51	99.0
PB04	12/ 3/85	12/ 4/85	.174	35.95	99.0
PB04	4/ 2/86	4/ 3/86	.162	20.25	99.0
PB05	12/ 3/85	12/ 4/85	.289	22.86	99.0
PB05	4/ 2/86	4/ 3/86	.247	14.10	99.0

*Legend

GB Gardinier background site.
MG Montgomery, Alabama background site.
PB Polk County background site.
99.0 Moisture sample not collected.

Table A.2
Radon flux and moisture content associated with Conserv stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
C01	7/24/85	7/25/85	18.213	.85	18.5
C01	8/19/85	8/20/85	12.412	1.05	9.1
C01	9/30/85	10/ 1/85	20.510	.80	7.6
C01	10/21/85	10/22/85	11.060	1.10	8.8
C01	11/18/85	11/19/85	26.934	.74	6.6
C01	12/16/85	12/17/85	24.526	.78	7.5
C01	1/13/86	1/14/86	33.271	.57	7.4
C01	2/24/86	2/25/86	16.769	.88	7.5
C01	3/17/86	3/18/86	18.734	.84	10.4
C01	4/14/86	4/15/86	12.490	.95	9.7
C01	5/12/86	5/13/86	9.874	1.14	5.9
C01	6/ 9/86	6/10/86	10.912	1.12	14.4
C01	7/ 7/86	7/ 8/86	14.618	.96	7.3
C02	7/24/85	7/25/85	41.415	.56	22.4
C02	8/19/85	8/20/85	21.127	.79	9.2
C02	9/30/85	10/ 1/85	26.775	.69	8.9
C02	10/21/85	10/22/85	12.124	1.05	6.4
C02	11/18/85	11/19/85	17.449	.93	6.6
C02	12/16/85	12/17/85	19.695	.87	6.5
C02	1/13/86	1/14/86	61.167	.42	10.8
C02	2/24/86	2/25/86	15.720	.91	6.4
C02	3/17/86	3/18/86	13.993	.98	10.1
C02	4/14/86	4/15/86	2.654	2.23	5.9
C02	5/12/86	5/13/86	16.322	.88	6.2
C02	6/ 9/86	6/10/86	18.159	.86	13.0
C02	7/ 7/86	7/ 8/86	15.876	.92	7.1
C03	7/24/85	7/25/85	45.563	.54	15.2
C03	8/19/85	8/20/85	15.598	.93	7.1
C03	9/30/85	10/ 1/85	15.433	.93	11.9
C03	10/21/85	10/22/85	2.386	2.63	10.5
C03	11/18/85	11/19/85	21.870	.83	5.2
C03	12/16/85	12/17/85	16.865	.94	13.9
C03	1/13/86	1/14/86	33.849	.57	10.6
C03	2/24/86	2/25/86	34.656	.61	7.3
C03	3/17/86	3/18/86	18.125	.85	9.9
C03	4/14/86	4/15/86	2.852	2.13	8.1
C03	5/12/86	5/13/86	13.338	.98	14.5
C03	6/ 9/86	6/10/86	13.644	1.00	11.3
C03	7/ 7/86	7/ 8/86	16.573	.90	6.1
C04	7/24/85	7/25/85	41.471	.57	17.1
C04	8/19/85	8/20/85	15.790	.93	11.9
C04	9/30/85	10/ 1/85	24.701	.72	9.6
C04	10/21/85	10/22/85	7.650	1.35	9.2
C04	11/18/85	11/19/85	9.454	1.28	10.0

Table A.2 - Continued
Radon flux and moisture content associated with Conserv stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
C04	12/16/85	12/17/85	18.711	.89	9.1
C04	1/13/86	1/14/86	32.391	.58	15.6
C04	2/24/86	2/25/86	26.132	.70	8.9
C04	3/17/86	3/18/86	21.326	.79	13.6
C04	4/14/86	4/15/86	7.470	1.25	10.3
C04	5/12/86	5/13/86	14.500	.93	8.0
C04	6/ 9/86	6/10/86	25.254	.72	15.5
C04	7/ 7/86	7/ 8/86	17.900	.86	8.6
C05	7/24/85	7/25/85	33.496	.63	19.6
C05	9/30/85	10/ 1/85	20.789	.79	14.1
C05	10/21/85	10/22/85	18.677	.85	6.3
C05	11/18/85	11/19/85	31.315	.69	7.1
C05	12/16/85	12/17/85	24.438	.78	7.4
C05	1/13/86	1/14/86	30.215	.60	15.0
C05	2/24/86	2/25/86	25.695	.71	8.9
C05	3/17/86	3/18/86	4.543	1.80	16.5
C05	4/14/86	4/15/86	9.434	1.10	11.1
C05	5/12/86	5/13/86	10.037	1.13	7.0
C05	6/ 9/86	6/10/86	24.134	.74	19.0
C05	7/ 7/86	7/ 8/86	10.534	1.14	9.4
C05#	8/19/85	8/20/85	20.248	.81	10.5
C06	7/24/85	7/25/85	341.922	.20	11.4
C06	8/19/85	8/20/85	207.148	.25	10.9
C06	9/30/85	10/ 1/85	4.083	1.94	19.0
C06	10/21/85	10/22/85	3.923	1.96	7.9
C06	11/18/85	11/19/85	12.195	1.12	7.7
C06	12/16/85	12/17/85	17.222	.93	6.0
C06	1/13/86	1/14/86	32.109	.59	9.7
C06	2/24/86	2/25/86	41.935	.55	10.0
C06	3/17/86	3/18/86	41.026	.56	20.3
C06	4/14/86	4/15/86	8.714	1.15	15.5
C06	5/12/86	5/13/86	11.548	1.05	8.7
C06	6/ 9/86	6/10/86	10.435	1.15	19.2
C06	7/ 7/86	7/ 8/86	25.532	.72	12.6
C07	7/24/85	7/25/85	34.091	.63	11.2
C07	8/19/85	8/20/85	23.674	.75	9.7
C07	9/30/85	10/ 1/85	27.221	.69	10.0
C07	10/21/85	10/22/85	14.689	.95	10.4
C07	11/18/85	11/19/85	59.415	.50	6.9
C07	12/16/85	12/17/85	34.875	.65	8.8
C07	1/13/86	1/14/86	25.147	.66	14.4
C07	2/24/86	2/25/86	39.174	.57	11.5
C07	3/17/86	3/18/86	32.591	.63	15.6
C07	4/14/86	4/15/86	16.652	.82	10.2

Table A.2 - Continued
Radon flux and moisture content associated with Conserv stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
C07	5/12/86	5/13/86	28.366	.66	11.4
C07	6/ 9/86	6/10/86	26.895	.70	19.9
C07	7/ 7/86	7/ 8/86	18.781	.84	13.9
C08	8/19/85	8/20/85	5.783	1.60	15.7
C08	9/30/85	10/ 1/85	18.477	.84	15.1
C08	10/21/85	10/22/85	14.244	.97	9.6
C08	11/18/85	11/19/85	30.636	.70	10.2
C08	12/16/85	12/17/85	30.547	.70	9.3
C08	1/13/86	1/14/86	29.659	.61	13.5
C08	2/24/86	2/25/86	22.229	.76	14.1
C08	3/17/86	3/18/86	13.179	1.01	18.0
C08	4/14/86	4/15/86	25.628	.65	8.4
C08	5/12/86	5/13/86	16.357	.87	9.0
C08	6/ 9/86	6/10/86	9.055	1.24	14.7
C08	7/ 7/86	7/ 8/86	14.899	.95	11.8
C08#	7/24/85	7/25/85	1.753	3.38	25.6
C09	7/24/85	7/25/85	34.578	.63	18.9
C09	8/19/85	8/20/85	22.574	.77	13.7
C09	9/30/85	10/ 1/85	34.035	.61	13.5
C09	10/21/85	10/22/85	9.298	1.21	7.6
C09	11/18/85	11/19/85	19.498	.88	4.6
C09	12/16/85	12/17/85	24.425	.78	7.6
C09	1/13/86	1/14/86	30.913	.60	14.6
C09	2/24/86	2/25/86	5.824	1.56	7.6
C09	3/17/86	3/18/86	28.285	.68	13.8
C09	4/14/86	4/15/86	12.922	.93	12.7
C09	5/12/86	5/13/86	20.069	.78	6.4
C09	6/ 9/86	6/10/86	10.916	1.12	17.3
C09	7/ 7/86	7/ 8/86	22.781	.76	11.1
C10	7/24/85	7/25/85	20.161	.82	21.2
C10	8/19/85	8/20/85	15.090	.95	5.6
C10	9/30/85	10/ 1/85	32.275	.63	11.4
C10	10/21/85	10/22/85	21.843	.77	7.9
C10	11/18/85	11/19/85	82.019	.42	7.9
C10	12/16/85	12/17/85	27.376	.74	7.3
C10	1/13/86	1/14/86	20.237	.74	12.9
C10	2/24/86	2/25/86	21.694	.77	15.6
C10	3/17/86	3/18/86	18.095	.86	15.6
C10	4/14/86	4/15/86	10.925	1.01	11.8
C10	5/12/86	5/13/86	21.632	.75	10.4
C10	6/ 9/86	6/10/86	12.534	1.04	19.1
C10	7/ 7/86	7/ 8/86	18.240	.86	9.4

*Legend

C Conserv.
Invalid flux measurement.

Table A.3
Radon flux and moisture content associated with Estech stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
E01	7/25/85	7/26/85	5.384	2.09	11.8
E01	9/ 9/85	9/10/85	1.342	3.73	10.6
E01	10/ 7/85	10/ 8/85	4.386	1.75	12.0
E01	10/28/85	10/29/85	4.475	1.73	12.5
E01	12/ 2/85	12/ 3/85	5.357	1.74	11.1
E01	12/23/85	12/24/85	4.069	2.33	11.5
E01	1/27/86	1/28/86	3.544	2.02	13.2
E01	2/17/86	2/18/86	5.434	1.63	12.7
E01	3/24/86	3/25/86	2.317	2.73	11.0
E01	4/21/86	4/22/86	4.902	1.70	8.4
E01	5/19/86	5/20/86	.669	6.69	11.4
E01	6/16/86	6/17/86	4.759	1.75	13.9
E01	7/14/86	7/15/86	4.753	1.74	8.5
E02	7/25/85	7/26/85	4.737	2.29	13.4
E02	9/ 9/85	9/10/85	3.299	2.12	13.7
E02	10/ 7/85	10/ 8/85	3.694	2.06	12.8
E02	10/28/85	10/29/85	3.543	1.98	12.3
E02	12/ 2/85	12/ 3/85	5.895	1.65	7.7
E02	12/23/85	12/24/85	7.043	1.72	8.8
E02	1/27/86	1/28/86	5.525	1.58	12.3
E02	2/17/86	2/18/86	6.211	1.52	12.8
E02	3/24/86	3/25/86	3.390	2.17	11.0
E02	4/21/86	4/22/86	5.565	1.58	7.0
E02	5/19/86	5/20/86	2.260	2.86	10.9
E02	6/16/86	6/17/86	3.525	2.08	19.2
E02	7/14/86	7/15/86	3.735	2.00	12.4
E03	7/25/85	7/26/85	2.094	3.83	8.3
E03	9/ 9/85	9/10/85	.566	6.98	35.9
E03	10/ 7/85	10/ 8/85	1.700	3.39	23.5
E03	10/28/85	10/29/85	2.008	2.79	18.2
E03	12/ 2/85	12/ 3/85	.598	7.14	20.1
E03	12/23/85	12/24/85	.953	6.04	19.3
E03	1/27/86	1/28/86	.815	5.23	20.1
E03	2/17/86	2/18/86	1.950	3.01	19.3
E03	3/24/86	3/25/86	1.384	3.80	22.0
E03	4/21/86	4/22/86	1.313	3.80	15.6
E03	5/19/86	5/20/86	1.194	4.37	16.0
E03	6/16/86	6/17/86	5.968	1.54	24.4
E03	7/14/86	7/15/86	1.600	3.36	21.0
E04	7/25/85	7/26/85	1.976	4.03	14.5
E04	9/ 9/85	9/10/85	1.961	2.91	11.8
E04	10/ 7/85	10/ 8/85	5.182	1.69	13.6
E04	10/28/85	10/29/85	4.098	1.83	4.5
E04	12/ 2/85	12/ 3/85	5.179	1.78	5.8
E04	12/23/85	12/24/85	7.564	1.65	5.6
E04	1/27/86	1/28/86	9.106	1.20	9.4
E04	2/17/86	2/18/86	6.381	1.52	6.3
E04	3/24/86	3/25/86	6.096	1.56	3.8

Table A.3 - Continued
Radon flux and moisture content associated with Estech stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
E04	4/21/86	4/22/86	4.652	1.75	3.8
E04	5/19/86	5/20/86	3.988	2.03	5.2
E04	6/16/86	6/17/86	9.428	1.21	27.6
E04	7/14/86	7/15/86	6.512	1.47	13.1
E05	7/25/85	7/26/85	3.986	2.56	8.3
E05	9/ 9/85	9/10/85	3.596	2.02	21.1
E05	10/ 7/85	10/ 8/85	6.292	1.51	10.8
E05	10/28/85	10/29/85	7.460	1.31	13.4
E05	12/ 2/85	12/ 3/85	2.869	2.50	14.5
E05	12/23/85	12/24/85	7.625	1.63	10.7
E05	1/27/86	1/28/86	4.221	1.82	17.7
E05	2/17/86	2/18/86	8.482	1.28	20.4
E05	3/24/86	3/25/86	3.486	2.14	10.5
E05	4/21/86	4/22/86	8.697	1.25	12.2
E05	5/19/86	5/20/86	2.000	3.10	14.8
E05	6/16/86	6/17/86	5.588	1.60	18.8
E05	7/14/86	7/15/86	2.974	2.29	12.3
E06	7/25/85	7/26/85	4.058	2.53	9.4
E06	9/ 9/85	9/10/85	2.724	2.39	14.8
E06	10/ 7/85	10/ 8/85	3.121	2.29	16.1
E06	10/28/85	10/29/85	3.957	1.86	13.7
E06	12/ 2/85	12/ 3/85	4.075	2.04	13.6
E06	12/23/85	12/24/85	5.686	1.93	9.6
E06	1/27/86	1/28/86	4.154	1.84	9.6
E06	2/17/86	2/18/86	5.815	1.58	12.9
E06	3/24/86	3/25/86	3.857	2.01	7.4
E06	4/21/86	4/22/86	3.204	2.19	2.9
E06	5/19/86	5/20/86	2.227	2.89	6.8
E06	6/16/86	6/17/86	5.754	1.58	16.6
E06	7/14/86	7/15/86	4.225	1.87	7.5
E07	7/25/85	7/26/85	2.779	3.25	5.3
E07	9/ 9/85	9/10/85	.977	4.68	14.4
E07	10/ 7/85	10/ 8/85	2.907	2.40	14.4
E07	10/28/85	10/29/85	3.231	2.10	15.2
E07	12/ 2/85	12/ 3/85	3.210	2.34	11.9
E07	12/23/85	12/24/85	3.289	2.66	13.9
E07	1/27/86	1/28/86	3.352	2.08	9.1
E07	2/17/86	2/18/86	4.449	1.84	15.0
E07	3/24/86	3/25/86	3.672	2.07	8.4
E07	4/21/86	4/22/86	5.021	1.70	8.5
E07	5/19/86	5/20/86	3.976	2.04	14.2
E07	6/16/86	6/17/86	7.888	1.33	12.4
E07	7/14/86	7/15/86	3.674	2.03	8.8
E08	7/25/85	7/26/85	5.532	2.11	14.1
E08	9/ 9/85	9/10/85	1.177	4.15	15.6
E08	10/ 7/85	10/ 8/85	2.188	2.86	12.6
E08	10/28/85	10/29/85	2.374	2.53	11.7
E08	12/ 2/85	12/ 3/85	2.577	2.67	12.3

Table A.3 - Continued
Radon flux and moisture content associated with Estech stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
E08	12/23/85	12/24/85	3.203	2.71	11.0
E08	1/27/86	1/28/86	3.352	2.09	13.8
E08	2/17/86	2/18/86	2.967	2.34	12.9
E08	3/24/86	3/25/86	3.514	2.13	12.1
E08	4/21/86	4/22/86	3.942	1.95	7.8
E08	5/19/86	5/20/86	3.645	2.15	8.5
E08	6/16/86	6/17/86	5.033	1.70	15.4
E08	7/14/86	7/15/86	2.649	2.46	11.4
E09	7/25/85	7/26/85	5.053	2.19	16.4
E09	9/ 9/85	9/10/85	1.787	3.11	15.8
E09	10/ 7/85	10/ 8/85	8.854	1.25	15.2
E09	10/28/85	10/29/85	9.915	1.13	14.5
E09	12/ 2/85	12/ 3/85	5.732	1.68	13.2
E09	12/23/85	12/24/85	13.565	1.21	13.4
E09	1/27/86	1/28/86	2.597	2.42	13.9
E09	2/17/86	2/18/86	14.051	.98	13.9
E09	3/24/86	3/25/86	4.457	1.85	14.1
E09	4/21/86	4/22/86	4.952	1.71	12.7
E09	5/19/86	5/20/86	7.029	1.48	13.4
E09	6/16/86	6/17/86	10.203	1.16	17.3
E09	7/14/86	7/15/86	7.588	1.35	12.7
E10	7/25/85	7/26/85	2.273	3.61	2.2
E10	9/ 9/85	9/10/85	1.202	4.06	16.1
E10	10/ 7/85	10/ 8/85	2.458	2.66	6.4
E10	10/28/85	10/29/85	2.555	2.42	4.1
E10	12/ 2/85	12/ 3/85	3.480	2.23	4.1
E10	12/23/85	12/24/85	4.579	2.19	4.8
E10	1/27/86	1/28/86	4.399	1.79	8.7
E10	2/17/86	2/18/86	5.356	1.66	5.5
E10	3/24/86	3/25/86	3.374	2.18	2.3
E10	4/21/86	4/22/86	4.813	1.74	.3
E10	5/19/86	5/20/86	7.459	1.43	.4
E10	6/16/86	6/17/86	14.496	.96	20.7
E10	7/14/86	7/15/86	3.828	1.98	13.5

*Legend

E Estech.

Table A.4
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G01	7/22/85	7/23/85	14.922	.94	11.1
G01	7/29/85	7/30/85	11.113	1.13	5.7
G01	8/ 5/85	8/ 6/85	21.971	.78	18.4
G01	8/12/85	8/13/85	.639	6.58	19.9
G01	8/19/85	8/20/85	5.142	1.70	12.3
G01	8/26/85	8/27/85	1.393	3.78	11.3
G01	9/ 3/85	9/ 4/85	23.561	.74	20.6
G01	9/ 9/85	9/10/85	9.805	1.16	12.1
G01	9/16/85	9/17/85	28.238	.68	6.8
G01	9/23/85	9/24/85	32.566	.63	9.1
G01	9/30/85	10/ 1/85	53.069	.49	9.4
G01	10/ 7/85	10/ 8/85	63.313	.45	7.5
G01	10/14/85	10/15/85	18.576	.84	11.5
G01	10/21/85	10/22/85	20.899	.80	9.7
G01	10/28/85	10/29/85	20.926	.79	9.6
G01	11/ 4/85	11/ 5/85	37.760	.59	14.5
G01	11/12/85	11/13/85	10.072	1.23	11.4
G01	11/18/85	11/19/85	29.642	.71	7.6
G01	11/25/85	11/26/85	27.427	.73	7.3
G01	12/ 2/85	12/ 3/85	27.534	.74	7.0
G01	12/ 9/85	12/10/85	21.310	.82	8.4
G01	12/16/85	12/17/85	22.125	.81	4.0
G01	12/23/85	12/24/85	23.121	.87	6.2
G01	12/30/85	12/31/85	25.510	.85	3.5
G01	1/ 6/86	1/ 7/86	17.295	.93	15.1
G01	1/13/86	1/14/86	10.613	1.13	12.9
G01	1/20/86	1/21/86	14.043	.97	9.4
G01	1/27/86	1/28/86	17.724	.85	7.4
G01	2/ 3/86	2/ 4/86	17.420	.86	3.7
G01	3/ 4/86	3/ 5/86	18.755	.84	10.1
G01	3/31/86	4/ 1/86	17.421	.87	8.3
G01	4/28/86	4/29/86	26.693	.69	10.2
G01	5/27/86	5/28/86	6.077	1.52	11.4
G01	6/23/86	6/24/86	14.781	.94	17.8
G02	7/22/85	7/23/85	2.524	2.51	15.2
G02	7/29/85	7/30/85	9.556	1.15	14.5
G02	8/ 5/85	8/ 6/85	19.772	.82	18.1
G02	8/12/85	8/13/85	62.785	.45	14.1
G02	8/19/85	8/20/85	28.635	.68	13.2
G02	9/ 3/85	9/ 4/85	8.623	1.26	18.7
G02	9/ 9/85	9/10/85	23.446	.74	10.4
G02	9/16/85	9/17/85	55.659	.48	8.8
G02	9/23/85	9/24/85	27.645	.68	7.7
G02	9/30/85	10/ 1/85	50.287	.50	9.0
G02	10/ 7/85	10/ 8/85	37.219	.59	12.0
G02	10/14/85	10/15/85	23.206	.75	29.7
G02	10/21/85	10/22/85	23.144	.76	8.9
G02	10/28/85	10/29/85	21.940	.77	8.9
G02	11/ 4/85	11/ 5/85	23.603	.75	14.9

Table A.4 - Continued
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G02	11/12/85	11/13/85	15.848	.97	9.8
G02	11/18/85	11/19/85	6.651	1.55	7.9
G02	11/25/85	11/26/85	18.082	.90	9.3
G02	12/ 2/85	12/ 3/85	12.806	1.10	6.3
G02	12/ 9/85	12/10/85	24.981	.76	7.9
G02	12/16/85	12/17/85	16.561	.94	8.3
G02	12/23/85	12/24/85	20.231	.94	7.2
G02	12/30/85	12/31/85	14.791	1.13	5.0
G02	1/ 6/86	1/ 7/86	7.492	1.44	14.6
G02	1/13/86	1/14/86	6.365	1.50	12.6
G02	1/20/86	1/21/86	16.977	.88	11.7
G02	1/27/86	1/28/86	11.888	1.05	8.9
G02	2/ 3/86	2/ 4/86	10.004	1.15	8.1
G02	3/ 4/86	3/ 5/86	11.743	1.07	12.1
G02	3/31/86	4/ 1/86	5.968	1.54	6.1
G02	4/28/86	4/29/86	7.447	1.34	6.1
G02	5/27/86	5/28/86	15.668	.91	15.6
G02	6/23/86	6/24/86	10.789	1.11	18.9
G02#	8/26/85	8/27/85	34.844	.61	13.8
G03	7/22/85	7/23/85	23.554	.74	15.5
G03	7/29/85	7/30/85	9.685	1.13	13.5
G03	8/ 5/85	8/ 6/85	10.258	1.16	17.6
G03	8/12/85	8/13/85	1.823	3.13	21.3
G03	8/19/85	8/20/85	1.317	4.02	19.6
G03	8/26/85	8/27/85	14.447	.99	23.3
G03	9/ 3/85	9/ 4/85	4.852	1.72	15.9
G03	9/ 9/85	9/10/85	7.225	1.37	12.5
G03	9/16/85	9/17/85	9.415	1.22	7.8
G03	9/23/85	9/24/85	10.324	1.14	9.8
G03	9/30/85	10/ 1/85	4.208	1.91	9.7
G03	10/ 7/85	10/ 8/85	28.999	.67	9.4
G03	10/14/85	10/15/85	12.513	1.03	8.3
G03	10/21/85	10/22/85	20.002	.82	6.2
G03	10/28/85	10/29/85	14.372	.96	7.8
G03	11/ 4/85	11/ 5/85	1.004	4.70	21.0
G03	11/12/85	11/13/85	19.199	.88	11.2
G03	11/18/85	11/19/85	16.671	.95	9.8
G03	11/25/85	11/26/85	18.011	.90	9.9
G03	12/ 2/85	12/ 3/85	19.626	.88	8.2
G03	12/ 9/85	12/10/85	20.209	.85	7.1
G03	12/16/85	12/17/85	28.971	.71	7.0
G03	12/23/85	12/24/85	29.367	.77	4.7
G03	12/30/85	12/31/85	24.579	.86	4.1

Table A.4 - Continued
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G03	1/ 6/86	1/ 7/86	28.684	.72	15.2
G03	1/13/86	1/14/86	44.950	.54	9.9
G03	1/20/86	1/21/86	10.635	1.12	10.3
G03	1/27/86	1/28/86	10.274	1.13	10.7
G03	2/ 3/86	2/ 4/86	17.766	.85	4.3
G03	3/ 4/86	3/ 5/86	27.031	.70	8.6
G03	3/31/86	4/ 1/86	11.440	1.08	7.4
G03	4/28/86	4/29/86	36.346	.59	9.4
G03	5/27/86	5/28/86	56.715	.47	9.4
G03	6/23/86	6/24/86	16.427	.89	24.2
G04	7/22/85	7/23/85	9.861	1.17	10.4
G04	7/29/85	7/30/85	7.245	1.42	6.6
G04	8/ 5/85	8/ 6/85	9.473	1.21	17.4
G04	8/12/85	8/13/85	.306	12.16	16.1
G04	8/19/85	8/20/85	.956	5.06	16.8
G04	8/26/85	8/27/85	10.902	1.15	14.6
G04	9/ 3/85	9/ 4/85	9.607	1.19	19.0
G04	9/ 9/85	9/10/85	19.132	.82	12.6
G04	9/16/85	9/17/85	4.948	1.74	8.4
G04	9/23/85	9/24/85	13.391	1.00	10.2
G04	9/30/85	10/ 1/85	15.993	.91	11.2
G04	10/ 7/85	10/ 8/85	5.251	1.69	11.7
G04	10/14/85	10/15/85	15.878	.90	10.5
G04	10/21/85	10/22/85	14.118	.98	9.9
G04	10/28/85	10/29/85	7.733	1.33	8.6
G04	11/ 4/85	11/ 5/85	15.669	.93	14.1
G04	11/12/85	11/13/85	14.526	1.01	10.0
G04	11/18/85	11/19/85	54.371	.52	4.5
G04	11/25/85	11/26/85	25.885	.75	9.9
G04	12/ 2/85	12/ 3/85	22.575	.81	10.7
G04	12/ 9/85	12/10/85	19.560	.86	8.8
G04	12/16/85	12/17/85	30.360	.69	5.2
G04	12/23/85	12/24/85	24.178	.86	7.1
G04	12/30/85	12/31/85	28.544	.80	6.5
G04	1/ 6/86	1/ 7/86	26.391	.75	11.4
G04	1/13/86	1/14/86	33.561	.62	9.1
G04	1/20/86	1/21/86	13.954	.97	9.2
G04	1/27/86	1/28/86	20.510	.79	13.8
G04	2/ 3/86	2/ 4/86	23.352	.74	12.0
G04	3/31/86	4/ 1/86	11.029	1.10	10.8
G04	4/28/86	4/29/86	13.999	.96	10.1
G04	5/27/86	5/28/86	34.245	.61	9.6
G04	6/23/86	6/24/86	28.602	.67	20.1
G05	7/22/85	7/23/85	31.633	.64	16.4
G05	7/29/85	7/30/85	21.027	.80	11.1
G05	8/ 5/85	8/ 6/85	33.863	.62	15.5
G05	8/12/85	8/13/85	12.109	1.07	13.0
G05	8/19/85	8/20/85	10.967	1.12	10.7

Table A.4 - Continued
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G05	8/26/85	8/27/85	9.888	1.22	12.0
G05	9/ 3/85	9/ 4/85	23.488	.74	16.9
G05	9/ 9/85	9/10/85	19.876	.80	11.0
G05	9/16/85	9/17/85	15.934	.92	7.5
G05	9/23/85	9/24/85	25.259	.71	8.6
G05	9/30/85	10/ 1/85	18.859	.83	8.9
G05	10/ 7/85	10/ 8/85	19.111	.84	11.1
G05	10/14/85	10/15/85	26.773	.69	8.4
G05	10/21/85	10/22/85	16.945	.89	10.2
G05	10/28/85	10/29/85	1.797	3.12	10.2
G05	11/ 4/85	11/ 5/85	21.304	.79	14.4
G05	11/12/85	11/13/85	21.798	.82	11.9
G05	11/18/85	11/19/85	17.266	.93	10.8
G05	11/25/85	11/26/85	21.011	.83	14.3
G05	12/ 2/85	12/ 3/85	43.459	.58	12.1
G05	12/ 9/85	12/10/85	25.820	.75	10.8
G05	12/16/85	12/17/85	3.651	2.13	8.2
G05	12/23/85	12/24/85	18.662	.98	7.3
G05	12/30/85	12/31/85	6.453	1.76	5.4
G05	1/ 6/86	1/ 7/86	19.631	.87	11.6
G05	1/13/86	1/14/86	11.535	1.09	13.7
G05	1/20/86	1/21/86	12.706	1.02	8.7
G05	1/27/86	1/28/86	15.157	.93	5.2
G05	2/ 3/86	2/ 4/86	12.789	1.02	4.6
G05	3/ 4/86	3/ 5/86	18.581	.84	12.0
G05	3/31/86	4/ 1/86	12.382	1.04	9.3
G05	4/28/86	4/29/86	24.303	.72	8.2
G05	5/27/86	5/28/86	7.262	1.38	6.5
G05	6/23/86	6/24/86	16.739	.89	22.1
G06	7/22/85	7/23/85	17.211	.88	13.3
G06	7/29/85	7/30/85	8.563	1.29	12.6
G06	8/ 5/85	8/ 6/85	16.021	.91	17.8
G06	8/12/85	8/13/85	5.210	1.69	18.9
G06	8/19/85	8/20/85	8.994	1.26	16.0
G06	8/26/85	8/27/85	1.190	4.40	14.6
G06	9/ 3/85	9/ 4/85	32.516	.63	18.5
G06	9/ 9/85	9/10/85	22.574	.75	11.9
G06	9/16/85	9/17/85	24.218	.74	9.3
G06	9/23/85	9/24/85	47.753	.52	10.8
G06	9/30/85	10/ 1/85	67.167	.43	11.0
G06	10/ 7/85	10/ 8/85	74.932	.42	12.5
G06	10/14/85	10/15/85	33.987	.61	9.3
G06	10/21/85	10/22/85	24.738	.73	8.7
G06	10/28/85	10/29/85	48.407	.51	9.3
G06	11/ 4/85	11/ 5/85	33.549	.63	13.7
G06	11/12/85	11/13/85	3.734	2.11	12.1
G06	11/18/85	11/19/85	5.900	1.65	10.5
G06	11/25/85	11/26/85	21.303	.83	9.8

Table A.4 - Continued
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G06	12/ 2/85	12/ 3/85	39.501	.61	10.7
G06	12/ 9/85	12/10/85	15.521	.97	9.9
G06	12/16/85	12/17/85	21.471	.82	8.5
G06	12/23/85	12/24/85	40.336	.66	10.3
G06	12/30/85	12/31/85	28.274	.81	6.9
G06	1/ 6/86	1/ 7/86	10.991	1.18	11.9
G06	1/13/86	1/14/86	37.625	.59	11.2
G06	1/20/86	1/21/86	51.826	.50	9.0
G06	1/27/86	1/28/86	49.890	.50	10.6
G06	2/ 3/86	2/ 4/86	30.798	.64	9.5
G06	3/ 4/86	3/ 5/86	4.520	1.80	9.4
G06	3/31/86	4/ 1/86	9.680	1.18	9.9
G06	4/28/86	4/29/86	31.493	.63	6.9
G06	5/27/86	5/28/86	8.993	1.23	10.0
G06	6/23/86	6/24/86	36.223	.60	19.8
G07	7/22/85	7/23/85	36.212	.60	17.1
G07	7/29/85	7/30/85	19.161	.79	9.7
G07	8/ 5/85	8/ 6/85	17.809	.87	15.7
G07	8/12/85	8/13/85	1.700	3.34	22.4
G07	8/19/85	8/20/85	7.217	1.42	13.7
G07	9/ 3/85	9/ 4/85	12.204	1.05	18.9
G07	9/ 9/85	9/10/85	10.895	1.10	12.8
G07	9/16/85	9/17/85	14.153	.98	7.8
G07	9/23/85	9/24/85	11.192	1.10	9.2
G07	9/30/85	10/ 1/85	40.871	.56	11.9
G07	10/ 7/85	10/ 8/85	53.605	.49	10.1
G07	10/14/85	10/15/85	29.012	.67	9.5
G07	10/21/85	10/22/85	31.998	.64	7.7
G07	10/28/85	10/29/85	29.024	.67	9.9
G07	1/ 4/85	11/ 5/85	.881	5.17	12.3
G07	11/12/85	11/13/85	.188	17.65	12.0
G07	11/18/85	11/19/85	26.400	.75	12.4
G07	11/25/85	11/26/85	15.041	.99	8.7
G07	12/ 2/85	12/ 3/85	27.006	.74	12.0
G07	12/ 9/85	12/10/85	16.139	.95	9.2
G07	12/16/85	12/17/85	25.880	.75	8.2
G07	12/23/85	12/24/85	34.512	.72	6.9
G07	12/30/85	12/31/85	21.081	.94	6.3
G07	1/ 6/86	1/ 7/86	26.747	.74	14.6
G07	1/13/86	1/14/86	23.107	.76	11.4
G07	1/20/86	1/21/86	19.871	.81	10.4
G07	1/27/86	1/28/86	10.689	1.12	9.3
G07	2/ 3/86	2/ 4/86	20.915	.79	11.1
G07	3/ 4/86	3/ 5/86	31.649	.64	10.8
G07	3/31/86	4/ 1/86	2.176	2.78	7.0
G07	4/28/86	4/29/86	14.228	.95	7.4
G07	5/27/86	5/28/86	23.453	.74	5.9
G07	6/23/86	6/24/86	14.295	.96	18.9

Table A.4 - Continued
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G07#	8/26/85	8/27/85	2.973	2.40	14.6
G08	7/22/85	7/23/85	35.327	.61	17.0
G08	8/ 5/85	8/ 6/85	27.640	.69	18.6
G08	8/12/85	8/13/85	5.976	1.57	20.8
G08	8/19/85	8/20/85	9.595	1.22	16.4
G08	8/26/85	8/27/85	10.725	1.12	15.0
G08	9/ 3/85	9/ 4/85	1.258	3.94	20.3
G08	9/ 9/85	9/10/85	2.077	2.84	12.6
G08	9/16/85	9/17/85	8.339	1.30	11.7
G08	9/23/85	9/24/85	2.986	2.33	11.4
G08	9/30/85	10/ 1/85	8.376	1.29	9.3
G08	10/ 7/85	10/ 8/85	7.282	1.41	10.2
G08	10/14/85	10/15/85	15.484	.93	9.3
G08	10/21/85	10/22/85	13.458	1.01	8.0
G08	10/28/85	10/29/85	11.889	1.06	8.7
G08	11/ 4/85	11/ 5/85	5.634	1.61	9.5
G08	11/12/85	11/13/85	9.770	1.25	9.6
G08	11/18/85	11/19/85	17.669	.92	8.3
G08	11/25/85	11/26/85	36.415	.63	7.0
G08	12/ 2/85	12/ 3/85	39.084	.61	7.0
G08	12/ 9/85	12/10/85	31.200	.68	7.0
G08	12/16/85	12/17/85	28.992	.71	7.6
G08	12/23/85	12/24/85	35.036	.71	5.5
G08	12/30/85	12/31/85	13.597	1.18	6.9
G08	1/ 6/86	1/ 7/86	22.688	.81	15.4
G08	1/13/86	1/14/86	1.378	3.79	8.5
G08	1/20/86	1/21/86	3.995	1.92	8.3
G08	1/27/86	1/28/86	8.490	1.26	7.4
G08	2/ 3/86	2/ 4/86	9.255	1.21	6.7
G08	3/ 4/86	3/ 5/86	23.986	.74	7.1
G08	3/31/86	4/ 1/86	4.790	1.74	4.6
G08	4/28/86	4/29/86	5.787	1.55	5.3
G08	5/27/86	5/28/86	14.581	.95	5.2
G08	6/23/86	6/24/86	7.039	1.40	17.8
G08#	7/29/85	7/30/85	19.442	.78	14.8
G09	7/22/85	7/23/85	15.537	.93	14.2
G09	7/29/85	7/30/85	9.982	1.10	13.2
G09	8/ 5/85	8/ 6/85	13.323	1.01	15.9
G09	8/12/85	8/13/85	39.432	.57	16.6
G09	8/19/85	8/20/85	26.352	.71	14.5
G09	8/26/85	8/27/85	12.891	1.01	14.7
G09	9/ 3/85	9/ 4/85	4.180	1.87	19.5
G09	9/ 9/85	9/10/85	18.331	.84	14.3
G09	9/16/85	9/17/85	25.803	.72	7.0
G09	9/23/85	9/24/85	22.845	.75	6.2
G09	9/30/85	10/ 1/85	21.542	.78	9.0
G09	10/ 7/85	10/ 8/85	23.290	.76	8.8
G09	10/14/85	10/15/85	20.116	.81	8.5

Table A.4 - Continued
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G09	10/21/85	10/22/85	20.368	.81	5.7
G09	10/28/85	10/29/85	17.431	.87	14.1
G09	11/ 4/85	11/ 5/85	23.747	.75	14.4
G09	11/12/85	11/13/85	2.925	2.43	14.6
G09	11/18/85	11/19/85	4.138	2.02	12.8
G09	11/25/85	11/26/85	13.779	1.04	12.4
G09	12/ 2/85	12/ 3/85	6.827	1.53	8.3
G09	12/ 9/85	12/10/85	10.265	1.21	6.7
G09	12/16/85	12/17/85	11.220	1.15	6.1
G09	12/23/85	12/24/85	15.375	1.09	5.1
G09	12/30/85	12/31/85	13.943	1.16	8.0
G09	1/ 6/86	1/ 7/86	13.900	1.04	13.9
G09	1/13/86	1/14/86	13.360	1.01	10.8
G09	1/20/86	1/21/86	9.409	1.20	11.0
G09	1/27/86	1/28/86	14.463	.95	10.8
G09	2/ 3/86	2/ 4/86	8.990	1.23	8.6
G09	3/ 4/86	3/ 5/86	32.238	.64	11.7
G09	3/31/86	4/ 1/86	6.421	1.48	9.6
G09	4/28/86	4/29/86	17.392	.86	4.0
G09	5/27/86	5/28/86	16.755	.89	5.6
G09	6/23/86	6/24/86	4.894	1.72	19.5
G10	7/22/85	7/23/85	99.141	.36	15.7
G10	7/29/85	7/30/85	27.316	.65	10.6
G10	8/ 5/85	8/ 6/85	62.096	.46	15.6
G10	8/12/85	8/13/85	46.456	.53	13.9
G10	8/19/85	8/20/85	17.289	.89	12.1
G10	8/26/85	8/27/85	27.468	.68	11.4
G10	9/ 3/85	9/ 4/85	28.306	.67	15.8
G10	9/ 9/85	9/10/85	14.575	.95	14.2
G10	9/16/85	9/17/85	27.179	.70	12.0
G10	9/23/85	9/24/85	22.675	.76	12.6
G10	9/30/85	10/ 1/85	21.631	.78	14.7
G10	10/ 7/85	10/ 8/85	12.862	1.04	9.7
G10	10/14/85	10/15/85	15.908	.92	10.8
G10	10/21/85	10/22/85	14.709	.96	8.8
G10	10/28/85	10/29/85	5.684	1.58	10.4
G10	11/ 4/85	11/ 5/85	16.380	.91	18.1
G10	11/12/85	11/13/85	18.786	.89	9.7
G10	11/18/85	11/19/85	69.659	.46	9.0
G10	11/25/85	11/26/85	17.376	.92	9.9
G10	12/ 2/85	12/ 3/85	14.625	1.02	9.4
G10	12/ 9/85	12/10/85	22.394	.81	8.2
G10	12/16/85	12/17/85	31.245	.68	6.6
G10	12/23/85	12/24/85	55.235	.56	4.6

Table A.4 - Continued
Radon flux and moisture content associated with Gardinier stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
G10	12/30/85	12/31/85	9.032	1.47	5.2
G10	1/ 6/86	1/ 7/86	16.647	.95	13.2
G10	1/13/86	1/14/86	1.669	3.34	12.3
G10	1/20/86	1/21/86	13.509	.99	11.6
G10	1/27/86	1/28/86	9.844	1.17	9.4
G10	2/ 3/86	2/ 4/86	56.234	.47	4.9
G10	3/ 4/86	3/ 5/86	33.958	.62	7.9
G10	3/31/86	4/ 1/86	1.743	3.20	7.3
G10	4/28/86	4/29/86	19.259	.82	10.3
G10	5/27/86	5/28/86	23.511	.75	7.2
G10	6/23/86	6/24/86	2.805	2.37	18.5

*Legend

G Gardinier.
Invalid flux measurement.

Table A.5
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR01	7/24/85	7/25/85	3.351	2.29	13.2
GR01	7/29/85	7/30/85	31.283	.66	6.3
GR01	8/ 5/85	8/ 6/85	1.100	4.55	14.0
GR01	8/12/85	8/13/85	4.441	1.84	15.1
GR01	8/19/85	8/20/85	19.321	.84	15.4
GR01	8/26/85	8/27/85	54.133	.48	10.3
GR01	9/ 3/85	9/ 4/85	32.941	.61	10.1
GR01	9/ 9/85	9/10/85	6.185	1.47	10.3
GR01	9/16/85	9/17/85	65.012	.44	5.8
GR01	9/23/85	9/24/85	23.384	.74	11.3
GR01	9/30/85	10/ 1/85	5.006	1.71	8.7
GR01	10/ 7/85	10/ 8/85	10.170	1.17	8.7
GR01	10/14/85	10/15/85	7.236	1.39	6.6
GR01	10/21/85	10/22/85	30.044	.65	4.5
GR01	10/28/85	10/29/85	17.112	.84	7.4
GR01	11/ 4/85	11/ 5/85	19.896	.82	7.6
GR01	11/12/85	11/13/85	33.431	.66	7.4
GR01	11/18/85	11/19/85	61.102	.48	6.8
GR01	11/25/85	11/26/85	20.458	.84	6.6
GR01	12/ 2/85	12/ 3/85	13.956	1.05	5.9
GR01	12/ 9/85	12/10/85	24.364	.77	7.3
GR01	12/16/85	12/17/85	14.871	1.00	6.7
GR01	12/23/85	12/24/85	16.578	1.07	7.0
GR01	12/30/85	12/31/85	15.177	1.12	5.8
GR01	1/ 6/86	1/ 7/86	24.725	.79	13.4
GR01	1/13/86	1/14/86	34.862	.60	11.8
GR01	1/20/86	1/21/86	21.209	.77	7.5
GR01	1/27/86	1/28/86	20.833	.77	9.2
GR01	2/ 3/86	2/ 4/86	29.311	.66	7.1
GR01	2/10/86	2/11/86	13.144	1.01	12.1
GR01	2/17/86	2/18/86	22.608	.76	9.4
GR01	2/24/86	2/25/86	25.923	.71	9.9
GR01	3/ 4/86	3/ 5/86	31.668	.64	10.3
GR01	3/10/86	3/11/86	24.235	.74	12.7
GR01	3/17/86	3/18/86	6.777	1.41	13.5
GR01	3/24/86	3/25/86	16.834	.89	7.8
GR01	3/31/86	4/ 1/86	20.206	.80	7.9
GR01	4/ 7/86	4/ 8/86	16.778	.91	8.8
GR01	4/14/86	4/15/86	26.940	.69	9.1
GR01	4/21/86	4/22/86	14.437	.96	7.6
GR01	4/28/86	4/29/86	14.033	.92	5.5
GR01	5/ 5/86	5/ 6/86	43.317	.54	4.0
GR01	5/12/86	5/13/86	25.225	.69	6.6
GR01	5/19/86	5/20/86	34.451	.63	4.3
GR01	5/27/86	5/28/86	4.149	1.89	3.8

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR01	6/ 2/86	6/ 3/86	3.392	2.20	4.9
GR01	6/ 9/86	6/10/86	5.050	1.71	10.2
GR01	6/16/86	6/17/86	12.052	1.05	14.9
GR01	6/23/86	6/24/86	12.569	1.03	14.3
GR01	6/30/86	7/ 1/86	6.676	1.45	9.3
GR01	7/ 7/86	7/ 8/86	13.091	1.01	11.7
GR01	7/14/86	7/15/86	12.971	1.01	8.7
GR01T	6/ 2/86	6/ 3/86	6.022	1.61	99.0
GR01T	7/14/86	7/15/86	2.622	2.53	99.0
GR02	7/24/85	7/25/85	2.766	2.52	17.2
GR02	7/29/85	7/30/85	23.354	.76	10.1
GR02	8/ 5/85	8/ 6/85	20.404	.83	12.5
GR02	8/12/85	8/13/85	18.520	.84	9.4
GR02	8/19/85	8/20/85	5.800	1.61	29.3
GR02	8/26/85	8/27/85	5.174	1.68	25.9
GR02	9/ 3/85	9/ 4/85	13.783	.96	22.5
GR02	9/ 9/85	9/10/85	2.617	2.43	20.8
GR02	9/16/85	9/17/85	19.991	.81	19.3
GR02	9/23/85	9/24/85	12.056	1.05	14.4
GR02	9/30/85	10/ 1/85	16.290	.90	17.2
GR02	10/ 7/85	10/ 8/85	20.981	.80	15.8
GR02	10/14/85	10/15/85	4.720	1.76	5.6
GR02	10/21/85	10/22/85	6.229	1.50	3.2
GR02	10/28/85	10/29/85	9.200	1.17	3.4
GR02	11/ 4/85	11/ 5/85	14.335	.98	6.0
GR02	11/12/85	11/13/85	15.477	.98	4.9
GR02	11/18/85	11/19/85	16.560	.95	5.6
GR02	11/25/85	11/26/85	9.925	1.23	5.6
GR02	12/ 2/85	12/ 3/85	12.896	1.10	3.7
GR02	12/ 9/85	12/10/85	10.094	1.21	6.9
GR02	12/16/85	12/17/85	9.920	1.24	5.9
GR02	12/23/85	12/24/85	9.250	1.47	4.7
GR02	12/30/85	12/31/85	12.393	1.25	3.0
GR02	1/ 6/86	1/ 7/86	8.763	1.37	6.9
GR02	1/13/86	1/14/86	11.705	1.06	6.4
GR02	1/20/86	1/21/86	11.323	1.08	5.2
GR02	1/27/86	1/28/86	7.779	1.30	5.8
GR02	2/ 3/86	2/ 4/86	11.772	1.07	5.2
GR02	2/10/86	2/11/86	20.655	.81	16.1
GR02	2/17/86	2/18/86	10.185	1.16	14.3
GR02	2/24/86	2/25/86	14.964	.94	12.1
GR02	3/ 4/86	3/ 5/86	13.313	1.01	9.1
GR02	3/10/86	3/11/86	9.862	1.18	11.1
GR02	3/17/86	3/18/86	4.004	1.90	11.9
GR02	3/24/86	3/25/86	6.677	1.46	6.8
GR02	3/31/86	4/ 1/86	5.790	1.59	7.2
GR02	4/ 7/86	4/ 8/86	10.053	1.20	3.8

Table A.5 - Continued
Radon Flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR02	4/14/86	4/15/86	5.527	1.60	6.1
GR02	4/21/86	4/22/86	15.912	.91	6.5
GR02	4/28/86	4/29/86	6.077	1.45	9.8
GR02	5/ 5/86	5/ 6/86	4.420	1.82	7.4
GR02	5/12/86	5/13/86	9.065	1.19	9.7
GR02	5/19/86	5/20/86	13.103	1.04	8.0
GR02	5/27/86	5/28/86	4.454	1.82	3.6
GR02	6/ 2/86	6/ 3/86	7.193	1.44	5.4
GR02	6/ 9/86	6/10/86	11.115	1.12	7.5
GR02	6/16/86	6/17/86	6.429	1.48	16.3
GR02	6/23/86	6/24/86	5.510	1.63	12.9
GR02	6/30/86	7/ 1/86	7.959	1.34	14.6
GR02	7/ 7/86	7/ 8/86	2.078	2.91	11.4
GR02	7/14/86	7/15/86	10.293	1.14	10.4
GR02T	6/ 2/86	6/ 3/86	37.098	.62	99.0
GR02T	6/ 2/86	6/ 3/86	17.406	.91	99.0
GR02T	7/14/86	7/15/86	28.834	.69	99.0
GR03	7/24/85	7/25/85	17.864	.88	11.1
GR03	7/29/85	7/30/85	23.220	.76	3.1
GR03	8/12/85	8/13/85	28.724	.67	10.5
GR03	8/19/85	8/20/85	25.478	.73	14.0
GR03	8/26/85	8/27/85	15.663	.92	13.4
GR03	9/ 3/85	9/ 4/85	13.950	.96	17.8
GR03	9/ 9/85	9/10/85	3.506	2.04	12.6
GR03	9/16/85	9/17/85	18.110	.85	7.9
GR03	9/23/85	9/24/85	16.173	.90	11.3
GR03	9/30/85	10/ 1/85	13.004	1.01	10.1
GR03	10/ 7/85	10/ 8/85	7.007	1.44	8.7
GR03	10/14/85	10/15/85	10.836	1.12	5.4
GR03	10/21/85	10/22/85	9.800	1.17	3.7
GR03	10/28/85	10/29/85	23.997	.71	6.1
GR03	11/ 4/85	11/ 5/85	19.525	.83	6.2
GR03	11/12/85	11/13/85	7.270	1.45	8.9
GR03	11/18/85	11/19/85	8.751	1.32	5.3
GR03	11/25/85	11/26/85	15.001	.99	3.6
GR03	12/ 2/85	12/ 3/85	9.280	1.30	7.3
GR03	12/ 9/85	12/10/85	11.734	1.12	8.0
GR03	12/16/85	12/17/85	13.597	1.05	7.3
GR03	12/23/85	12/24/85	21.748	.93	7.6
GR03	12/30/85	12/31/85	15.291	1.12	6.9
GR03	1/ 6/86	1/ 7/86	10.236	1.26	11.6
GR03	1/13/86	1/14/86	14.611	.94	13.1
GR03	1/20/86	1/21/86	13.667	.97	8.5
GR03	1/27/86	1/28/86	14.335	.94	8.3
GR03	2/ 3/86	2/ 4/86	14.178	.97	5.9
GR03	2/10/86	2/11/86	18.523	.85	15.2
GR03	2/17/86	2/18/86	26.759	.70	11.2
GR03	2/24/86	2/25/86	18.145	.85	14.6
GR03	3/ 4/86	3/ 5/86	16.404	.90	9.2

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR03	3/10/86	3/11/86	19.438	.83	11.4
GR03	3/17/86	3/18/86	4.781	1.72	24.1
GR03	3/24/86	3/25/86	12.765	1.03	10.4
GR03	3/31/86	4/ 1/86	13.042	1.02	7.9
GR03	4/ 7/86	4/ 8/86	15.493	.95	5.4
GR03	4/14/86	4/15/86	10.236	1.14	8.2
GR03	4/21/86	4/22/86	16.043	.91	6.1
GR03	4/28/86	4/29/86	11.788	1.02	8.0
GR03	5/ 5/86	5/ 6/86	10.964	1.10	6.0
GR03	5/12/86	5/13/86	20.089	.78	6.9
GR03	5/19/86	5/20/86	20.035	.83	7.5
GR03	5/27/86	5/28/86	11.853	1.07	2.6
GR03	6/ 2/86	6/ 3/86	18.012	.89	3.8
GR03	6/ 9/86	6/10/86	20.076	.82	13.1
GR03	6/16/86	6/17/86	14.103	.97	21.4
GR03	6/23/86	6/24/86	5.540	1.62	22.4
GR03	6/30/86	7/ 1/86	35.069	.61	13.8
GR03	7/ 7/86	7/ 8/86	3.768	2.01	18.9
GR03	7/14/86	7/15/86	7.112	1.39	12.5
GR03#	8/ 5/85	8/ 6/85	29.913	.68	16.5
GR03T	6/ 2/86	6/ 3/86	15.514	.97	99.0
GR03T	7/14/86	7/15/86	7.270	1.42	99.0
GR04	7/24/85	7/25/85	12.463	1.07	9.3
GR04	7/29/85	7/30/85	21.583	.79	6.4
GR04	8/ 5/85	8/ 6/85	22.322	.79	12.8
GR04	8/12/85	8/13/85	23.459	.74	10.4
GR04	8/19/85	8/20/85	22.680	.77	11.0
GR04	8/26/85	8/27/85	15.897	.91	8.2
GR04	9/ 3/85	9/ 4/85	18.332	.83	12.1
GR04	9/ 9/85	9/10/85	21.576	.76	9.3
GR04	9/16/85	9/17/85	12.726	1.02	6.4
GR04	9/23/85	9/24/85	16.080	.90	8.5
GR04	9/30/85	10/ 1/85	17.098	.87	7.5
GR04	10/ 7/85	10/ 8/85	11.633	1.09	7.7
GR04	10/14/85	10/15/85	14.495	.96	6.4
GR04	10/21/85	10/22/85	9.504	1.19	2.6
GR04	10/28/85	10/29/85	18.544	.81	5.9
GR04	11/ 4/85	11/ 5/85	21.608	.79	7.7
GR04	11/12/85	11/13/85	17.502	.91	6.6
GR04	11/18/85	11/19/85	15.372	.98	5.7
GR04	11/25/85	11/26/85	20.991	.83	8.6
GR04	12/ 2/85	12/ 3/85	20.281	.87	6.0
GR04	12/ 9/85	12/10/85	17.184	.92	8.3
GR04	12/16/85	12/17/85	23.304	.79	7.1
GR04	12/23/85	12/24/85	23.196	.90	6.2
GR04	12/30/85	12/31/85	22.551	.92	5.7
GR04	1/ 6/86	1/ 7/86	17.052	.96	10.9

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR04	1/13/86	1/14/86	12.426	1.03	10.8
GR04	1/20/86	1/21/86	18.233	.84	6.8
GR04	1/27/86	1/28/86	19.281	.81	7.6
GR04	2/ 3/86	2/ 4/86	19.913	.81	5.5
GR04	2/10/86	2/11/86	39.080	.58	15.1
GR04	2/17/86	2/18/86	31.806	.64	8.7
GR04	2/24/86	2/25/86	31.117	.64	13.4
GR04	3/ 4/86	3/ 5/86	15.115	.94	6.9
GR04	3/10/86	3/11/86	30.229	.66	10.5
GR04	3/17/86	3/18/86	10.925	1.10	17.0
GR04	3/24/86	3/25/86	24.621	.73	5.6
GR04	3/31/86	4/ 1/86	10.200	1.16	6.2
GR04	4/ 7/86	4/ 8/86	12.757	1.05	3.7
GR04	4/14/86	4/15/86	12.695	1.02	7.7
GR04	4/21/86	4/22/86	9.789	1.18	3.9
GR04	4/28/86	4/29/86	4.750	1.66	4.3
GR04	5/ 5/86	5/ 6/86	12.549	1.02	4.4
GR04	5/12/86	5/13/86	16.246	.87	6.0
GR04	5/19/86	5/20/86	21.616	.80	6.7
GR04	5/27/86	5/28/86	13.414	1.00	2.7
GR04	6/ 2/86	6/ 3/86	18.991	.86	4.3
GR04	6/ 9/86	6/10/86	12.619	1.04	12.6
GR04	6/16/86	6/17/86	7.963	1.31	20.5
GR04	6/23/86	6/24/86	7.401	1.38	19.1
GR04	6/30/86	7/ 1/86	7.038	1.42	16.7
GR04	7/ 7/86	7/ 8/86	7.559	1.36	15.8
GR04	7/14/86	7/15/86	7.589	1.34	8.1
GR04T	6/ 2/86	6/ 3/86	1.473	3.77	99.0
GR04T	7/14/86	7/15/86	1.139	4.36	99.0
GR05	7/24/85	7/25/85	7.613	1.39	12.1
GR05	7/29/85	7/30/85	20.705	.81	4.7
GR05	8/ 5/85	8/ 6/85	42.504	.57	16.6
GR05	8/12/85	8/13/85	34.616	.61	12.6
GR05	8/19/85	8/20/85	23.354	.76	12.1
GR05	8/26/85	8/27/85	23.415	.74	7.6
GR05	9/ 3/85	9/ 4/85	28.515	.66	11.3
GR05	9/ 9/85	9/10/85	12.149	1.03	13.9
GR05	9/16/85	9/17/85	20.369	.80	8.3
GR05	9/23/85	9/24/85	23.421	.74	13.1
GR05	9/30/85	10/ 1/85	20.799	.79	7.7
GR05	10/ 7/85	10/ 8/85	18.649	.85	7.9
GR05	10/14/85	10/15/85	17.141	.88	5.5
GR05	10/21/85	10/22/85	20.199	.80	6.0
GR05	10/28/85	10/29/85	20.548	.77	5.6
GR05	11/ 4/85	11/ 5/85	20.630	.81	10.2
GR05	11/12/85	11/13/85	22.286	.81	7.7
GR05	11/18/85	11/19/85	21.149	.83	6.1

Table A.5 - Continued
Radon Flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR05	11/25/85	11/26/85	27.209	.73	6.4
GR05	12/ 2/85	12/ 3/85	22.843	.81	5.0
GR05	12/ 9/85	12/10/85	23.771	.78	7.3
GR05	12/16/85	12/17/85	22.365	.81	6.2
GR05	12/23/85	12/24/85	21.016	.95	5.3
GR05	12/30/85	12/31/85	23.413	.90	6.5
GR05	1/ 6/86	1/ 7/86	21.598	.85	15.9
GR05	1/13/86	1/14/86	36.657	.59	18.2
GR05	1/20/86	1/21/86	24.022	.73	7.7
GR05	1/27/86	1/28/86	31.554	.63	8.8
GR05	2/ 3/86	2/ 4/86	24.505	.73	5.6
GR05	2/10/86	2/11/86	24.836	.73	15.6
GR05	2/17/86	2/18/86	12.398	1.04	9.9
GR05	2/24/86	2/25/86	33.640	.62	13.3
GR05	3/ 4/86	3/ 5/86	25.199	.72	8.5
GR05	3/10/86	3/11/86	32.912	.63	12.5
GR05	3/17/86	3/18/86	25.617	.70	20.8
GR05	3/24/86	3/25/86	22.009	.78	7.5
GR05	3/31/86	4/ 1/86	20.474	.80	8.3
GR05	4/ 7/86	4/ 8/86	11.986	1.09	5.7
GR05	4/14/86	4/15/86	16.666	.88	7.8
GR05	4/21/86	4/22/86	13.317	1.00	5.4
GR05	4/28/86	4/29/86	10.725	1.07	2.8
GR05	5/ 5/86	5/ 6/86	42.598	.54	3.3
GR05	5/12/86	5/13/86	16.441	.87	5.5
GR05	5/19/86	5/20/86	27.304	.71	6.0
GR05	5/27/86	5/28/86	38.326	.58	3.5
GR05	6/ 2/86	6/ 3/86	18.027	.88	3.4
GR05	6/ 9/86	6/10/86	11.029	1.12	14.0
GR05	6/16/86	6/17/86	19.551	.82	24.5
GR05	6/23/86	6/24/86	17.269	.88	19.9
GR05	6/30/86	7/ 1/86	15.235	.94	15.0
GR05	7/ 7/86	7/ 8/86	14.864	.95	14.9
GR05	7/14/86	7/15/86	11.794	1.06	7.3
GR05T	6/ 2/86	6/ 3/86	.496	8.37	99.0
GR05T	7/14/86	7/15/86	.484	8.23	99.0
GR06	7/24/85	7/25/85	2.833	2.45	17.3
GR06	7/29/85	7/30/85	13.622	1.00	15.0
GR06	8/ 5/85	8/ 6/85	.220	16.88	32.7
GR06	8/12/85	8/13/85	.505	7.93	17.5
GR06	8/19/85	8/20/85	1.937	3.12	26.9
GR06	8/26/85	8/27/85	4.019	1.93	9.8
GR06	9/ 3/85	9/ 4/85	1.046	4.33	28.7
GR06	9/ 9/85	9/10/85	.356	10.06	16.3
GR06	9/16/85	9/17/85	1.081	4.51	15.6
GR06	9/23/85	9/24/85	1.222	4.20	16.1
GR06	9/30/85	10/ 1/85	1.811	3.22	9.2

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR06	10/ 7/85	10/ 8/85	1.599	3.56	14.1
GR06	10/14/85	10/15/85	2.368	2.65	7.4
GR06	10/21/85	10/22/85	2.614	2.47	5.9
GR06	10/28/85	10/29/85	3.051	2.16	7.3
GR06	11/ 4/85	11/ 5/85	1.302	3.95	13.4
GR06	11/12/85	11/13/85	3.819	2.06	7.7
GR06	11/18/85	11/19/85	3.751	2.11	7.0
GR06	11/25/85	11/26/85	7.051	1.47	6.1
GR06	12/ 2/85	12/ 3/85	5.097	1.81	6.4
GR06	12/ 9/85	12/10/85	6.364	1.56	8.4
GR06	12/16/85	12/17/85	4.314	1.95	6.2
GR06	12/23/85	12/24/85	7.208	1.68	6.0
GR06	12/30/85	12/31/85	9.221	1.47	4.9
GR06	1/ 6/86	1/ 7/86	5.790	1.71	17.1
GR06	1/13/86	1/14/86	2.436	2.56	14.3
GR06	1/20/86	1/21/86	3.323	2.11	7.8
GR06	1/27/86	1/28/86	2.062	2.79	7.2
GR06	2/ 3/86	2/ 4/86	7.762	1.33	5.8
GR06	2/10/86	2/11/86	.998	4.82	20.1
GR06	2/17/86	2/18/86	7.120	1.41	11.7
GR06	2/24/86	2/25/86	2.223	2.75	13.9
GR06	3/ 4/86	3/ 5/86	7.958	1.32	9.9
GR06	3/10/86	3/11/86	13.890	.99	11.2
GR06	3/17/86	3/18/86	1.725	3.15	21.6
GR06	3/24/86	3/25/86	4.123	1.91	12.9
GR06	3/31/86	4/ 1/86	3.372	2.13	11.8
GR06	4/ 7/86	4/ 8/86	3.653	2.09	8.5
GR06	4/14/86	4/15/86	4.374	1.82	9.7
GR06	4/21/86	4/22/86	2.924	2.32	7.0
GR06	4/28/86	4/29/86	3.209	2.08	5.2
GR06	5/ 5/86	5/ 6/86	9.431	1.19	4.3
GR06	5/12/86	5/13/86	10.139	1.12	7.0
GR06	5/19/86	5/20/86	17.458	.89	9.4
GR06	5/27/86	5/28/86	22.275	.77	4.0
GR06	6/ 2/86	6/ 3/86	13.983	1.01	4.0
GR06	6/ 9/86	6/10/86	6.831	1.45	9.9
GR06	6/16/86	6/17/86	.726	5.75	24.1
GR06	6/23/86	6/24/86	9.273	1.22	15.7
GR06	6/30/86	7/ 1/86	2.205	2.78	11.2
GR06	7/ 7/86	7/ 8/86	5.713	1.58	15.3
GR06	7/14/86	7/15/86	3.731	1.99	10.4
GR06T	6/ 2/86	6/ 3/86	3.673	2.13	99.0
GR06T	7/14/86	7/15/86	2.094	2.90	99.0
GR07	7/24/85	7/25/85	14.529	.88	12.1
GR07	7/29/85	7/30/85	14.942	.96	12.1
GR07	8/ 5/85	8/ 6/85	13.537	1.02	18.8
GR07	8/12/85	8/13/85	15.887	.91	17.6

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR07	8/19/85	8/20/85	13.567	1.01	19.2
GR07	8/26/85	8/27/85	11.017	1.10	12.8
GR07	9/ 3/85	9/ 4/85	2.885	2.26	18.5
GR07	9/ 9/85	9/10/85	2.809	2.32	17.1
GR07	9/16/85	9/17/85	10.110	1.15	10.4
GR07	9/23/85	9/24/85	9.523	1.19	13.4
GR07	9/30/85	10/ 1/85	14.590	.95	11.5
GR07	10/ 7/85	10/ 8/85	14.805	.95	12.7
GR07	10/14/85	10/15/85	11.493	1.09	10.9
GR07	10/21/85	10/22/85	10.388	1.13	6.9
GR07	10/28/85	10/29/85	19.234	.79	10.6
GR07	11/ 4/85	11/ 5/85	4.844	1.75	11.9
GR07	11/12/85	11/13/85	11.300	1.15	9.8
GR07	11/18/85	11/19/85	7.002	1.49	9.8
GR07	11/25/85	11/26/85	19.070	.87	8.1
GR07	12/ 2/85	12/ 3/85	22.922	.81	7.7
GR07	12/ 9/85	12/10/85	16.864	.93	9.5
GR07	12/16/85	12/17/85	63.139	.48	7.1
GR07	12/23/85	12/24/85	47.285	.62	7.6
GR07	12/30/85	12/31/85	30.574	.78	7.0
GR07	1/ 6/86	1/ 7/86	30.011	.72	16.9
GR07	1/13/86	1/14/86	40.967	.55	16.2
GR07	1/20/86	1/21/86	23.811	.73	11.2
GR07	1/27/86	1/28/86	47.624	.51	11.0
GR07	2/ 3/86	2/ 4/86	21.825	.77	8.1
GR07	2/10/86	2/11/86	210.174	.25	12.5
GR07	2/17/86	2/18/86	38.863	.58	11.0
GR07	2/24/86	2/25/86	7.033	1.41	12.6
GR07	3/ 4/86	3/ 5/86	38.043	.58	9.8
GR07	3/10/86	3/11/86	22.750	.77	12.3
GR07	3/17/86	3/18/86	4.330	1.82	19.2
GR07	3/24/86	3/25/86	7.720	1.35	12.2
GR07	3/31/86	4/ 1/86	18.169	.85	13.3
GR07	4/ 7/86	4/ 8/86	15.198	.96	10.9
GR07	4/14/86	4/15/86	15.667	.91	11.6
GR07	4/21/86	4/22/86	16.716	.89	9.5
GR07	4/28/86	4/29/86	13.132	.96	9.5
GR07	5/ 5/86	5/ 6/86	21.588	.77	8.9
GR07	5/12/86	5/13/86	21.569	.75	10.7
GR07	5/19/86	5/20/86	36.084	.61	8.1
GR07	5/27/86	5/28/86	25.575	.71	6.5
GR07	6/ 2/86	6/ 3/86	27.437	.71	6.7
GR07	6/ 9/86	6/10/86	27.535	.69	10.9
GR07	6/16/86	6/17/86	7.839	1.32	20.1
GR07	6/23/86	6/24/86	5.671	1.59	18.4
GR07	6/30/86	7/ 1/86	32.546	.63	16.0
GR07	7/ 7/86	7/ 8/86	14.938	.94	12.5

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR07	7/14/86	7/15/86	17.078	.87	10.9
GR07T	6/ 2/86	6/ 3/86	1.088	4.62	99.0
GR07T	7/14/86	7/15/86	1.217	4.17	99.0
GR08	7/24/85	7/25/85	13.271	.96	11.8
GR08	7/29/85	7/30/85	12.684	1.04	9.2
GR08	8/ 5/85	8/ 6/85	9.717	1.21	18.1
GR08	8/12/85	8/13/85	14.832	.94	16.8
GR08	8/19/85	8/20/85	5.761	1.61	17.2
GR08	8/26/85	8/27/85	11.309	1.09	14.2
GR08	9/ 3/85	9/ 4/85	17.904	.83	16.2
GR08	9/ 9/85	9/10/85	8.054	1.28	16.3
GR08	9/16/85	9/17/85	18.759	.83	10.1
GR08	9/23/85	9/24/85	11.072	1.10	14.5
GR08	9/30/85	10/ 1/85	10.569	1.13	9.3
GR08	10/ 7/85	10/ 8/85	8.505	1.29	13.2
GR08	10/14/85	10/15/85	9.811	1.18	9.6
GR08	10/21/85	10/22/85	11.442	1.07	9.4
GR08	10/28/85	10/29/85	11.034	1.06	8.7
GR08	11/ 4/85	11/ 5/85	.272	13.16	9.9
GR08	11/12/85	11/13/85	5.310	1.72	6.6
GR08	11/18/85	11/19/85	28.509	.72	8.3
GR08	11/25/85	11/26/85	16.033	.95	8.9
GR08	12/ 2/85	12/ 3/85	14.557	1.03	7.2
GR08	12/ 9/85	12/10/85	16.694	.93	9.2
GR08	12/16/85	12/17/85	12.339	1.10	8.2
GR08	12/23/85	12/24/85	8.683	1.51	6.9
GR08	12/30/85	12/31/85	10.426	1.37	5.0
GR08	1/ 6/86	1/ 7/86	7.831	1.45	13.3
GR08	1/13/86	1/14/86	19.217	.82	11.9
GR08	1/20/86	1/21/86	14.059	.96	7.9
GR08	1/27/86	1/28/86	19.967	.79	8.9
GR08	2/ 3/86	2/ 4/86	10.177	1.15	6.7
GR08	2/10/86	2/11/86	14.445	.97	16.3
GR08	2/17/86	2/18/86	16.082	.91	14.3
GR08	2/24/86	2/25/86	14.248	.96	16.5
GR08	3/ 4/86	3/ 5/86	21.354	.78	11.8
GR08	3/10/86	3/11/86	14.084	.99	13.0
GR08	3/17/86	3/18/86	4.432	1.79	18.3
GR08	3/24/86	3/25/86	7.103	1.41	12.9
GR08	3/31/86	4/ 1/86	10.255	1.15	10.3
GR08	4/ 7/86	4/ 8/86	9.411	1.23	9.1
GR08	4/14/86	4/15/86	9.048	1.22	9.9
GR08	4/21/86	4/22/86	10.663	1.12	8.5
GR08	4/28/86	4/29/86	9.881	1.11	7.9
GR08	5/ 5/86	5/ 6/86	18.970	.82	7.7
GR08	5/12/86	5/13/86	15.324	.90	7.7
GR08	5/19/86	5/20/86	14.202	.99	6.4

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR08	5/27/86	5/28/86	17.052	.88	5.9
GR08	6/ 2/86	6/ 3/86	13.694	1.02	6.1
GR08	6/ 9/86	6/10/86	9.670	1.20	12.0
GR08	6/16/86	6/17/86	8.184	1.29	22.3
GR08	6/23/86	6/24/86	3.098	2.24	15.6
GR08	6/30/86	7/ 1/86	4.775	1.75	14.4
GR08	7/ 7/86	7/ 8/86	32.083	.64	9.8
GR08	7/14/86	7/15/86	12.730	1.02	7.1
GR09	7/24/85	7/25/85	18.616	.89	5.5
GR09	7/29/85	7/30/85	17.086	.89	6.7
GR09	8/ 5/85	8/ 6/85	27.027	.71	10.3
GR09	8/12/85	8/13/85	22.036	.76	9.1
GR09	8/19/85	8/20/85	16.236	.92	9.1
GR09	8/26/85	8/27/85	15.804	.91	9.7
GR09	9/ 3/85	9/ 4/85	9.250	1.18	10.8
GR09	9/ 9/85	9/10/85	4.116	1.86	13.6
GR09	9/16/85	9/17/85	21.144	.78	6.9
GR09	9/23/85	9/24/85	16.930	.88	10.8
GR09	9/30/85	10/ 1/85	16.541	.89	8.0
GR09	10/ 7/85	10/ 8/85	17.596	.87	7.4
GR09	10/14/85	10/15/85	12.764	1.03	9.1
GR09	10/21/85	10/22/85	6.156	1.50	11.8
GR09	10/28/85	10/29/85	4.418	1.74	9.4
GR09	11/ 4/85	11/ 5/85	7.409	1.39	8.2
GR09	11/12/85	11/13/85	6.827	1.50	8.3
GR09	11/18/85	11/19/85	10.284	1.22	9.9
GR09	11/25/85	11/26/85	7.724	1.40	9.2
GR09	12/ 2/85	12/ 3/85	9.466	1.29	8.3
GR09	12/ 9/85	12/10/85	8.479	1.33	8.2
GR09	12/16/85	12/17/85	9.084	1.30	8.2
GR09	12/23/85	12/24/85	5.990	1.86	8.0
GR09	12/30/85	12/31/85	8.646	1.52	7.3
GR09	1/ 6/86	1/ 7/86	15.357	1.02	10.7
GR09	1/13/86	1/14/86	8.967	1.22	10.0
GR09	1/20/86	1/21/86	7.168	1.37	7.6
GR09	1/27/86	1/28/86	8.383	1.25	7.6
GR09	2/ 3/86	2/ 4/86	7.415	1.36	7.7
GR09	2/10/86	2/11/86	11.248	1.11	10.3
GR09	2/17/86	2/18/86	9.412	1.21	9.5
GR09	2/24/86	2/25/86	5.574	1.60	8.8
GR09	3/ 4/86	3/ 5/86	16.779	.89	7.4
GR09	3/10/86	3/11/86	16.508	.91	10.8
GR09	3/17/86	3/18/86	23.023	.74	14.7
GR09	3/24/86	3/25/86	7.226	1.40	14.1
GR09	3/31/86	4/ 1/86	19.535	.82	8.4
GR09	4/ 7/86	4/ 8/86	4.744	1.80	5.6
GR09	4/14/86	4/15/86	23.223	.74	7.4

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR09	4/21/86	4/22/86	10.224	1.15	7.2
GR09	4/28/86	4/29/86	5.793	1.49	5.0
GR09	5/ 5/86	5/ 6/86	20.432	.79	4.2
GR09	5/12/86	5/13/86	11.685	1.03	5.9
GR09	5/19/86	5/20/86	10.346	1.18	6.7
GR09	5/27/86	5/28/86	28.115	.68	4.0
GR09	6/ 2/86	6/ 3/86	13.614	1.02	3.5
GR09	6/ 9/86	6/10/86	3.283	2.19	10.4
GR09	6/16/86	6/17/86	1.753	3.15	20.3
GR09	6/23/86	6/24/86	64.793	.45	15.4
GR09	6/30/86	7/ 1/86	25.892	.72	8.7
GR09	7/ 7/86	7/ 8/86	11.820	1.07	12.6
GR09	7/14/86	7/15/86	8.696	1.25	10.0
GR10	7/24/85	7/25/85	7.747	1.31	8.4
GR10	7/29/85	7/30/85	7.690	1.36	8.5
GR10	8/ 5/85	8/ 6/85	9.781	1.21	9.7
GR10	8/12/85	8/13/85	14.921	.93	13.1
GR10	8/19/85	8/20/85	2.048	3.00	13.4
GR10	8/26/85	8/27/85	6.055	1.52	13.7
GR10	9/ 3/85	9/ 4/85	24.198	.71	14.3
GR10	9/ 9/85	9/10/85	.255	13.25	13.2
GR10	9/16/85	9/17/85	3.969	1.94	7.3
GR10	9/23/85	9/24/85	1.981	3.02	14.2
GR10	9/30/85	10/ 1/85	24.595	.72	10.1
GR10	10/ 7/85	10/ 8/85	25.293	.72	8.7
GR10	10/14/85	10/15/85	17.887	.86	7.8
GR10	10/21/85	10/22/85	22.461	.76	6.3
GR10	10/28/85	10/29/85	20.578	.76	7.4
GR10	11/ 4/85	11/ 5/85	53.515	.50	9.2
GR10	11/12/85	11/13/85	17.855	.90	6.9
GR10	11/18/85	11/19/85	23.390	.79	8.2
GR10	11/25/85	11/26/85	20.800	.83	8.5
GR10	12/ 2/85	12/ 3/85	29.132	.72	7.3
GR10	12/ 9/85	12/10/85	30.254	.69	8.2
GR10	12/16/85	12/17/85	29.196	.71	7.1
GR10	12/23/85	12/24/85	26.587	.84	7.1
GR10	12/30/85	12/31/85	23.380	.89	4.4
GR10	1/ 6/86	1/ 7/86	9.499	1.31	16.7
GR10	1/13/86	1/14/86	17.174	.86	14.7
GR10	1/20/86	1/21/86	9.022	1.21	9.3
GR10	1/27/86	1/28/86	22.158	.75	9.8
GR10	2/ 3/86	2/ 4/86	18.100	.84	6.7
GR10	2/10/86	2/11/86	48.980	.52	12.0
GR10	2/17/86	2/18/86	33.242	.63	11.0
GR10	2/24/86	2/25/86	7.494	1.36	11.9
GR10	3/ 4/86	3/ 5/86	23.288	.75	10.2

Table A.5 - Continued
Radon flux and moisture content associated with W.R. Grace stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
GR10	3/10/86	3/11/86	16.785	.90	16.0
GR10	3/17/86	3/18/86	1.542	3.39	19.8
GR10	3/24/86	3/25/86	4.978	1.71	16.7
GR10	3/31/86	4/ 1/86	7.030	1.40	10.9
GR10	4/ 7/86	4/ 8/86	10.136	1.19	9.2
GR10	4/14/86	4/15/86	10.198	1.14	13.1
GR10	4/21/86	4/22/86	12.800	1.02	8.3
GR10	4/28/86	4/29/86	13.044	.96	9.1
GR10	5/ 5/86	5/ 6/86	20.800	.78	7.3
GR10	5/12/86	5/13/86	21.870	.74	9.0
GR10	5/19/86	5/20/86	29.215	.68	7.6
GR10	5/27/86	5/28/86	28.274	.68	5.6
GR10	6/ 2/86	6/ 3/86	27.541	.71	6.9
GR10	6/ 9/86	6/10/86	14.840	.96	8.9
GR10	6/16/86	6/17/86	10.196	1.15	21.6
GR10	6/23/86	6/24/86	.960	4.78	17.6
GR10	6/30/86	7/ 1/86	1.938	2.99	11.4
GR10	7/ 7/86	7/ 8/86	3.391	2.12	8.1
GR10	7/14/86	7/15/86	5.038	1.68	8.0

*Legend

GR W.R. Grace.
Invalid flux measurement.
99.0 Moisture sample not collected.
T Alpha track detector location.

Table A.6
Radon flux and moisture content associated with Royster stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
R01	7/25/85	7/26/85	31.436	.81	10.5
R01	9/ 3/85	9/ 4/85	33.756	.60	18.7
R01	9/23/85	9/24/85	21.037	.79	6.7
R01	10/14/85	10/15/85	15.490	.92	3.3
R01	11/12/85	11/13/85	37.349	.62	5.6
R01	12/ 9/85	12/10/85	41.588	.59	6.3
R01	1/ 6/86	1/ 7/86	22.902	.82	15.4
R01	2/10/86	2/11/86	39.803	.57	11.1
R01	3/10/86	3/11/86	4.511	1.77	15.0
R01	4/ 7/86	4/ 8/86	7.619	1.37	14.8
R01	5/ 5/86	5/ 6/86	4.760	1.75	7.9
R01	6/30/86	7/ 1/86	.588	6.85	19.3
R01#	6/ 2/86	6/ 3/86	5.841	1.59	26.2
R02	7/25/85	7/26/85	22.238	.97	9.6
R02	9/ 3/85	9/ 4/85	29.486	.64	20.3
R02	9/23/85	9/24/85	20.875	.79	5.3
R02	10/14/85	10/15/85	17.307	.87	5.8
R02	11/12/85	11/13/85	30.227	.69	5.9
R02	12/ 9/85	12/10/85	31.904	.67	6.4
R02	1/ 6/86	1/ 7/86	80.687	.43	19.7
R02	2/10/86	2/11/86	26.444	.70	35.8
R02	3/10/86	3/11/86	1.711	3.16	30.9
R02	4/ 7/86	4/ 8/86	11.363	1.10	14.9
R02	5/ 5/86	5/ 6/86	3.502	2.09	20.9
R02	6/ 2/86	6/ 3/86	35.691	.61	10.2
R02	6/30/86	7/ 1/86	2.001	2.92	18.7
R03	7/25/85	7/26/85	55.865	.61	12.8
R03	9/ 3/85	9/ 4/85	60.600	.44	18.3
R03	9/23/85	9/24/85	17.511	.87	6.9
R03	10/14/85	10/15/85	13.540	.99	7.7
R03	11/12/85	11/13/85	18.451	.89	8.0
R03	12/ 9/85	12/10/85	17.162	.92	8.9
R03	1/ 6/86	1/ 7/86	11.355	1.18	19.7
R03	2/10/86	2/11/86	21.866	.77	27.5
R03	3/10/86	3/11/86	2.976	2.26	31.7
R03	4/ 7/86	4/ 8/86	6.362	1.50	14.1
R03	5/ 5/86	5/ 6/86	4.457	1.82	13.9
R03	6/ 2/86	6/ 3/86	9.364	1.23	11.6
R03	6/30/86	7/ 1/86	1.740	3.20	23.9
R04	7/25/85	7/26/85	41.955	.70	10.9
R04	9/ 3/85	9/ 4/85	36.324	.58	20.6
R04	9/23/85	9/24/85	17.644	.86	4.5
R04	10/14/85	10/15/85	14.243	.96	5.8
R04	11/12/85	11/13/85	24.951	.76	7.1
R04	12/ 9/85	12/10/85	29.681	.70	6.6
R04	1/ 6/86	1/ 7/86	11.427	1.17	15.6
R04	2/10/86	2/11/86	17.796	.86	17.7
R04	3/10/86	3/11/86	26.904	.69	22.4

Table A.6 - Continued
Radon flux and moisture content associated with Royster stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
R04	4/ 7/86	4/ 8/86	2.630	2.50	12.7
R04	5/ 5/86	5/ 6/86	4.582	1.79	8.1
R04	6/ 2/86	6/ 3/86	5.212	1.69	19.3
R04	6/30/86	7/ 1/86	2.708	2.43	21.2
R05	7/25/85	7/26/85	19.975	1.04	12.3
R05	9/ 3/85	9/ 4/85	12.095	1.02	28.8
R05	9/23/85	9/24/85	12.719	1.02	6.7
R05	10/14/85	10/15/85	13.610	.99	4.9
R05	11/12/85	11/13/85	12.611	1.09	9.4
R05	12/ 9/85	12/10/85	15.952	.96	7.8
R05	1/ 6/86	1/ 7/86	36.623	.64	13.0
R05	2/10/86	2/11/86	21.209	.78	14.4
R05	3/10/86	3/11/86	13.988	.96	11.7
R05	4/ 7/86	4/ 8/86	3.178	2.24	24.4
R05	5/ 5/86	5/ 6/86	23.897	.74	12.8
R05	6/ 2/86	6/ 3/86	11.380	1.11	11.4
R05	6/30/86	7/ 1/86	17.913	.86	17.1
R06	7/25/85	7/26/85	41.391	.71	15.2
R06	9/ 3/85	9/ 4/85	22.271	.74	29.9
R06	9/23/85	9/24/85	36.773	.59	11.7
R06	10/14/85	10/15/85	23.650	.75	15.3
R06	11/12/85	11/13/85	3.704	2.11	5.8
R06	12/ 9/85	12/10/85	35.682	.63	11.2
R06	1/ 6/86	1/ 7/86	25.655	.77	14.8
R06	2/10/86	2/11/86	43.945	.54	10.2
R06	3/10/86	3/11/86	26.155	.69	15.9
R06	4/ 7/86	4/ 8/86	3.453	2.13	18.5
R06	5/ 5/86	5/ 6/86	10.469	1.14	18.8
R06	6/ 2/86	6/ 3/86	14.558	.97	9.2
R06	6/30/86	7/ 1/86	28.348	.68	24.0
R07	7/25/85	7/26/85	41.125	.72	13.6
R07	9/ 3/85	9/ 4/85	17.445	.84	26.2
R07	9/23/85	9/24/85	18.193	.84	11.0
R07	10/14/85	10/15/85	24.824	.72	5.9
R07	11/12/85	11/13/85	22.330	.81	8.5
R07	12/ 9/85	12/10/85	44.582	.57	9.1
R07	1/ 6/86	1/ 7/86	6.956	1.54	16.0
R07	2/10/86	2/11/86	41.113	.56	14.3
R07	3/10/86	3/11/86	49.957	.50	12.7
R07	4/ 7/86	4/ 8/86	5.866	1.58	11.5
R07	5/ 5/86	5/ 6/86	6.160	1.51	18.6
R07	6/ 2/86	6/ 3/86	10.100	1.18	12.2
R07	6/30/86	7/ 1/86	24.233	.74	24.2
R08	7/25/85	7/26/85	26.989	.90	11.7
R08	9/ 3/85	9/ 4/85	24.467	.70	22.9
R08	9/23/85	9/24/85	18.955	.82	5.0
R08	10/14/85	10/15/85	11.851	1.07	1.7
R08	11/12/85	11/13/85	16.769	.94	2.8

Table A.6 - Continued
Radon flux and moisture content associated with Royster stack

Location*	Date On	Date Off	Radon Flux (pCi/m2-sec)	Percent Error	Percent Moisture
R08	12/ 9/85	12/10/85	26.870	.73	6.1
R08	1/ 6/86	1/ 7/86	19.691	.89	21.8
R08	2/10/86	2/11/86	67.258	.43	14.5
R08	3/10/86	3/11/86	35.804	.59	22.0
R08	4/ 7/86	4/ 8/86	8.418	1.30	8.0
R08	5/ 5/86	5/ 6/86	14.515	.95	18.9
R08	6/ 2/86	6/ 3/86	16.348	.92	9.5
R08	6/30/86	7/ 1/86	59.272	.47	17.2
R09	7/25/85	7/26/85	18.707	1.08	14.0
R09	9/ 3/85	9/ 4/85	16.787	.85	21.3
R09	9/23/85	9/24/85	24.330	.72	6.3
R09	10/14/85	10/15/85	9.696	1.19	3.7
R09	11/12/85	11/13/85	20.345	.85	5.2
R09	1/ 6/86	1/ 7/86	24.601	.79	20.5
R09	3/10/86	3/11/86	37.946	.57	29.5
R09	4/ 7/86	4/ 8/86	8.127	1.32	17.7
R09	5/ 5/86	5/ 6/86	17.413	.87	20.1
R09	6/ 2/86	6/ 3/86	16.713	.91	8.1
R09	6/30/86	7/ 1/86	24.234	.74	20.3
R09#	12/ 9/85	12/10/85	13.941	1.03	5.9
R10	7/25/85	7/26/85	32.547	.81	13.7
R10	9/ 3/85	9/ 4/85	41.439	.54	24.2
R10	9/23/85	9/24/85	18.788	.83	6.5
R10	10/14/85	10/15/85	17.275	.88	6.7
R10	11/12/85	11/13/85	30.787	.69	5.8
R10	12/ 9/85	12/10/85	29.777	.69	7.8
R10	1/ 6/86	1/ 7/86	20.821	.86	18.8
R10	2/10/86	2/11/86	7.857	1.33	15.7
R10	3/10/86	3/11/86	2.988	2.25	23.0
R10	4/ 7/86	4/ 8/86	15.485	.94	12.2
R10	5/ 5/86	5/ 6/86	16.949	.88	7.6
R10	6/30/86	7/ 1/86	6.905	1.43	20.8
R10#	6/ 2/86	6/ 3/86	3.782	2.04	37.0

*Legend

R Royster.
Invalid flux measurement.

APPENDIX B

Radionuclide concentrations measured in high-volume air samples and particle size samples

Table B.1 Gross radioactivity results[a] in high volume air samples - background location (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
07/27/85-08/26/85	4.5E-5	3.4E-5	4.1E-5	1.2E-6	3.7E-5	2.1E-6	3.5E-7	3.8E-5	1.1E-5
08/26/85-09/30/85	3.4E-5	-	2.7E-5	7.2E-7	2.7E-5	1.2E-6	1.2E-6	2.2E-5	9.9E-6
09/30/85-11/04/85	3.4E-5	-	4.2E-5	2.2E-6	3.5E-5	-5.2E-7	4.6E-6	4.0E-5	6.8E-6
11/04/85-12/03/85	2.6E-5	-	2.6E-5	2.0E-6	2.7E-5	1.6E-6	5.4E-6	2.8E-5	3.9E-6
12/03/85-12/30/85	2.4E-5	-	2.5E-5	8.7E-7	2.8E-5	3.8E-7	4.8E-6	2.2E-5	4.7E-6
12/30/85-02/03/86	3.6E-5	-	2.3E-5	6.4E-7	2.4E-5	-4.6E-7	7.1E-6	3.3E-5	5.5E-6
02/03/86-03/03/86	4.6E-5	-	4.8E-5	2.5E-6	4.3E-5	1.7E-6	6.3E-6	5.6E-5	4.6E-6
03/03/86-03/31/86	2.6E-5	-	1.9E-5	6.6E-7	1.7E-5	7.9E-7	4.8E-6	2.4E-5	5.5E-6
03/31/86-04/28/86	5.8E-5	-	4.2E-5	2.5E-6	5.4E-5	4.4E-6	6.5E-6	3.7E-5	1.8E-5
04/28/86-05/27/86	4.8E-5	-	3.2E-5	2.1E-6	2.9E-5	1.2E-6	2.9E-7	3.5E-5	8.3E-6
05/27/86-06/23/86	6.1E-5	-	2.7E-5	1.3E-6	2.3E-5	3.8E-7	8.7E-7	3.0E-5	6.7E-6
06/23/86-07/17/86	7.9E-5	-	1.9E-5	5.4E-6	3.4E-5	0.0E+0	1.4E-5	5.1E-5	2.3E-5

[a] Radioactivity in blank filters has not been subtracted.

Table B.2 Net radioactivity results[a] in high volume air samples - background location
(Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
07/27/85-08/26/85	4.2E-5	1.6E-5	3.9E-5	9.5E-7	3.6E-5	1.6E-6	3.5E-7	3.8E-5	1.1E-5
08/26/85-09/30/85	3.2E-5	-	2.5E-5	4.5E-7	2.6E-5	7.6E-7	1.2E-6	2.2E-5	9.4E-6
09/30/85-11/04/85	3.2E-5	-	4.0E-5	1.9E-6	3.3E-5	0.0E+0	4.6E-6	4.0E-5	6.2E-6
11/04/85-12/03/85	2.3E-5	-	2.5E-5	1.7E-6	2.7E-5	1.2E-6	5.4E-6	2.8E-5	3.6E-6
12/03/85-12/30/85	2.2E-5	-	2.4E-5	6.2E-7	2.7E-5	0.0E+0	4.8E-6	2.2E-5	4.3E-6
12/30/85-02/03/86	3.4E-5	-	2.1E-5	3.8E-7	2.3E-5	0.0E+0	7.1E-6	3.3E-5	5.3E-6
02/03/86-03/03/86	4.3E-5	-	4.6E-5	2.2E-6	4.2E-5	1.2E-6	6.3E-6	5.6E-5	4.2E-6
03/03/86-03/31/86	2.3E-5	-	1.8E-5	4.3E-7	1.7E-5	3.9E-7	4.8E-6	2.4E-5	5.2E-6
03/31/86-04/28/86	5.5E-5	-	4.0E-5	2.2E-6	5.3E-5	3.9E-6	6.5E-6	3.7E-5	1.7E-5
04/28/86-05/27/86	4.5E-5	-	3.0E-5	1.8E-6	2.8E-5	7.6E-7	2.9E-7	3.5E-5	8.0E-6
05/27/86-06/23/86	4.6E-5	-	2.0E-5	1.0E-6	1.8E-5	0.0E+0	8.7E-7	3.0E-5	6.3E-6
06/23/86-07/17/86	7.5E-5	-	1.7E-5	5.1E-6	3.3E-5	0.0E+0	1.4E-5	5.1E-5	2.3E-5

[a]Radioactivity in blank filters has been subtracted.

Table B.3 Gross radioactivity results[a] in high volume air samples - southeast corner of W.R. Grace stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
03/07/86-03/31/86	1.5E-4	-	1.2E-4	3.7E-6	1.2E-4	1.8E-6	3.5E-6	1.3E-4	4.3E-6
03/31/86-04/28/86	1.7E-4	-	1.6E-4	1.3E-5	1.4E-4	3.9E-6	1.8E-6	1.5E-4	1.2E-5
04/28/86-05/27/86	2.3E-4	-	1.9E-4	6.7E-6	1.9E-4	6.7E-6	-7.2E-6	1.6E-4	1.5E-5
05/27/86-06/23/86	1.3E-4	-	1.2E-4	5.2E-6	1.1E-4	1.4E-6	7.1E-6	1.5E-4	9.3E-6
06/23/86-07/17/86	2.1E-4	-	1.4E-4	6.5E-6	1.4E-4	2.0E-6	1.3E-5	1.7E-4	1.7E-5

[a]Radioactivity in blank filters has not been subtracted. Radioactivity due to background contributions also has not been subtracted.

Table B.4 Gross radioactivity results[a] in high volume air samples - northwest corner of W.R. Grace stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
03/31/86-04/28/86	2.9E-4	-	2.5E-4	1.2E-5	2.5E-4	1.6E-6	8.3E-6	2.6E-4	2.2E-5
04/28/86-05/27/86	2.5E-4	-	2.7E-4	7.7E-6	2.6E-4	9.4E-7	3.9E-6	2.7E-4	2.2E-5
05/27/86-06/23/86	3.9E-4	-	1.4E-4	6.9E-6	1.3E-4	8.0E-6	-1.0E-6	1.2E-4	7.7E-6
06/23/86-07/17/86	1.9E-4	-	1.5E-4	7.1E-6	1.6E-4	2.9E-6	1.6E-5	1.6E-4	2.9E-5

[a]Radioactivity in blank filters has not been subtracted. Radioactivity due to background contributions also has not been subtracted.

Table B.5 Net radioactivity results[a] in high volume air samples - southeast corner of W.R. Grace stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
03/07/86-03/31/86	1.5E-4	-	1.2E-4	3.4E-6	1.2E-4	1.3E-6	3.5E-6	1.3E-4	3.9E-6
03/31/86-04/28/86	1.6E-4	-	1.6E-4	1.2E-5	1.4E-4	3.4E-6	1.8E-6	1.5E-4	1.1E-5
04/28/86-05/27/86	2.2E-4	-	1.9E-4	6.5E-6	1.9E-4	6.3E-6	0.0E+0	1.6E-4	1.5E-5
05/27/86-06/23/86	1.4E-4	-	1.2E-4	5.2E-6	1.1E-4	1.1E-6	7.1E-6	1.5E-4	9.3E-6
06/23/86-07/17/86	1.9E-4	-	1.4E-4	6.3E-6	1.4E-4	1.5E-6	1.3E-5	1.7E-4	1.7E-5

[a]Radioactivity in blank filters has been subtracted. Radioactivity due to background contributions has not been subtracted.

Table B.6 Net radioactivity results[a] in high volume air samples - northwest corner of W.R. Grace stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
03/31/86-04/28/86	2.8E-4	-	2.5E-4	1.2E-5	2.4E-4	1.2E-6	8.3E-6	2.6E-4	2.1E-5
04/28/86-05/27/86	2.4E-4	-	2.7E-4	7.5E-6	2.6E-4	3.9E-7	3.9E-6	2.7E-4	2.1E-5
05/27/86-06/23/86	4.1E-4	-	1.3E-4	6.9E-6	1.2E-4	8.0E-6	0.0E+0	1.1E-4	7.7E-6
06/23/86-07/17/86	1.9E-4	-	1.7E-4	6.8E-6	1.8E-4	2.4E-6	1.6E-5	1.6E-4	2.9E-5

[a]Radioactivity in blank filters has been subtracted. Radioactivity due to background contributions has not been subtracted.

Table B.7 Gross radioactivity results[a] in high volume air samples - northeast corner of Gardinier stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
07/26/85-08/26/85	3.3E-3	2.2E-4	1.4E-3	3.6E-5	1.4E-3	4.0E-5	5.1E-5	1.3E-3	2.7E-5
08/26/85-09/30/85	4.6E-4	-	3.6E-4	4.3E-6	3.5E-4	2.2E-5	-3.9E-6	2.9E-4	7.9E-6
09/30/85-11/04/85	3.3E-4	-	2.6E-4	9.5E-6	2.4E-4	1.8E-5	2.0E-6	1.8E-4	1.4E-5
11/04/85-12/04/85	2.3E-3	-	9.5E-4	4.0E-5	6.5E-4	6.7E-5	2.4E-5	8.6E-4	1.5E-5
12/04/85-12/30/85	3.9E-4	-	2.1E-4	9.1E-6	2.2E-4	8.8E-6	6.7E-5	2.1E-4	5.5E-6
12/30/85-02/03/86	3.6E-4	-	1.3E-4	1.6E-6	1.2E-4	5.5E-6	6.8E-6	1.4E-4	7.1E-6

[a]Radioactivity in blank filters has not been subtracted. Radioactivity due to background contributions also has not been subtracted.

Table B.8 Gross radioactivity results[a] in high volume air samples - southwest corner of Gardinier stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
07/26/85-08/26/85	8.1E-4	1.7E-4	2.6E-3	7.1E-5	2.4E-3	4.0E-5	1.7E-5	2.2E-3	4.9E-5
08/26/85-09/30/85	1.0E-3	-	1.6E-3	7.7E-5	1.6E-3	3.2E-5	3.0E-5	1.3E-3	3.2E-5
09/30/85-11/04/85	4.3E-4	-	6.2E-4	2.5E-5	6.0E-4	1.7E-5	1.1E-5	6.5E-4	1.7E-5
11/04/85-12/04/85	7.7E-4	-	7.5E-4	1.9E-5	7.5E-4	6.0E-5	2.3E-5	9.9E-4	2.3E-5
12/04/85-12/30/85	3.0E-4	-	3.7E-4	1.3E-5	3.2E-4	1.3E-5	1.3E-5	3.3E-4	8.6E-6
12/30/85-02/03/86	5.9E-4	-	3.9E-4	1.3E-5	3.5E-4	1.4E-5	1.9E-5	5.6E-4	1.4E-5

[a]Radioactivity in blank filters has not been subtracted. Radioactivity due to background contributions also has not been subtracted.

Table B.9 Net radioactivity results[a] in high volume air samples - northeast corner of Gardinier stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
07/26/85-08/26/85	3.3E-3	1.9E-4	1.4E-3	3.5E-5	1.4E-3	3.9E-5	5.1E-5	1.3E-3	2.6E-5
08/26/85-09/30/85	4.6E-4	-	3.6E-4	4.0E-6	3.4E-4	2.1E-5	0.0E+0	2.9E-4	7.4E-6
09/30/85-11/04/85	3.3E-4	-	2.5E-4	9.1E-6	2.3E-4	1.7E-5	2.0E-6	1.8E-4	1.4E-5
11/04/85-12/04/85	2.3E-3	-	9.5E-4	4.0E-5	6.5E-4	6.7E-5	2.4E-5	8.6E-4	1.4E-5
12/04/85-12/30/85	3.9E-4	-	2.1E-4	8.8E-6	2.2E-4	8.3E-6	6.7E-5	2.1E-4	5.0E-6
12/30/85-02/03/86	3.6E-4	-	1.3E-4	1.3E-6	1.2E-4	5.1E-6	6.8E-6	1.4E-4	6.7E-6

[a]Radioactivity in blank filters has been subtracted. Radioactivity due to background contributions has not been subtracted.

Table B.10 Net radioactivity results[a] in high volume air samples - southwest corner of Gardinier stack (Concentrations in pCi/m^3)

Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
07/26/85-08/26/85	8.1E-4	1.4E-4	2.6E-3	7.1E-5	2.4E-3	4.0E-5	1.7E-5	2.2E-3	4.8E-5
08/26/85-09/30/85	1.0E-3	-	1.6E-3	7.5E-5	1.6E-3	3.1E-5	3.0E-5	1.3E-3	3.1E-5
09/30/85-11/04/85	4.2E-4	-	6.2E-4	2.5E-5	6.0E-4	1.7E-5	1.1E-5	6.5E-4	1.6E-5
11/04/85-12/04/85	7.7E-4	-	7.5E-4	1.8E-5	7.5E-4	5.9E-5	2.3E-5	9.9E-4	2.2E-5
12/04/85-12/30/85	2.9E-4	-	3.6E-4	1.3E-5	3.2E-4	1.3E-5	1.3E-5	3.3E-4	8.0E-6
12/30/85-02/03/86	5.9E-4	-	3.9E-4	1.2E-5	3.5E-4	1.3E-5	1.9E-5	5.6E-4	1.4E-5

[a]Radioactivity in blank filters has been subtracted. Radioactivity due to background contributions has not been subtracted.

Table B.11 Gross radioactivity results[a] in Andersen air samples - background location[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	2.5E-4 ± 17[c]	2.9E-4 ± 15	1.6E-4 ± 25	2.9E-4 ± 20	1.1E-3 ± 6	2.1E-3
U-234	1.0E-4 ± 88	7.9E-5 ± 86	3.5E-5 ±180	1.1E-4 ± 65	9.0E-4 ± 19	1.2E-3
U-235	9.3E-6 ±200	0.0E+0	9.1E-6 ±200	5.2E-6 ±250	6.5E-5 ± 70	8.9E-5
U-238	9.3E-5 ± 64	7.0E-5 ± 79	4.0E-5 ± 97	6.0E-5 ± 85	1.1E-3 ± 17	1.4E-3
Th-227	-4.1E-2 ± 12	4.5E-5 ±200	0.0E+0	9.7E-5 ±140	2.6E-5 ±280	1.7E-4[d]
Th-228	1.3E-3 ± 47	9.2E-4 ± 50	1.2E-3 ± 39	2.1E-3 ± 27	-3.8E-4 ± 26	5.5E-3[d]
Th-230	-2.0E-4 ±210	3.3E-4 ± 75	2.3E-4 ± 80	2.6E-4 ± 61	6.2E-4 ± 21	1.4E-3[d]
Th-232	9.1E-5 ±210	1.1E-4 ±130	1.7E-4 ± 80	1.9E-4 ± 71	2.2E-4 ± 35	7.8E-4
Pb-210	1.1E-3 ±190	1.5E-3 ±140	4.1E-3 ± 46	3.5E-3 ± 64	1.1E-2 ± 28	2.1E-2
Po-210	2.9E-4 ± 39	5.2E-4 ± 29	6.2E-4 ± 26	9.5E-4 ± 21	8.6E-3 ± 11	1.1E-2

(a) Radioactivity in blank filters has not been subtracted.
(b) Sampled volume of 915 m^3 collected from 7/14/86 1040 to 7/15/86 1335.
(c) Two sigma counting error in percent.
(d) Negative values not included in activity summation.

Table B.12 Net radioactivity results[a] in Andersen air samples - background location[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	7.7E-5	2.2E-4	7.7E-5	1.1E-4	< 1E-4	< 5.8E-4
U-234	3.3E-5	< 1E-4	< 8E-5	< 1E-4	< 3E-4	< 6.1E-4
U-235	< 3E-5	< 5E-5	< 3E-5	5.2E-6	2.7E-5	< 1.4E-4
U-238	4.5E-5	5.7E-5	< 6E-5	4.7E-5	< 3E-4	< 5.1E-4
Th-227	< 5E-3	4.5E-5	< 9E-5	9.7E-5	< 1E-4	< 5.3E-3
Th-228	1.3E-3	9.2E-4	1.2E-3	2.1E-3	< 2E-4	< 5.7E-3
Th-230	< 3E-4	2.7E-4	1.9E-4	2.1E-4	< 3E-4	< 1.3E-3
Th-232	9.1E-5	1.1E-4	1.6E-4	1.9E-4	< 1E-4	< 6.5E-4
Pb-210	3.0E-5	< 3E-3	3.0E-3	1.3E-3	8.4E-3	< 1.6E-2
Po-210	2.3E-4	4.3E-4	5.6E-4	8.6E-4	7.4E-3	9.5E-3

[a]Radioactivity in blank filters has been subtracted.
[b]Sampled volume of 915 m^3 collected from 7/14/86 1040 to 7/15/86 1335.

Table B.13 Gross radioactivity results[a] in Andersen air samples - southeast corner of W.R. Grace stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	NA	NA	3.0E-4 ± 16	NA	2.0E-3 ± 5	2.3E-3
U-234	3.0E-4 ± 37[c]	-4.2E-5 ±190	-2.8E-5 ± 200	3.7E-5 ±120	1.7E-3 ± 17	2.0E-3[d]
U-235	8.6E-5 ± 65	1.7E-5 ±180	2.8E-5 ± 120	1.2E-5 ±200	6.5E-5 ± 74	2.1E-4
U-238	1.2E-4 ± 59	1.6E-4 ± 59	7.6E-5 ± 71	0.0E+0	1.6E-3 ± 17	2.0E-3
Th-227	3.2E-5 ±140	1.4E-5 ±200	3.2E-5 ± 240	4.2E-5 ±140	0.0E+0	1.2E-4
Th-228	-2.4E-4 ± 39	-2.5E-4 ± 36	-1.8E-4 ± 43	-2.1E-4 ± 57	7.7E-5 ±210	7.7E-5[d]
Th-230	1.7E-4 ± 43	5.3E-5 ± 79	5.3E-5 ± 130	1.1E-4 ± 79	1.2E-3 ± 16	1.6E-3
Th-232	0.0E+0	6.6E-6 ±350	0.0E+0	0.0E+0	2.5E-4 ± 34	2.6E-4
Pb-210	-3.4E-4 ±530	6.9E-4 ±260	-1.2E-4 ±1500	3.0E-3 ± 68	2.0E-2 ± 18	2.4E-2[d]
Po-210	3.9E-4 ± 36	2.9E-4 ± 50	2.7E-4 ± 43	4.9E-4 ± 36	4.5E-3 ± 12	5.9E-3

(a) Radioactivity in blank filters has not been subtracted.
(b) Sampled volume of 812 m^3 collected from 4/21/86 1038 to 4/22/86 1030.
(c) Two sigma counting error in percent.
(d) Negative values not included in activity summation.
NA-No analysis.

Table B.14 Gross radioactivity results[a] in Andersen air samples - southeast corner of W.R. Grace stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	2.8E-4 ± 17[c]	2.5E-4 ± 23	2.1E-4 ± 21	NA	1.9E-3 ± 5	2.6E-3
U-234	2.7E-4 ± 45	9.5E-5 ± 57	1.1E-4 ± 57	5.1E-5 ± 79	1.2E-3 ± 17	1.7E-3
U-235	5.1E-5 ± 89	8.2E-6 ±190	0.0E+0	0.0E+0	1.0E-4 ± 55	1.6E-4
U-238	3.0E-4 ± 37	8.2E-5 ± 71	1.1E-4 ± 56	9.3E-5 ± 59	1.4E-3 ± 16	2.0E-3
Th-227	-3.2E-5 ±140	0.0E+0	-1.5E-5 ±200	-1.6E-5 ±200	2.2E-4 ± 64	2.2E-4[d]
Th-228	-2.3E-5 ±800	-8.9E-4 ± 38	-3.0E-4 ± 51	-7.8E-5 ±230	-3.6E-4 ± 37	(d)
Th-230	1.2E-4 ± 56	0.0E+0	1.2E-4 ± 49	1.1E-4 ± 54	3.7E-4 ± 31	7.2E-4
Th-232	3.1E-5 ±120	0.0E+0	7.3E-6 ±530	2.3E-5 ±120	2.8E-4 ± 35	3.4E-4
Pb-210	-9.7E-4 ±200	1.2E-3 ±180	1.6E-3 ±110	2.3E-3 ± 92	1.7E-2 ± 24	2.2E-2[d]
Po-210	3.1E-4 ± 44	3.7E-4 ± 46	3.8E-4 ± 46	5.9E-4 ± 35	7.4E-3 ± 13	9.1E-3

[a] Radioactivity in blank filters has not been subtracted.
[b] Sampled volume of 813 m^3 collected from 7/17/86 1145 to 7/18/86 1140.
[c] Two sigma counting error in percent.
[d] Negative values not included in activity summation.
NA-No analysis.

Table B.15 Gross radioactivity results[a] in Andersen air samples - northwest corner of W.R. Grace stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	NA	NA	NA	NA	1.9E-3 ± 7	1.9E-3
U-234	2.5E-4 ± 45[c]	1.1E-4 ±120	1.7E-4 ± 50	1.8E-5 ±250	1.5E-3 ± 21	2.1E-3
U-235	8.3E-5 ± 67	6.3E-5 ±100	0.0E+0	0.0E+0	1.4E-5 ±200	1.6E-4
U-238	2.9E-4 ± 41	1.6E-4 ± 64	1.6E-4 ± 53	1.5E-4 ± 57	1.4E-3 ± 21	2.2E-3
Th-227	3.5E-5 ±240	1.9E-5 ±200	1.3E-5 ±200	0.0E+0	-2.8E-5 ±200	6.7E-5[d]
Th-228	-1.1E-4 ±110	-1.7E-4 ± 66	-1.0E-4 ± 89	-2.0E-4 ± 44	4.6E-4 ± 77	4.6E-4[d]
Th-230	2.5E-4 ± 41	1.4E-4 ± 55	9.7E-5 ± 55	1.0E-4 ± 62	1.6E-3 ± 19	2.2E-3
Th-232	8.4E-6 ±200	9.2E-6 ±200	6.4E-6 ±350	-8.6E-6 ±200	3.2E-4 ± 42	3.4E-4[d]
Pb-210	3.8E-4 ±490	1.2E-3 ±170	5.7E-3 ± 43	2.5E-3 ± 89	2.0E-2 ± 7	3.0E-2
Po-210	3.8E-4 ± 35	2.7E-4 ± 44	4.5E-4 ± 38	5.7E-4 ± 33	1.6E-2 ± 5	1.8E-2

[a] Radioactivity in blank filters has not been subtracted.
[b] Sampled volume of 845 m^3 collected from 4/21/86 1001 to 4/22/86 1052.
[c] Two sigma counting error in percent.
[d] Negative values not included in activity summation.
NA-No analysis.

Table B.16 Gross radioactivity results[a] in Andersen air samples - northwest corner of W.R. Grace stack[b] (Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	3.3E-4 ± 17[c]	3.2E-4 ± 14	2.1E-4 ± 21	2.1E-4 ± 24	1.6E-3 ± 5	2.7E-3
U-234	1.6E-4 ± 50	1.5E-4 ± 58	7.7E-5 ± 82	7.5E-5 ± 70	9.3E-4 ± 22	1.4E-3
U-235	8.2E-6 ±350	3.5E-5 ±120	0.0E+0	7.5E-6 ±350	1.0E-5 ±200	6.1E-5
U-238	1.9E-4 ± 44	8.1E-5 ± 66	7.1E-5 ± 61	6.0E-5 ± 71	1.2E-3 ± 20	1.6E-3
Th-227	0.0E+0	0.0E+0	-1.7E-5 ±200	0.0E+0	2.1E-4 ± 75	2.1E-4[d]
Th-228	-6.5E-5 ±310	-1.9E-4 ±100	-3.0E-4 ± 60	-1.6E-4 ±130	-1.1E-4 ±150	(d)
Th-230	1.1E-4 ± 71	4.2E-5 ±190	6.7E-5 ± 71	6.4E-5 ±150	1.3E-3 ± 18	1.6E-3
Th-232	8.7E-6 ±200	3.3E-5 ±170	0.0E+0	1.8E-5 ±200	1.3E-4 ± 60	1.9E-4
Pb-210	8.3E-4 ±230	2.2E-3 ± 89	5.7E-3 ± 40	4.1E-3 ± 58	1.6E-2 ± 21	2.9E-2
Po-210	2.7E-4 ± 40	3.4E-4 ± 41	2.4E-4 ± 50	3.6E-4 ± 40	6.3E-3 ± 12	7.5E-3

[a] Radioactivity in blank filters has not been subtracted.
[b] Sampled volume of 842 m^3 collected from 7/17/86 1115 to 7/18/86 1200.
[c] Two sigma counting error in percent.
[d] Negative values not included in activity summation.

Table B.17 Net radioactivity results[a] in Andersen air samples - southeast corner of W.R. Grace stack[b] (Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	NA	NA	2.1E-4	NA	1.2E-4	> 3.3E-4
U-234	2.3E-4	< 1E-4	< 8E-5	< 6E-5	4.8E-4	< 9.5E-4
U-235	6.7E-5	1.7E-5	1.1E-5	1.2E-5	2.2E-5	1.3E-4
U-238	7.0E-5	1.5E-4	3.2E-5	< 9E-5	2.1E-4	< 5.5E-4
Th-227	< 7E-5	1.4E-5	< 9E-5	4.2E-5	< 2E-4	< 4.2E-4
Th-228	< 1E-4	< 3E-4	< 2E-4	< 2E-4	< 2E-4	< 1E-3
Th-230	1.4E-4	< 6E-5	1.4E-5	5.8E-5	< 3E-4	< 5.7E-4
Th-232	< 3E-5	6.6E-6	< 3E-5	< 3E-5	< 2E-4	< 3.0E-4
Pb-210	< 3E-3	< 2E-3	< 3E-3	5.1E-4	1.8E-2	< 2.7E-2
Po-210	3.2E-4	1.9E-4	2.0E-4	3.9E-4	3.3E-3	4.4E-3

[a] Radioactivity in blank filters has been subtracted.
[b] Sampled volume of 812 m^3 collected from 4/21/86 1038 to 4/22/86 1030.
NA-No analysis.

Table B.18 Net radioactivity results[a] in Andersen air samples - southeast corner of W.R. Grace stack[b] (Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	8.6E-5	1.2E-4	8.6E-5	NA	2.7E-4	> 5.6E-4
U-234	2.0E-4	< 1E-4	3.2E-5	< 9E-5	1.4E-5	< 4.4E-4
U-235	3.1E-5	8.2E-6	< 5E-5	< 5E-5	5.8E-5	< 2.0E-4
U-238	2.6E-4	7.0E-5	6.2E-5	8.1E-5	7.4E-5	5.5E-4
Th-227	< 9E-5	< 6E-5	< 6E-5	< 6E-5	1.1E-4	< 3.8E-4
Th-228	< 2E-4	< 4E-4	< 2E-4	< 2E-4	< 2E-4	< 1E-3
Th-230	8.7E-5	< 1E-4	8.7E-5	5.6E-5	< 3E-4	< 6.3E-4
Th-232	2.4E-5	< 4E-5	< 4E-5	2.3E-5	2.0E-5	< 1.5E-4
Pb-210	< 3E-3	< 3E-3	4.1E-4	< 3E-3	1.4E-2	< 2.3E-2
Po-210	2.4E-4	2.7E-4	3.1E-4	4.9E-4	6.1E-3	7.4E-3

[a]Radioactivity in blank filters has been subtracted.
[b]Sampled volume of 813 m^3 collected from 7/17/86 1145 to 7/18/86 1140.
NA-No analysis.

Table B.19 Net radioactivity results[a] in Andersen air samples - northwest corner of W.R. Grace stack[b] (Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	NA	NA	NA	NA	5.9E-4	> 5.9E-4
U-234	1.9E-4	< 2E-4	9.7E-5	< 9E-5	3.4E-4	< 9.2E-4
U-235	6.9E-5	6.3E-5	< 5E-5	< 5E-5	< 6E-5	< 2.9E-4
U-238	2.7E-4	1.4E-4	1.1E-4	1.5E-4	1.5E-4	8.2E-4
Th-227	5.1E-6	1.9E-5	< 5E-5	< 6E-5	< 1E-4	< 2.3E-4
Th-228	< 2E-4	< 2E-4	< 3E-4	< 3E-4	3.4E-4	< 1.3E-3
Th-230	2.3E-4	9.6E-5	6.5E-5	5.8E-5	3.8E-4	8.3E-4
Th-232	1.2E-6	9.2E-6	< 3E-5	< 3E-5	6.4E-5	< 1.3E-4
Pb-210	< 3E-3	< 3E-3	4.6E-3	1.9E-4	1.8E-2	< 2.9E-2
Po-210	3.1E-4	1.7E-4	3.9E-4	4.7E-4	1.5E-2	1.6E-2

[a] Radioactivity in blank filters has been subtracted.
[b] Sampled volume of 845 m^3 collected from 4/21/86 1001 to 4/22/86 1052.
NA-No analysis.

Table B.20 Net radioactivity results[a] in Andersen air samples - northwest corner of W.R. Grace stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	2.1E-4	2.4E-4	8.3E-5	1.2E-4	1.4E-4	7.9E-4
U-234	8.8E-5	3.7E-5	1.8E-6	< 9E-5	< 3E-4	< 5.2E-4
U-235	< 4E-5	3.5E-5	< 5E-5	7.5E-6	< 6E-5	< 1.9E-4
U-238	1.4E-4	6.6E-5	1.9E-5	4.6E-5	< 3E-4	< 5.7E-4
Th-227	< 5E-5	< 6E-5	< 6E-5	< 6E-5	1.0E-4	< 3.3E-4
Th-228	< 2E-4	< 2E-4	< 2E-4	< 3E-4	< 2E-4	< 1E-3
Th-230	7.2E-5	< 9E-5	2.7E-5	1.0E-5	8.2E-5	< 2.8E-4
Th-232	7.4E-7	3.3E-5	< 3E-5	1.8E-5	< 1E-4	< 1.8E-4
Pb-210	< 1E-3	< 3E-3	4.5E-3	1.7E-3	1.3E-2	< 2.3E-2
Po-210	2.1E-4	2.4E-4	1.7E-4	2.6E-4	5.0E-3	5.9E-3

[a] Radioactivity in blank filters has been subtracted.
[b] Sampled volume of 842 m^3 collected from 7/17/86 1115 to 7/18/86 1200.

Table B.21 Background radionuclide concentrations of blank filters of the Andersen Sampler, pCi/filter[a]

	First and Third Stages	Second and Fourth Stages	Fifth Stage[b]
Ra-226	0.13 ± 0.04	0.10 ± 0.04	1.28 ± 0.10
U-234	0.063 ± 0.048	0.096 ± 0.065	0.99 ± 0.23
U-235	0.017 ± 0.022	NA	0.035 ± 0.044
U-238	0.043 ± 0.036	0.012 ± 0.035	1.10 ± 0.23
Th-227	0.028 ± 0.040	NA	0.09 ± 0.07
Th-228	0.00 ± 0.12	0.00 ± 0.12	0.10 ± 0.15
Th-230	0.033 ± 0.030	0.045 ± 0.039	1.06 ± 0.20
Th-232	0.007 ± 0.013	NA	0.22 ± 0.08
Pb-210	1.00 ± 1.91	1.99 ± 1.33	2.15 ± 1.03
Po-210	0.058 ± 0.052	0.083 ± 0.062	1.02 ± 0.23

[a] ± values are 2 standard deviations of the counting rates.
[b] Backup filter - Average of duplicate analyses.
NA-Not Analyzed

Table B.22 Gross radioactivity results[a] in Andersen air samples - northeast corner of Gardinier stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	5.3E-4 ± 10[c]	2.8E-4 ± 16	2.3E-4 ± 18	1.9E-4 ± 22	1.4E-3 ± 5	2.6E-3
U-234	3.6E-4 ± 31	1.8E-4 ± 45	1.5E-4 ± 44	7.2E-5 ± 86	1.1E-3 ± 21	1.9E-3
U-235	3.4E-5 ± 98	2.7E-5 ±120	2.7E-5 ±100	3.6E-6 ±310	0.0E+0	9.2E-5
U-238	3.4E-4 ± 33	2.1E-4 ± 43	9.4E-5 ± 60	2.4E-5 ±160	1.0E-3 ± 22	1.7E-3
Th-227	1.4E-5 ± 200	3.5E-5 ±200	-1.3E-5 ±200	0.0E+0	1.5E-5 ±350	6.4E-5[d]
Th-228	3.5E-5 ± 400	2.3E-5 ±670	-1.7E-4 ± 67	-2.3E-4 ± 50	2.2E-4 ± 74	2.8E-4[d]
Th-230	3.5E-4 ± 33	1.6E-4 ± 52	5.0E-5 ± 72	3.6E-5 ±120	1.1E-3 ± 21	1.7E-3
Th-232	1.4E-5 ± 140	1.7E-5 ±200	6.3E-6 ±200	0.0E+0	1.5E-4 ± 49	1.9E-4
Pb-210	2.4E-4 ±1300	-8.6E-4 ±220	2.5E-3 ±140	-9.7-4E ±170	1.9E-2 ± 24	2.2E-2[d]
Po-210	4.1E-4 ± 38	4.2E-4 ± 35	1.9E-4 ± 59	3.6E-4 ± 41	6.7E-3 ± 14	8.1E-3

[a] Radioactivity in blank filters has not been subtracted.
[b] Sampled volume of 828 m^3 collected from 9/9/85 1055 to 9/10/85 1114.
[c] Two sigma counting error in percent.
[d] Negative values not included in activity summation.

Table B.23 Gross radioactivity results[a] in Andersen air samples - northeast corner of Gardinier stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	2.2E-3 ± 4[c]	9.3E-4 ± 8	6.9E-4 ± 15	4.2E-4 ± 13	1.8E-3 ± 8	6.0E-3
U-234	5.8E-4 ± 28	2.6E-4 ± 41	2.2E-4 ± 44	3.4E-4 ± 44	1.7E-3 ± 21	3.1E-3
U-235	9.8E-5 ± 68	4.4E-5 ±110	3.9E-5 ±100	9.7E-5 ± 72	1.0E-4 ± 80	3.8E-4
U-238	5.7E-4 ± 28	1.3E-4 ± 52	1.7E-4 ± 49	2.2E-4 ± 55	1.3E-3 ± 24	2.4E-3
Th-227	NA	NA	NA	NA	9.2E-5 ±180	9.2E-5
Th-228	NA	NA	NA	NA	-1.9E-4 ±240	(d)
Th-230	NA	NA	NA	NA	1.6E-3 ± 21	1.6E-3
Th-232	NA	NA	NA	NA	2.8E-4 ± 47	2.8E-4
Pb-210	3.1E-3 ± 93	2.0E-3 ±100	4.1E-3 ± 55	2.4E-3 ± 92	1.7E-2 ± 29	2.9E-2
Po-210	1.3E-3 ± 23	7.0E-4 ± 29	4.5E-4 ± 38	5.1E-4 ± 34	6.5E-3 ± 15	9.5E-3

(a) Radioactivity in blank filters has not been subtracted.
(b) Sampled volume of 783 m^3 collected from 2/3/86 1223 to 2/4/86 1124.
(c) Two sigma counting error in percent.
(d) Negative values not included in activity summation.
NA-No analysis.

Table B.24 Gross radioactivity results[a] in Andersen air samples - southwest corner of Gardinier stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm[e]	Activity summation for all particle size ranges
Ra-226	9.9E-4 ± 6[c]	5.2E-4 ± 11	3.7E-4 ± 13	3.3E-4 ± 16	7.7E-5 ± 52	2.3E-3
U-234	1.2E-3 ± 19	5.8E-4 ± 26	2.2E-4 ± 45	1.4E-4 ± 53	1.6E-3 ± 18	3.7E-3
U-235	4.1E-5 ± 88	3.1E-5 ±100	1.6E-6 ±500	2.2E-5 ±120	8.8E-5 ± 64	1.8E-4
U-238	1.2E-3 ± 19	4.1E-4 ± 31	2.2E-4 ± 44	8.8E-5 ± 67	1.2E-3 ± 19	3.1E-3
Th-227	1.6E-5 ±200	0.0E+0	2.7E-5 ±140	0.0E+0	0.0E+0	4.3E-5
Th-228	-9.1E-5 ±170	7.8E-5 ±190	-2.4E-5 ±580	-3.9E-5 ±360	-1.0E-4 ±160	7.8E-5[d]
Th-230	1.2E-3 ± 21	4.7E-4 ± 28	3.1E-4 ± 33	1.7E-4 ± 48	2.0E-4 ± 44	2.4E-3
Th-232	-2.3E-5 ±180	2.8E-5 ±100	1.3E-5 ±140	7.7E-6 ±350	7.7E-5 ± 68	1.3E-4[d]
Pb-210	1.6E-3 ±160	8.1E-4 ±240	8.8E-4 ±190	8.7E-4 ±380	1.4E-2 ± 27	1.8E-2
Po-210	8.9E-4 ± 23	5.2E-4 ± 30	6.3E-4 ± 27	3.6E-4 ± 41	7.4E-3 ± 11	9.8E-3

[a] Radioactivity in blank filters has not been subtracted.
[b] Sampled volume of 828 m^3 collected from 9/9/85 1110 to 9/10/85 1126.
[c] Two sigma counting error in percent.
[d] Negative values not included in activity summation.
[e] Some radioactivity may have been lost during sample preparation.

Table B.25 Gross radioactivity results[a] in Andersen air samples - southwest corner of Gardinier stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	7.3E-4 ± 9[c]	3.9E-4 ± 14	3.9E-4 ± 13	2.6E-4 ± 19	2.0E-3 ± 7	3.8E-3
U-234	7.0E-4 ± 26	6.3E-4 ± 69	2.6E-4 ± 50	1.6E-4 ± 67	1.3E-3 ± 25	3.1E-3
U-235	4.9E-5 ±100	8.2E-5 ± 280	1.8E-5 ±240	0.0E+0	3.0E-5 ±160	1.8E-4
U-238	3.6E-4 ± 37	8.5E-4 ± 51	1.5E-4 ± 65	9.6E-5 ±100	1.3E-3 ± 25	2.8E-3
Th-227	NA	NA	NA	NA	6.2E-5 ±200	6.2E-5
Th-228	NA	NA	NA	NA	-3.6E-4 ±110	(d)
Th-230	NA	NA	NA	NA	1.3E-3 ± 23	1.3E-3
Th-232	NA	NA	NA	NA	2.7E-4 ± 48	2.7E-4
Pb-210	1.9E-3 ±120	1.6E-4 ±1000	4.2E-3 ± 46	3.9E-3 ± 45	2.0E-2 ± 30	3.0E-2
Po-210	9.7E-4 ± 24	2.6E-4 ± 44	2.8E-4 ± 42	4.0E-4 ± 36	6.9E-3 ± 15	8.8E-3

(a) Radioactivity in blank filters has not been subtracted.
(b) Sampled volume of 820 m^3 collected from 2/3/86 1201 to 2/4/86 1147.
(c) Two sigma counting error in percent.
(d) Negative values not included in activity summation.
NA-No analysis.

Table B.26 Net radioactivity results[a] in Andersen air samples - northeast corner of Gardinier stack[b] (Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	3.7E-4	1.6E-4	7.3E-5	7.3E-5	0.0E+0	6.8E-4
U-234	2.8E-4	7.0E-5	8.0E-5	0.0E+0	0.0E+0	4.3E-4
U-235	1.3E-5	2.7E-5	6.4E-6	3.6E-6	0.0E+0	5.0E-5
U-238	2.9E-4	2.0E-4	4.3E-5	9.7E-6	0.0E+0	5.4E-4
Th-227	0.0E+0	3.5E-5	0.0E+0	0.0E+0	0.0E+0	3.5E-5
Th-228	3.5E-5	2.3E-5	0.0E+0	0.0E+0	9.3E-5	1.5E-4
Th-230	3.1E-4	1.1E-4	1.1E-5	0.0E+0	0.0E+0	4.3E-4
Th-232	5.9E-6	1.7E-5	0.0E+0	0.0E+0	0.0E+0	2.3E-5
Pb-210	0.0E+0	0.0E+0	1.2E-3	0.0E+0	1.7E-2	1.8E-2
Po-210	3.3E-4	3.2E-4	1.2E-4	2.5E-4	5.5E-3	6.5E-3

[a] Radioactivity in blank filters has been subtracted.
[b] Sampled volume of 828 m^3 collected from 9/9/85 1055 to 9/10/85 1114.

Table B.27 Net radioactivity results[a] in Andersen air samples - northeast corner of Gardinier stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	2.0E-3	8.1E-4	5.2E-4	2.9E-4	0.0E+0	3.6E-3
U-234	5.0E-4	1.4E-4	1.4E-4	2.1E-4	3.7E-4	1.4E-3
U-235	7.6E-5	4.4E-5	1.6E-5	9.7E-5	5.6E-5	2.9E-4
U-238	5.1E-4	1.1E-4	1.1E-4	2.0E-4	0.0E+0	9.3E-4
Th-227	NA	NA	NA	NA	0.0E+0	0.0E+0
Th-228	NA	NA	NA	NA	0.0E+0	0.0E+0
Th-230	NA	NA	NA	NA	2.3E-4	2.3E-4
Th-232	NA	NA	NA	NA	0.0E+0	0.0E+0
Pb-210	1.8E-3	0.0E+0	2.8E-3	0.0E+0	1.4E-2	1.9E-2
Po-210	1.3E-3	5.9E-4	3.7E-4	4.1E-4	5.2E-3	7.9E-3

[a] Radioactivity in blank filters has been subtracted.
[b] Sampled volume of 783 m^3 collected from 2/3/86 1223 to 2/4/86 1124.
NA-No analysis.

Table B.28 Net radioactivity results[a] in Andersen air samples - southwest corner of Gardinier stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm[c]	Activity summation for all particle size ranges
Ra-226	8.3E-4	4.0E-4	2.2E-4	2.1E-4	0.0E+0	1.7E-3
U-234	1.2E-3	4.7E-4	1.5E-4	2.1E-5	3.6E-4	2.2E-3
U-235	2.1E-5	3.1E-5	0.0E+0	2.2E-5	4.7E-5	1.2E-4
U-238	1.2E-3	3.9E-4	1.7E-4	7.4E-5	0.0E+0	1.8E-3
Th-227	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
Th-228	0.0E+0	7.8E-5	0.0E+0	0.0E+0	0.0E+0	7.8E-5
Th-230	1.2E-3	4.2E-4	2.8E-4	1.2E-4	0.0E+0	2.0E-3
Th-232	0.0E+0	2.8E-5	5.2E-6	7.7E-6	0.0E+0	4.1E-5
Pb-210	3.4E-4	0.0E+0	0.0E+0	0.0E+0	1.1E-2	1.1E-2
Po-210	8.1E-4	4.0E-4	5.5E-4	2.5E-4	6.1E-3	8.1E-3

(a) Radioactivity in blank filters has been subtracted.
(b) Sampled volume of 828 m^3 collected from 9/9/85 1110 to 9/10/85 1126.
(c) Some radioactivity may have been lost during sample preparation.

Table B.29 Net radioactivity results[a] in Andersen air samples - southwest corner of Gardinier stack[b]
(Concentrations in pCi/m^3)

Radionuclide	- Particle Size Ranges - > 7 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	< 1.1 μm	Activity summation for all particle size ranges
Ra-226	5.7E-4	2.7E-4	2.3E-4	1.5E-4	4.6E-4	1.7E-3
U-234	6.2E-4	5.2E-4	1.8E-4	4.8E-5	1.6E-4	1.5E-3
U-235	2.8E-5	8.2E-5	0.0E+0	0.0E+0	0.0E+0	1.1E-4
U-238	3.1E-4	8.5E-4	9.4E-5	8.2E-5	0.0E+0	1.3E-3
Th-227	NA	NA	NA	NA	0.0E+0	0.0E+0
Th-228	NA	NA	NA	NA	0.0E+0	0.0E+0
Th-230	NA	NA	NA	NA	6.1E-5	6.1E-5
Th-232	NA	NA	NA	NA	9.2E-6	9.2E-6
Pb-210	6.6E-4	0.0E+0	3.0E-3	1.5E-3	1.7E-2	2.2E-2
Po-210	9.0E-4	1.6E-4	2.1E-4	3.0E-4	5.6E-3	7.2E-3

[a] Radioactivity in blank filters has been subtracted.
[b] Sampled volume of 820 m^3 collected from 2/3/86 1201 to 2/4/86 1147.
NA-No analysis.

APPENDIX C

Radionuclide concentrations in background soil samples

Table C.1 Radioactivity in background soil samples

Location[a]	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232	Po-210	Pb-210
	-------- Concentration, pCi/g dry weight --------										
PB01	0.31	-0.20	0.056	0.0077	0.042	0.0092	0.021	0.066	0.044	0.35	0.49
PB02	0.35	0.060	0.14	0.013	0.088	0.0	0.069	0.069	0.046	0.57	0.90
PB03	0.32	-0.060	0.13	0.0026	0.12	-0.0083	0.015	0.060	0.077	0.52	0.35
PB04	0.50	0.90	0.30	0.031	0.27	0.016	0.15	0.19	0.16	0.39	0.40
PB05	0.76	0.10	0.48	0.022	0.47	0.016	0.034	0.32	0.081	0.60	1.2
GB01	0.36	0.30	0.19	0.0040	0.092	0.029	0.075	0.25	0.073	0.35	0.96
GB03	0.75	0.90	0.62	0.060	0.56	0.015	0.052	0.48	0.046	0.70	0.87
GB04	0.49	-0.60	0.48	0.012	0.46	0.037	0.16	0.30	0.17	0.50	0.62
GB05	0.29	0.80	0.17	0.0048	0.19	0.14	1.4	0.98	0.33	0.35	0.84
Average	0.46	0.25	0.29	0.018	0.25	0.028	0.22	0.30	0.11	0.48	0.74

[a]PB-Polk County, Florida and GB-Hillsborough County, Florida.

APPENDIX D

Outdoor radon concentrations

Table D.1 Outdoor radon concentrations in air

Site/Location	Concentrations, pCi/l		
	First Period	Second Period	Third Period
Conserv/C01	0.0,0.44,0.44	3 lost	1.65,1.92,0.76
Conserv/C02	0.70,0.65,0.65	0.65,0.67,0.72	1.36,2.64*,2.11
Conserv/C03	0.49, 2 lost	0.61,0.62,0.68	3 lost
Conserv/C04	0.20*,0.15*,0.20*	0.32,0.43,0.30	0.50*, 2 lost
Estech/E01	0.31,0.40,0.35	0.54,0.57,0.50	0.53*,1.70*,1.45*
Estech/E02	0.59,0.37,0.53	0.46,0.48,0.67	1.30,1.30*,0.50*
Estech/E03	0.38*,0.34*,0.42*	0.67,1.03,0.56	0.86,0.95, 1 lost
Estech/E04	0.73,0.40,0.44	0.84,0.95,1.22	1.48*,0.98*, 1 lost
Estech/E05	1.31,0.73,0.59	0.67,0.81,0.81	1.79*,0.81,1.54
Gardinier/G01	0.42,0.03,0.43	0.34,0.35,0.21	0.31,0.32,0.36
Gardinier/G02	0.67,0.38,0.41	0.36,0.31,0.35	0.41,0.38,0.80
Gardinier/G03	1.43, 2 lost	0.31,0.23,0.29	0.53,0.42,0.44
Gardinier/G04	0.44,0.39, 1 lost	0.40,0.36,0.41	0.92,0.53,0.53
Gardinier/G05	0.79,0.46,0.61	0.44,0.50,0.47	0.59,0.56,0.66
Gardinier/G06	1.76,0.80, 1 lost	0.60,0.43,0.62	0.59,0.65,0.58
Gardinier/G07	3 lost	0.38,0.30,0.36	3 lost
Gardinier/G08	3 lost	0.13,0.24,0.16	0.17,0.27,0.28
Gardinier/G09	0.21, 2 lost	0.26,0.17,0.26	0.33,0.34,0.19
Gardinier/G10	3 lost	0.27,0.24,0.25	0.28,0.25,0.25
Gardinier/G11	0.27,0.11, 1 lost	0.15,0.25,0.22	0.23,0.29,0.20
Gardinier/G12	3 lost	0.18,0.19,0.16	0.22,0.24,0.30
Grace/GR01	1.08*,0.03*,0.06	0.85,0.50,0.65	3 lost
Grace/GR02	5.58,4.28,3.28	11.60*,9.43*,10.71*	2.82,2.81,2.35
Grace/GR03	0.45,0.66,2.46*	0.39,0.45,0.47	0.38,0.41*,0.60
Grace/GR04	0.74,1.03,0.68	0.46,0.47,0.77	0.64,0.89,0.70
Grace/GR05	0.46,0.48, 1 lost	1.11,0.46,0.55	1.04,0.63,0.95
Grace/GR06	0.45,0.38,0.60	0.50,0.32,0.44	0.68**,0.68**,0.56**
Grace/GR07	0.48,0.49,0.54	0.64,0.49,0.38	0.81,0.80,0.61
Grace/GR08	3.29*,0.37*,0.44*	0.39,0.26,0.21	3 lost
Grace/GR09	0.66,0.57,0.52	0.41,0.52,0.37	0.77,0.72,0.53
Grace/GR10	1.04,0.76,0.59	0.59,0.63,0.55	0.65,0.88,1.00
Grace/GR11	1.97,1.86,1.44	0.99,1.06,1.18	1.85,2.20,2.20
Grace/GR12	1.03,0.86,0.79	1.06*,0.85*,0.81*	0.92,0.96,1.07
Grace/GR13	0.41,0.51,0.30	0.38,0.30,0.34	0.46**,0.59***,0.49**
Royster/R01	0.44,0.43,0.44	0.55,0.43,0.49	1.65**,1.92**,0.76**
Royster/R02	0.29,0.29,0.30*	0.40,0.32,0.50	1.36,2.64*,2.11
Royster/R03	0.22,0.27,0.21	0.33,0.39,0.33	3 lost
Royster/R04	0.27*,0.26*,0.28*	0.48,0.53,0.37	0.50*, 2 lost

Table D.1 Outdoor radon concentrations in air - Continued

Site/Location	Concentrations, pCi/l		
	First Period	Second Period	Third Period
Background/PB01	0.11,0.07,0.12	0.18,0.16,0.17	0.21,0.19,0.18
Background/PB02	0.12,0.14,0.11	0.13,0.22,0.12	0.25,0.18,0.25
Background/PB03	0.11,0.09,0.09	0.20,0.11,0.16	0.30,0.26,0.17
Background/PB04	0.14,0.12,0.20	0.12,0.20,0.30	0.27,0.21,0.22
Background/PB05	0.10,0.24*,0.24	0.17,0.16,0.24	1.44,0.14,0.43
Background/GB01	3 lost	0.20,0.97,0.71	0.86,0.41,0.40
Background/GB02	3 lost	moved site	moved site
Background/GB03	0.12,0.12,0.09	0.29,0.29,0.24	1.72,0.61,0.73
Background/GB04	0.09,0.17,0.09	0.13,0.19,0.17	0.34,0.28,0.27
Background/GB05	no detectors	0.20,0.19,0.22	1.82,0.63,0.28

*Questionable result due to damaged filter.
**Detectors not sealed properly from supplier.

Table D.2 Calibration of alpha track detectors (first period)

Exposure Level, pCi/l day*	Measured Exposure, pCi/l day	Actual Exposure / Average Measured Exposure
54	55	
54	47	
54	36	1.18
54	49	
54	41	
106	78	
106	95	
106	95	1.19
106	90	
106	89	
541	466	
541	437	
541	436	1.28
541	402	
541	373	
953	776	
953	718	
953	693	1.36
953	686	
953	621	
	First Period Average	1.25

*Four sets of five detectors each exposed in EERF radon calibration chamber during the first measurement period and sent to supplier for readout at the end of the first period.

Table D.3 Calibration of alpha track detectors (second and third periods)

Exposure Period	Exposure Level, pCi/l day*	Measured Exposure, pCi/l day	Actual Exposure / Average Measured Exposure
Second	476	426	1.02
	476	425	
	476	632	
	476	454	
	476	403	
Third	52	72	0.65
	52	44	
	52	160	
	52	46	
	52	77	
Third	99	119	0.64
	99	101	
	99	168	
	99	218	
	99	166	
Third	518	828	0.64
	518	686	
	518	537	
	518	976	
	518	1010	
Third	1060	1470	0.74
	1060	1400	
	1060	1530	
	1060	1550	
	1060	1230	
		Third Period Average	0.67

*Detectors exposed in EERF radon calibration chamber during indicated exposure period and sent to supplier for readout at the end of the respective period.

APPENDIX E

Quality assurance results

E.1 Radon Flux Canisters

During the period of the study, 15 radon flux canisters were spiked with known quantities of Ra-226 and sent to the Polk County Health Department for measurement using the standard procedures. Included with each set of canisters was at least one unexposed (blank) canister. The results are presented in Table E.1.

All blank canisters were correctly identified and reported as containing less than 0.16 nCi (3σ) of radioactivity. This indicates that the charcoal canisters and associated counting equipment were uncontaminated and that all background activity was correctly deleted from the radon flux results.

The errors in measuring the radioactivity in the spiked canisters ranged from less than one percent to about 9 percent, and was not related to the amount of radioactivity present. These errors exceed the 2σ counting uncertainties which ranged from about 3 percent for the low activity canisters to 0.6 percent for the high activity canisters. Also, it is important to note that all measured activities were less than the known quantities added, suggesting a slight negative bias in the measurement procedure.

For every 10 radon flux canisters counted, one was selected from the group for a recount. Generally, the canister selected for a recount was one that contained either an unusually high or low count on the first

measurement. The recount was usually performed within two hours of the first count. These results are presented in Table E.2. Forty-four (38 percent) of the 117 duplicate counts differed by more than the 2σ counting error. Twenty percent of the duplicate counts differed by more than the 3σ counting error, while 10 percent differed by more than twice the

Table E.1 The results for spiked and blank radon flux canisters

Spiked Sample or Blank	Date Counted	Calculated Activity*, nCi	Known Activity, nCi	Percent Difference
THRA08	09/18/85	< 0.16	blank	-
THRA12	09/18/85	108	112	- 3.6
THRA13	09/18/85	106	112	- 5.4
THRA01	10/16/85	11.2	11.3	- 0.88
THRA03	10/16/85	54.9	56.6	- 3.0
THRA07	10/16/85	< 0.16	blank	-
THRA02	12/04/85	26.8	28.3	- 5.3
THRA04	12/04/85	80.6	84.5	- 4.6
THRA05	12/04/85	161	169	- 4.7
THRA06	12/04/85	10.7	11.3	- 5.3
THRA08	12/04/85	< 0.16	blank	-
THRA09	12/04/85	< 0.16	blank	-
THRA02	03/26/86	25.7	28.3	- 9.2
THRA04	03/26/86	80.0	84.5	- 5.3
THRA05	03/26/86	164	169	- 3.0
THRA06	03/26/86	10.8	11.3	- 4.4
THRA08	03/26/86	< 0.16	blank	-
THRA09	03/26/86	< 0.16	blank	-
THRA01	06/11/86	11.1	11.3	- 1.8
THRA03	06/11/86	54.6	56.6	- 3.5
THRA04	06/11/86	81.1	84.5	- 4.0
THRA07	06/11/86	< 0.16	blank	-
THRA08	06/11/86	< 0.16	blank	-
THRA09	06/11/86	< 0.16	blank	-

*Calculated activity based on Polk County Health Department counting results.

Table E.2 Duplicate counting results for radon flux canisters

Site/Sampling Location	Date on	Date off	Radon Flux, $pCi/m^2\text{-}s$[a]	Radon Flux, $pCi/m^2\text{-}s$[b]	Percent Error[c]	Percent Difference
Conserv/C01	10/21/85	10/22/85	11.060	11.036	1.10	0.22
Conserv/C02	09/30/85	10/01/85	26.775	26.873	0.69	-0.36
Conserv/C02	11/18/85	11/19/85	17.449	17.529	0.93	-0.46
Conserv/C02	01/13/86	01/14/86	61.167	60.281	0.42	1.5
Conserv/C02	02/24/86	02/25/86	15.720	15.732	0.91	-0.08
Conserv/C04	12/16/85	12/17/85	18.711	18.890	0.89	-0.95
Conserv/C04	05/12/86	05/13/86	14.500	14.614	0.93	-0.78
Conserv/C04	07/07/86	07/08/86	17.900	18.036	0.86	-0.75
Conserv/C06	08/19/85	08/20/85	207.148	204.124	0.25	1.5
Conserv/C07	06/09/86	06/10/86	26.895	27.200	0.70	-1.1
Estech/E02	09/09/85	09/10/85	3.299	3.356	2.12	-1.7
Estech/E02	12/02/85	12/03/85	5.895	5.917	1.65	-0.37
Estech/E04	10/07/85	10/08/85	5.182	5.229	1.69	-0.90
Estech/E04	10/28/85	10/29/85	4.098	4.181	1.83	-0.47
Estech/E04	06/16/86	06/17/86	9.428	9.560	1.21	-1.4
Estech/E05	12/23/85	12/24/85	7.625	7.785	1.63	-2.1
Estech/E05	04/21/86	04/22/86	8.697	8.718	1.25	-0.24
Estech/E06	03/24/86	03/25/86	3.857	3.843	2.01	0.36
Estech/E09	02/17/86	02/18/86	14.051	13.881	0.98	1.2
Estech/E09	07/14/86	07/15/86	7.588	7.541	1.35	0.62
Estech/E10	01/27/86	01/28/86	4.399	4.456	1.79	-1.3
Estech/E10	05/19/86	05/20/86	7.459	7.424	1.43	0.47
Gardinier/G01	10/21/85	10/22/85	20.899	20.361	0.80	2.6
Gardinier/G01	11/04/85	11/05/85	37.760	37.893	0.59	-0.35
Gardinier/G01	12/23/85	12/24/85	23.121	23.042	0.87	0.34
Gardinier/G01	03/31/86	04/01/86	17.421	17.512	0.87	-0.52

Table E.2 Duplicate counting results for radon flux canisters - Continued

Site/Sampling Location	Date on	Date off	Radon Flux, $pCi/m^2\text{-}s$ [a]	Radon Flux, $pCi/m^2\text{-}s$ [b]	Percent Error [c]	Percent Difference
Gardinier/G02	11/18/85	11/19/85	6.651	6.667	1.51	-0.24
Gardinier/G02	03/04/86	03/05/86	11.743	11.779	1.07	-0.31
Gardinier/G02	05/27/86	05/28/86	15.668	16.060	0.91	-2.4
Gardinier/G03	09/09/85	09/10/85	7.225	7.368	1.37	-1.9
Gardinier/G03	10/14/85	10/15/85	12.513	12.739	1.03	-1.8
Gardinier/G03	11/25/85	11/26/85	18.011	18.104	0.90	-0.51
Gardinier/G03	01/06/86	01/07/86	28.684	28.229	0.72	1.6
Gardinier/G03	01/13/86	01/14/86	44.950	44.667	0.54	0.63
Gardinier/G03	04/28/86	04/29/86	36.346	36.138	0.59	0.58
Gardinier/G04	09/03/85	09/04/85	9.607	9.530	1.19	0.81
Gardinier/G04	09/16/85	09/17/85	4.948	4.853	1.74	2.0
Gardinier/G04	09/30/85	10/01/85	15.993	16.135	0.91	-0.88
Gardinier/G04	11/12/85	11/13/85	14.526	14.617	1.01	-0.62
Gardinier/G04	12/02/85	12/03/85	22.575	22.555	0.81	0.09
Gardinier/G04	12/09/85	12/10/85	19.560	19.545	0.86	0.08
Gardinier/G04	12/16/85	12/17/85	30.360	30.023	0.69	1.1
Gardinier/G04	12/30/85	12/31/85	28.544	28.216	0.80	1.2
Gardinier/G04	01/27/86	01/28/86	20.510	20.695	0.79	-0.89
Gardinier/G04	02/03/86	02/04/86	23.352	23.374	0.74	-0.09
Gardinier/G05	08/05/85	08/06/85	33.863	34.109	0.62	-0.72
Gardinier/G05	08/12/85	08/13/85	12.109	12.078	1.07	0.26
Gardinier/G05	08/19/85	08/20/85	10.967	10.787	1.12	1.7
Gardinier/G05	01/20/86	01/21/86	12.706	12.632	1.02	0.59
Gardinier/G06	09/23/85	09/24/85	47.753	47.324	0.52	0.91
Gardinier/G06	10/28/85	10/29/85	48.407	48.386	0.51	0.04

Table E.2 Duplicate counting results for radon flux canisters - Continued

Site/Sampling Location	Date on	Date off	Radon Flux, $pCi/m^2\text{-}s$[a]	Radon Flux, $pCi/m^2\text{-}s$[b]	Percent Error[c]	Percent Difference
Gardinier/G06	06/23/86	06/24/86	36.223	35.973	0.60	0.69
Gardinier/G08	10/07/85	10/08/85	7.282	7.306	1.41	-0.33
Gardinier/G10	08/26/85	08/27/85	27.468	27.004	0.68	1.7
Grace/GR01	10/21/85	10/22/85	30.044	28.790	0.65	4.4
Grace/GR01	11/18/85	11/19/85	61.102	61.815	0.48	-1.2
Grace/GR01	04/07/86	04/08/86	16.778	17.025	0.91	-1.5
Grace/GR01	04/28/86	04/29/86	14.033	14.061	0.92	-0.20
Grace/GR02	11/25/85	11/26/85	9.925	9.795	1.23	1.3
Grace/GR02	12/16/85	12/17/85	9.920	10.006	1.24	-0.86
Grace/GR03	11/12/85	11/13/85	7.270	7.316	1.45	-0.63
Grace/GR04	03/10/86	03/11/86	30.229	30.126	0.66	0.34
Grace/GR04	04/14/86	04/15/86	12.695	12.750	1.02	-0.43
Grace/GR04T	06/02/86	06/03/86	1.473	1.501	3.77	-1.9
Grace/GR05	12/09/85	12/10/85	23.771	23.927	0.78	-0.65
Grace/GR05	01/20/86	01/21/86	24.022	24.104	0.73	-0.34
Grace/GR05	03/04/86	03/05/86	25.199	25.202	0.72	-0.01
Grace/GR05	03/17/86	03/18/86	25.617	25.539	0.70	0.31
Grace/GR05	03/31/86	04/01/86	20.474	20.583	0.80	-0.53
Grace/GR05	06/02/86	06/03/86	18.027	18.246	0.88	-1.2
Grace/GR05	06/16/86	06/17/86	19.551	19.417	0.82	0.69
Grace/GR05	07/07/86	07/08/86	14.864	15.061	0.95	-1.3
Grace/GR05	07/14/86	07/15/86	11.794	11.911	1.06	-0.98
Grace/GR06	08/12/85	08/13/85	0.505	0.531	7.93	-4.9
Grace/GR06	08/26/85	08/27/85	4.019	4.089	1.93	-1.7

Table E.2 Duplicate counting results for radon flux canisters - Continued

Site/Sampling Location	Date on	Date off	Radon Flux, $pCi/m^2\text{-}s$[a]	Radon Flux, $pCi/m^2\text{-}s$[b]	Percent Error[c]	Percent Difference
Grace/GR06	12/02/85	12/03/85	5.097	5.018	1.81	1.6
Grace/GR06	01/27/86	01/28/86	2.062	2.105	2.79	-2.0
Grace/GR06	02/24/86	02/25/86	2.223	2.127	2.75	4.5
Grace/GR07	08/05/85	08/06/85	13.537	13.463	1.02	0.55
Grace/GR07	08/19/85	08/20/85	13.567	13.668	1.01	-0.74
Grace/GR07	09/03/85	09/04/85	2.885	2.847	2.26	1.3
Grace/GR07	09/16/85	09/17/85	10.110	10.145	1.15	-0.34
Grace/GR07	12/23/85	12/24/85	47.285	46.713	0.62	1.2
Grace/GR07	12/30/85	12/31/85	30.574	30.413	0.78	0.53
Grace/GR07	01/06/86	01/07/86	30.011	29.829	0.72	0.61
Grace/GR07	01/13/86	01/14/86	40.967	40.343	0.55	1.6
Grace/GR07	02/03/86	02/04/86	21.825	21.676	0.77	0.69
Grace/GR07	02/10/86	02/11/86	210.174	209.457	0.25	0.34
Grace/GR07	02/17/86	02/18/86	38.863	38.006	0.58	2.3
Grace/GR07	04/21/86	04/22/86	16.716	16.342	0.89	2.3
Grace/GR07	05/05/86	05/06/86	21.588	21.598	0.77	-0.05
Grace/GR07	05/12/86	05/13/86	21.569	21.453	0.75	0.54
Grace/GR07	06/09/86	06/10/86	27.535	27.320	0.69	0.79
Grace/GR07	06/30/86	07/01/86	32.546	32.297	0.63	0.77
Grace/GR07T	07/14/86	07/15/86	1.217	1.268	4.17	-4.0
Grace/GR08	09/23/85	09/24/85	11.072	11.156	1.10	-0.75
Grace/GR08	10/14/85	10/15/85	9.811	10.018	1.18	-2.1
Grace/GR09	09/09/85	09/10/85	4.116	4.117	1.86	-0.02
Grace/GR09	09/30/85	10/01/85	16.541	16.721	0.89	-1.1

Table E.2 Duplicate counting results for radon flux canisters - Continued

Site/Sampling Location	Date on	Date off	Radon Flux, pCi/m^2-s[a]	Radon Flux, pCi/m^2-s[b]	Percent Error[c]	Percent Difference
Grace/GR09	03/24/86	03/25/86	7.226	7.414	1.40	-2.5
Grace/GR09	06/23/86	06/24/86	64.793	65.140	0.45	-0.53
Grace/GR10	10/07/85	10/08/85	25.293	25.293	0.72	0.0
Grace/GR10	10/28/85	10/29/85	20.578	20.840	0.76	-1.3
Grace/GR10	11/04/85	11/05/85	53.515	53.718	0.50	-0.38
Grace/GR10	05/19/86	05/20/86	29.215	29.264	0.68	-0.17
Royster/R01	09/03/85	09/04/85	33.756	33.894	0.60	-0.41
Royster/R02	01/06/86	01/07/86	80.687	80.194	0.43	0.61
Royster/R03	10/14/85	10/15/85	13.540	13.592	0.99	-0.38
Royster/R03	02/10/86	02/11/86	21.866	21.235	0.77	3.0
Royster/R04	11/12/85	11/13/85	24.951	24.785	0.76	0.67
Royster/R04	12/09/85	12/10/85	29.681	29.689	0.70	-0.03
Royster/R04	03/10/86	03/11/86	26.904	26.943	0.69	-0.14
Royster/R06	06/30/86	07/01/86	28.348	28.271	0.68	0.27
Royster/R09	05/05/86	05/06/86	17.413	17.350	0.87	0.36
Royster/R09	06/02/86	06/03/86	16.713	16.857	0.91	-0.85
Royster/R10	09/23/85	09/24/85	18.788	18.676	0.83	0.60
Royster/R10	04/07/86	04/08/86	15.485	15.106	0.94	2.5

[a] First counting.
[b] Second counting.
[c] The percent error in the measurement based on 2σ counting statistics.
Note: The number of figures reported for radon flux is for comparison purposes only. The number of significant figures is three or less.

reported 2σ counting error. A comparison of the first count to the second count yields 53 positive deviations averaging a difference of 1.08 percent and 64 negative deviations averaging a difference of -0.95 percent. The algebraic sum of the percent differences for the 117 duplicate counts was -3.2 percent, or an average of about -0.03 percent per duplicate count.

E.2 Radionuclide Content of Phosphogypsum and Soil Samples

A duplicate Ra-226 analysis was performed on one phosphogypsum sample from each of the five stacks. The results of the duplicate analyses are given in Table E.3. Two one-gram aliquots were obtained from the sample listed in the first column of the table and analyzed for Ra-226. The differences in the results of the two analyses are listed in the last column. The differences between the two analyses are very large considering the small 2σ counting error (1 percent) and the proven accuracy of the emanation method for measuring Ra-226. The differences in these analyses are as great as those measured in samples collected at different locations on a stack. These results strongly indicate that these samples of phosphogypsum were not homogeneous.

A background soil sample, collected on December 4, 1985 from Polk County Florida, was analyzed in duplicate for its natural radionuclide content. The results of the duplicate analysis are presented in Table E.4. In the 4th column are listed the analytical (2σ) uncertainties in the analyses and in the 5th column are given the percent differences

Table E.3 Quality assurance results for Ra-226 in phosphogypsum

Site/Location	Date of Collection	Ra-226, pCi/g[a]	Ra-226, pCi/g[b]	Percent Difference
Conserv/C06	07/25/85	81.1	95.5	18
Estech/E03	07/26/85	25.1	24.4	3
Gardinier/G04	07/23/85	33.9	29.6	13
Grace/GR06	07/25/85	28.9	31.6	9
Royster/R04	07/26/85	33.4	24.8	26

[a]First analysis-The 2σ counting error is 1 percent.
[b]Second analysis-The 2σ counting error is 1 percent.

Table E.4 Quality assurance results for radioactivity in background soil[a]

Radionuclide	Concentration, pCi/g dry weight [b]	Concentration, pCi/g dry weight [c]	Analytical Error, Percent	Percent Difference
Ra-226	0.50	0.54	7	8
Ra-228	0.90	0.70	140	22
U-234	0.30	0.33	21	10
U-235	0.031	0.015	63	52
U-238	0.27	0.21	22	22
Th-227	0.016	0.025	100	56
Th-228	0.15	0.18	36	20
Th-230	0.19	NA[d]	23	-
Th-232	0.16	0.12	25	25
Po-210	0.39	0.46	20	18
Pb-210	0.40	0.93	220	133

[a]Sample-PB04 collected in Polk County, Florida.
[b]First analysis.
[c]Second analysis.
[d]Not analyzed.

between the two analyses. The percent differences between the two analyses were all equal to or less than the 2σ uncertainty of the analyses. These results indicate that the soil sample was homogeneous, as expected for a background sample, and that the analytical methods employed yielded accurate results.

E.3 Moisture Content of Phosphogypsum

Phosphogypsum samples collected for soil moisture determination were periodically split into duplicate samples. The duplicate samples were handled and analyzed in exactly the same manner (see Section 3.2.3). The results of the analyses on the duplicate samples are presented in Table E.5.

The percent difference in the two determinations ranged from 0 percent to 32 percent, with an average difference of 3 percent. The differences observed are probably due to a combination of measurement error, an actual difference in the moisture content of the two samples, and to different exposure times to the air, although effort was made to keep the latter to a minimum. About 34 percent of the duplicate analyses differed by 1 percent or less, while only 18 percent differed by more than 5 percent. The errors appear to be similar for samples measured in 1985 and in 1986. The magnitude of the difference in the results of the duplicate analyses may be somewhat dependent on the moisture content. The duplicate analyses for samples containing more than 10 percent moisture

Table E.5 Quality assurance results for moisture content measurements

Site/Sampling Location	Date	Moisture, Percent[a]	Moisture, Percent[b]	Percent Difference
Conserv/C10	08/20/85	5.6	5.5	1.8
Conserv/C03	10/01/85	11.9	12.0	-0.8
Conserv/C05	10/22/85	6.3	6.4	-1.6
Conserv/C04	11/20/85	10.0	10.1	-1.0
Conserv/C04	12/17/85	9.1	9.3	-2.2
Conserv/C01	01/14/86	7.4	7.5	-1.3
Conserv/C02	02/25/86	6.4	6.5	-1.5
Conserv/C04	03/18/86	13.6	14.2	-4.2
Conserv/C10	04/15/86	11.8	12.3	-4.1
Conserv/C10	05/13/86	10.4	9.8	6.1
Conserv/C02	06/10/86	13.0	12.5	4.0
Conserv/C03	07/08/86	6.1	6.2	-1.6
Estech/E06	09/10/85	14.8	14.9	-0.7
Estech/E04	10/08/85	13.6	14.1	-3.5
Estech/E03	10/29/85	18.2	20.7	-12.1
Estech/E07	12/03/85	11.9	11.7	1.7
Estech/E06	12/24/85	9.6	9.9	-3.0
Estech/E07	01/28/86	9.1	9.0	1.1
Estech/E09	02/18/86	14.0	13.9	0.7
Estech/E06	03/25/86	7.4	7.4	0
Estech/E01	04/22/86	8.4	8.4	0
Estech/E04	05/20/86	5.2	5.4	-3.7
Estech/E06	06/17/86	16.6	16.5	0.6
Estech/E06	07/15/86	7.5	7.7	-2.6
Gardinier/G10	08/06/85	15.6	15.5	0.6
Gardinier/G10	08/13/85	13.9	14.2	-2.1
Gardinier/G10	08/20/85	12.1	12.1	0
Gardinier/G05	08/27/85	12.0	11.8	1.7
Gardinier/G10	09/04/85	15.8	15.9	-0.6
Gardinier/G06	09/10/85	11.9	12.2	-2.4
Gardinier/G08	09/17/85	11.7	11.5	1.7
Gardinier/G03	09/24/85	9.8	9.5	3.2
Gardinier/G06	10/01/85	11.0	11.7	-6.0
Gardinier/G07	10/08/85	10.1	10.2	-1.0
Gardinier/G10	10/15/85	10.8	10.5	2.8
Gardinier/G10	10/22/85	8.8	8.8	0
Gardinier/G03	10/29/85	7.8	7.9	-1.3
Gardinier/G02	11/05/85	14.9	14.7	1.4
Gardinier/G05	11/14/85	11.9	11.9	0
Gardinier/G09	11/20/85	12.8	13.1	-2.3
Gardinier/G06	11/26/85	9.8	9.9	-1.0

Table E.5 Quality assurance results for moisture content measurements - Continued

Site/Sampling Location	Date	Moisture, Percent[a]	Moisture, Percent[b]	Percent Difference
Gardinier/G04	12/03/85	10.7	11.0	-2.7
Gardinier/G07	12/10/85	9.2	9.3	-1.1
Gardinier/G04	12/17/85	5.2	5.4	-3.7
Gardinier/G03	12/24/85	4.7	4.6	2.2
Gardinier/G02	12/31/85	5.0	4.6	8.7
Gardinier/G05	01/07/86	11.6	11.7	-0.8
Gardinier/G07	01/14/86	11.4	11.3	0.9
Gardinier/G07	01/21/86	10.4	10.2	2.0
Gardinier/G04	01/28/86	13.8	13.9	-0.7
Gardinier/G10	02/04/86	4.9	5.1	-3.9
Gardinier/G05	03/05/86	12.0	12.2	-1.6
Gardinier/G01	04/01/86	8.3	9.4	-11.7
Gardinier/G07	04/29/86	7.4	7.9	-6.3
Gardinier/G03	05/28/86	9.4	8.9	5.6
Gardinier/G01	06/24/86	17.8	17.6	1.1
Grace/GR10	08/06/85	9.7	9.2	5.4
Grace/GR01	08/13/85	15.1	15.8	-4.4
Grace/GR02	08/20/85	29.3	29.0	1.0
Grace/GR02	08/27/85	25.9	25.2	2.8
Grace/GR02	09/04/85	22.5	23.7	-5.1
Grace/GR01	09/10/85	10.3	10.3	0
Grace/GR01	09/17/85	5.8	5.7	1.8
Grace/GR09	09/24/85	10.8	10.7	0.9
Grace/GR04	10/01/85	7.5	7.6	-1.3
Grace/GR07	10/08/85	12.7	12.7	0
Grace/GR02	10/15/85	5.6	5.3	5.7
Grace/GR02	10/22/85	3.2	3.6	-11.1
Grace/GR03	10/29/85	6.1	7.7	-20.8
Grace/GR08	11/05/85	9.9	10.1	-2.0
Grace/GR10	11/14/85	6.9	6.9	0
Grace/GR09	11/20/85	9.9	9.8	1.0
Grace/GR08	11/26/85	8.9	8.8	1.1
Grace/GR06	12/03/85	6.4	6.4	0
Grace/GR04	12/10/85	8.3	8.2	1.2
Grace/GR04	12/17/85	7.1	7.1	0
Grace/GR09	12/24/85	8.0	8.3	-3.6
Grace/GR08	12/31/85	5.0	4.5	11.1
Grace/GR04	01/07/86	10.9	10.6	2.8
Grace/GR10	01/14/86	14.7	14.6	0.7
Grace/GR02	01/21/86	5.2	5.1	2.0
Grace/GR04	01/28/86	8.9	7.5	18.7

Table E.5 Quality assurance results for moisture content measurements - Continued

Site/Sampling Location	Date	Moisture, Percent[a]	Moisture, Percent[b]	Percent Difference
Grace/GR04	02/04/86	5.5	5.2	5.8
Grace/GR07	02/11/86	12.5	12.8	-2.3
Grace/GR01	02/18/86	9.4	9.5	-1.0
Grace/GR07	02/25/86	12.6	12.5	0.8
Grace/GR01	03/05/86	10.3	10.3	0
Grace/GR06	03/11/86	11.2	11.3	-0.9
Grace/GR09	03/18/86	14.7	14.6	0.7
Grace/GR06	03/25/86	12.9	13.5	-4.4
Grace/GR08	04/01/86	10.3	9.9	4.0
Grace/GR08	04/08/86	9.1	9.1	0
Grace/GR08	04/15/86	9.9	9.8	1.0
Grace/GR10	04/22/86	8.3	8.2	1.2
Grace/GR09	04/29/86	5.0	4.7	6.4
Grace/GR07	05/06/86	8.9	9.0	-1.1
Grace/GR06	05/13/86	7.0	6.9	1.4
Grace/GR06	05/20/86	9.4	10.5	-10.5
Grace/GR06	05/28/86	4.0	4.0	0
Grace/GR09	06/03/86	3.5	3.5	0
Grace/GR10	06/10/86	8.9	9.2	-3.3
Grace/GR09	06/17/86	20.3	20.0	1.5
Grace/GR03	06/24/86	22.4	21.3	5.2
Grace/GR08	07/01/86	14.4	14.6	-1.4
Grace/GR05	07/08/86	14.9	14.7	1.4
Grace/GR06	07/15/86	10.4	10.5	-1.0
Grace/GR03T	07/15/86	7.0	7.4	-5.4
Royster/R06	09/04/85	29.9	29.6	1.0
Royster/R10	09/24/86	6.5	6.5	0
Royster/R08	10/15/85	1.7	2.5	-32.0
Royster/R05	11/14/85	9.4	10.5	-10.5
Royster/R10	12/10/85	7.8	7.9	-1.3
Royster/R03	01/07/86	19.7	19.9	-1.0
Royster/R04	02/11/86	17.7	17.9	-1.1
Royster/R10	03/11/86	23.0	22.5	2.2
Royster/R07	04/08/86	11.5	11.6	-0.9
Royster/R07	05/06/86	18.6	19.2	-3.1
Royster/R05	06/03/86	11.4	11.4	0
Royster/R10	07/01/86	20.7	20.8	-0.5

[a] First analysis.
[b] Second analysis.

content differed on the average by 2 percent, while samples containing less than 5 percent moisture differed on the average by about 8 percent, although the latter is greatly influenced by the one duplicate analysis that differed by 32 percent. In general, the results of the duplicate analyses for moisture content indicate that the measurements for this study are satisfactory.

E.4 Alpha Track Detectors

Five control (unexposed) track etch detectors were retained at the Eastern Environmental Radiation Facility (EERF) in Montgomery, Alabama and at the Polk County Health Department in Winter Haven, Florida during each of the three exposure periods, July 22, 1985 to December 4, 1985, December 2, 1985 to April 3, 1986 and April 2, 1986 to July 23, 1986. At the end of each period, the detectors were briefly opened to indicate exposure and then returned to the supplier for reading. The radon concentrations reported by the supplier for these control detectors are listed in Table E.6.

The apparent concentrations read from the control detectors by the supplier are all similar and reasonably low except for those retained by the Polk County Health Department during the third exposure period. This is apparent from the following table which lists the average concentrations for each period at each site. Excluding the third period controls from the Polk County Health Department, the average radon

Location/Sample	Radon Concentration Reported, pCi/l		
	First Period	Second Period	Third Period
EERF/control	0.10 ± 0.02	0.05 ± 0.01	0.08 ± 0.01
Polk County/control	0.07 ± 0.01	0.09 ± 0.01	0.27 ± 0.06
Stack Perimeters/ exposed[a]	0.77	0.55	0.82
Polk County, Bkg[b]	0.16	0.18	0.16

[a]Average radon concentration measured at the 5 phosphogypsum stack perimeters, see Table 4.13.
[b]See Table 4.13.

Table E.6 Alpha track detector controls

Control Location	Radon Concentration, pCi/l		
	First Period	Second Period	Third Period
EERF[a]	0.13	0.05	0.11
EERF	0.06	0.04	0.06
EERF	0.07	0.09	0.08
EERF	0.14	0.03	0.07
EERF	0.08	0.04	0.09
Polk County[b]	0.09	0.09	0.12
Polk County	0.05	0.06	0.18
Polk County	0.05	0.08	0.10
Polk County	0.08	0.09	0.86
Polk County	0.06	0.11	0.11

[a]Eastern Environmental Radiation Facility, USEPA, Montgomery, Alabama.
[b]Polk County Health Department, Winter Haven, Florida.

concentration reported for the controls is 0.08 pCi/l, which is about half the background concentration and 8 to 10 times less than the average concentrations measured at the perimeters of the five phosphogypsum stacks. However, the average apparent concentration read from the third period control detectors from the Polk County Health Department is nearly twice the background concentration and about a third of the average concentration measured at the phosphogypsum stacks for that period. In fact, one control detector indicated a concentration of 0.86 pCi/l which exceeds the average concentration measured at the phosphogypsum stacks. The supplier could not render an explanation for this anomoly. It should be noted that these control concentrations were not considered in determining the radon concentrations at the phosphogypsum stacks.

The alpha-track detectors were calibrated during each exposure period by exposing a set of detectors to different concentrations of radon in the Eastern Environmental Radiation Facility's radon calibration chamber and then shipping the exposed detectors to the supplier for measurement. The results of these measurements are given in Table E.7. The supplier measured the concentrations low by 25 percent during the first period, high by 50 percent during the third period, and accurately only during the second period. The radon concentrations measured at the phosphogypsum stacks were adjusted according to the average ratio, actual exposure divided by the average measured exposure, listed for each period in the 5th column of the table. The standard deviations for these average ratios are 4, 3, and 5 percent for the first, second, and third period measurements,

respectively. The precision of these measurements, indicated by the standard deviation of the individual measurements to the mean concentration (4th column in Table E.7), varied from 3 to 9 percent for the first period, 5 to 10 percent for the second period, and 5 to 30 percent for the third period measurements. Thus, the precision was not particularly good. Radon concentrations measured during the third period clearly have the greatest uncertainties associated with their values.

E.5 High-Volume Air Samples

Duplicate radiochemical analyses were performed on three composite high-volume air filter samples: two from the southeast location at the W.R. Grace stack and one from the background location in Winter Haven, Florida. The composite air filters were ashed and two aliquots of the ash were taken for the duplicate analysis. Thus, the homogeneity of the sample is questionable. The results of these duplicate analyses are shown in Table E.8.

Comparing the duplicate results for Ra-228, U-235, Th-227, and Th-228 has little meaning because the 2σ errors associated with the measured concentrations are at best 160 percent, 70 percent, 100 percent and 80 percent, respectively. These radionuclides are in low abundances. The percent difference in the principal radionuclide concentrations measured in the duplicate samples along with their 2σ counting errors are listed in the table below.

Table E.7 Calibration of the alpha-track detectors[a]

Exposure Period	Number of Detectors	Exposure,[b] pCi/l	Average Measured Exposure, pCi/l[c]	Actual Exposure / Average Measured Exposure
First	5	54	46 ± 4	1.17
First	5	106	89 ± 3	1.19
First	5	541	423 ± 18	1.28
First	5	953	699 ± 28	1.36
			Average	1.25 ± 0.05
Second	5	476	468 ± 47	1.02
Second[d]	10	476	486 ± 24	0.98
			Average	1.00 ± 0.03
Third	5	52	80 ± 24	0.65
Third	5	99	154 ± 23	0.64
Third	5	518	807 ± 99	0.64
Third	5	1060	1436 ± 65	0.74
			Average	0.67 ± 0.03

[a]See Appendix D, Tables D.2 and D.3.
[b]Detectors were exposed in the Eastern Environmental Radiation Facility's radon calibration chamber.
[c]± values are the standard deviations of the means.
[d]Detectors were exposed during the second period but read during the third period.

Table E.8 Quality assurance results for radionuclide concentrations in high-volume air samples, pCi/l

Location	Sampling Period	Ra-226	Ra-228	U-234	U-235	U-238	Th-227	Th-228	Th-230	Th-232
W.R. Grace[a]	3/31/86-4/28/86	1.7E-4	-	1.6E-4	1.3E-5	1.4E-4	3.9E-6	1.8E-6	1.5E-4	1.2E-5
	3/31/86-4/28/86	1.8E-4	-	1.7E-4	6.7E-7	1.6E-4	1.3E-6	-6.4E-6	1.7E-4	1.5E-5
W.R. Grace[a]	5/27/86-6/23/86	1.4E-4	-	1.2E-4	5.2E-6	1.1E-4	1.4E-6	7.1E-6	1.5E-4	9.3E-6
	5/27/86-6/23/86	1.8E-4	-	1.1E-4	3.7E-6	1.0E-4	3.1E-6	1.7E-5	1.3E-4	1.4E-5
Background[b]	7/27/85-08/26/85	4.5E-5	3.4E-5	4.1E-5	1.2E-6	3.7E-5	2.1E-6	3.5E-7	3.8E-5	1.1E-5
	7/27/85-08/26/85	4.0E-5	1.8E-5	3.8E-5	1.4E-6	3.9E-5	2.9E-6	7.3E-6	3.5E-5	8.9E-6

[a] Samples collected from the southeast location at the W.R. Grace stack.
[b] Winter Haven, Florida.

The percent difference observed between the concentrations measured in the duplicate samples for all radionuclides except Ra-226 were less than the 2σ counting errors. For the Ra-226 analyses, the differences in two duplicate results were near the counting error, while for the third, W.R. Grace (5/27-6/23/86), a difference of about 20 percent was observed in the two results compared to a counting error of 3 percent. However, the actual difference in the concentrations measured is not large, 1.4×10^{-4} pCi/l and 1.8×10^{-4} pCi/l. In general, these results indicate that the radiochemical analyses of the high-volume air samples were satisfactory.

Sample	Sampling Period	Percent Difference in Duplicate Analyses				
		Ra-226	U-234	U-238	Th-230	Th-232
W.R. Grace	3/31-4/28/86	6	6	14	13	25
W.R. Grace	5/27-6/23/86	22	8	9	13	50
Counting Error (Percent)	-----	3	15	15	14	44
Background	7/27-8/26/85	11	7	5	8	19
Counting Error (Percent)		6	20	20	22	37

APPENDIX F

The average radon-222 flux measured during each sampling period on the phosphogypsum stacks

Table F.1 The average radon flux by sampling period on the phosphogypsum stacks

Sampling Period	Radon Flux, pCi/m^2 - sec				
	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Values
		Gardinier Stack			
07/22/85-07/23/85	29	27	2.5	99	10
07/29/85-07/30/85	14	7	7.2	27	9
08/05/85-08/06/85	23	16	9.5	62	10
08/12/85-08/13/85	18	23	0.31	63	10
08/19/85-08/20/85	12	10	0.96	29	10
08/26/85-08/27/85	11	8	1.2	28	8
09/03/85-09/04/85	15	11	1.3	33	10
09/09/85-09/10/85	15	7	2.1	23	10
09/16/85-09/17/85	21	15	4.9	56	10
09/23/85-09/24/85	22	13	3.0	48	10
09/30/85-10/01/85	30	21	4.2	67	10
10/07/85-10/08/85	33	24	5.3	75	10
10/14/85-10/15/85	21	7	13	34	10
10/21/85-10/22/85	20	6	14	32	10
10/28/85-10/29/85	18	14	1.8	48	10
11/04/85-11/05/85	18	13	0.88	38	10
11/12/85-11/13/85	12	8	0.19	22	10
11/18/85-11/19/85	25	22	4.1	70	10
11/25/85-11/26/85	21	7	14	36	10
12/02/85-12/03/85	25	12	6.8	44	10
12/09/85-12/10/85	21	6	10	31	10
12/16/85-12/17/85	22	9	3.7	31	10
12/23/85-12/24/85	30	12	15	55	10
12/30/85-12/31/85	19	8	6.5	29	10
01/06/86-01/07/86	19	7	7.5	29	10
01/13/86-01/14/86	18	16	1.4	45	10
01/20/86-01/21/86	17	13	4.0	52	10
01/27/86-01/28/86	17	12	8.5	50	10
02/03/86-02/04/86	21	14	9.0	56	10
03/04/86-03/05/86	23	10	4.5	34	9
03/31/86-04/01/86	8	5	1.7	17	10
04/28/86-04/29/86	20	10	5.8	36	10
05/27/86-05/28/86	21	15	6.1	57	10
06/23/86-06/24/86	15	10	2.8	36	10

Table F.1 The average radon flux by sampling period on the phosphogypsum stacks - Continued

Sampling Period	Radon Flux, pCi/m^2 - sec				
	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Values
		W.R. Grace Stack			
07/24/85-07/25/85	10	6	2.8	19	10
07/29/85-07/30/85	19	7	7.7	31	10
08/05/85-08/06/85	16	13	0.22	43	9
08/12/85-08/13/85	18	10	0.51	35	10
08/19/85-08/20/85	14	9	1.9	26	10
08/26/85-08/27/85	16	15	4.0	54	10
09/03/85-09/04/85	16	10	1.0	33	10
09/09/85-09/10/85	6	7	0.26	22	10
09/16/85-09/17/85	19	18	1.1	65	10
09/23/85-09/24/85	13	8	1.2	23	10
09/30/85-10/01/85	14	7	1.8	25	10
10/07/85-10/08/85	14	7	1.6	25	10
10/14/85-10/15/85	11	5	2.4	18	10
10/21/85-10/22/85	13	9	2.6	30	10
10/28/85-10/29/85	15	7	3.1	24	10
11/04/85-11/05/85	16	16	0.27	54	10
11/12/85-11/13/85	14	9	3.8	33	10
11/18/85-11/19/85	20	17	3.8	61	10
11/25/85-11/26/85	16	7	7.1	27	10
12/02/85-12/03/85	16	8	5.1	29	10
12/09/85-12/10/85	17	8	6.4	30	10
12/16/85-12/17/85	20	17	4.3	63	10
12/23/85-12/24/85	19	13	6.0	47	10
12/30/85-12/31/85	17	7	8.6	31	10
01/06/86-01/07/86	15	8	5.8	30	10
01/13/86-01/14/86	20	13	2.4	41	10
01/20/86-01/21/86	15	7	3.3	24	10
01/27/86-01/28/86	19	13	2.1	48	10
02/03/86-02/04/86	17	7	7.4	29	10
02/10/86-02/11/86	40	61	1.0	210	10
02/17/86-02/18/86	21	11	7.1	39	10
02/24/86-02/25/86	16	11	2.2	34	10
03/04/86-03/05/86	21	9	8.0	38	10
03/10/86-03/11/86	20	7	9.9	33	10
03/17/86-03/18/86	9	9	1.5	26	10
03/24/86-03/25/86	11	7	4.1	25	10
03/31/86-04/01/86	13	6	3.4	21	10
04/07/86-04/08/86	11	4	3.7	17	10
04/14/86-04/15/86	14	7	4.4	27	10
04/21/86-04/22/86	12	4	2.9	17	10
04/28/86-04/29/86	9	4	3.2	14	10
05/05/86-05/06/86	21	13	4.4	43	10

Table F.1 The average radon flux by sampling period on the phosphogypsum stacks - Continued

Sampling Period	Radon Flux, pCi/m^2 - sec				
	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Values
05/12/86-05/13/86	17	5	9.1	25	10
05/19/86-05/20/86	22	9	10.3	36	10
05/27/86-05/28/86	19	11	4.1	38	10
06/02/86-06/03/86	16	8	3.4	28	10
06/09/86-06/10/86	12	7	3.3	28	10
06/16/86-06/17/86	9	6	0.73	20	10
06/23/86-06/24/86	13	19	0.96	65	10
06/30/86-07/01/86	14	13	1.9	35	10
07/07/86-07/08/86	11	9	2.1	32	10
07/14/86-07/15/86	10	4	3.7	17	10
Royster Stack					
07/25/85-07/26/85	33	12	19	56	10
09/03/85-09/04/85	30	14	12	61	10
09/23/85-09/24/85	21	6	13	37	10
10/14/85-10/15/85	16	5	9.7	25	10
11/12/85-11/13/85	22	10	3.7	37	10
12/09/85-12/10/85	30	10	16	45	9
01/06/86-01/07/86	26	21	7.0	81	10
02/10/86-02/11/86	32	18	7.9	67	9
03/10/86-03/11/86	20	18	1.7	50	10
04/07/86-04/08/86	7	4	2.6	16	10
05/05/86-05/06/86	11	7	3.5	24	10
06/02/86-06/03/86	15	9	5.2	36	8
06/30/86-07/01/86	17	18	0.59	59	10
Conserv Stack					
07/24/85-07/25/85	68	103	18	340	9
08/19/85-08/20/85	38	64	5.8	210	9
09/30/85-10/01/85	22	9	4.1	34	10
10/21/85-10/22/85	12	6	2.4	22	10
11/18/85-11/19/85	31	23	9.5	82	10
12/16/85-12/17/85	24	6	17	35	10
01/13/86-01/14/86	33	11	20	61	10
02/24/86-02/25/86	25	11	5.8	42	10
03/17/86-03/18/86	15	11	1.5	41	10
04/14/86-04/15/86	11	7	2.7	26	10
05/12/86-05/13/86	16	6	9.9	28	10
06/09/86-06/10/86	16	7	9.1	27	10
07/07/86-07/08/86	18	4	11	26	10

Table F.1 The average radon flux by sampling period on the phosphogypsum stacks - Continued

Sampling Period	Radon Flux, pCi/m^2 - sec				
	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Values
		Estech Stack			
07/25/85-07/26/85	3.8	1.4	2.0	5.5	10
09/09/85-09/10/85	1.9	1.0	0.57	3.6	10
10/07/85-10/08/85	4.1	2.2	1.7	8.9	10
10/28/85-10/29/85	4.4	2.5	2.0	9.9	10
12/02/85-12/03/85	3.9	1.7	0.60	5.9	10
12/23/85-12/24/85	5.8	3.5	0.95	14.	10
01/27/86-01/28/86	4.1	2.2	0.82	9.1	10
02/17/86-02/18/86	6.1	3.3	2.0	14	10
03/24/86-03/25/86	3.6	1.2	1.4	6.1	10
04/21/86-04/22/86	4.7	1.9	1.3	8.7	10
05/19/86-05/20/86	3.4	2.3	0.67	7.5	10
06/16/86-06/17/86	7.3	3.3	3.5	15	10
07/14/86-07/15/86	4.2	1.8	1.6	7.6	10