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Radon and Radon Daughter Measurements at and near the Former Middlesex Sampling Plant, Middlesex, New Jersey

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HEALTH AND SAFETY RESEARCH DIVISION
OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

The results of the radon and radon daughter measurements made to date (1978) at the Middlesex Sampling Plant in Middlesex, New Jersey, are presented in this report. These measurements were one portion of a more comprehensive radiological survey conducted at this site and the surrounding area from 1976 to 1978. The surveyed property served as a uranium ore sampling plant during the 1940's and early 1950's and as a result contains elevated levels of surface and subsurface contamination. The survey was undertaken by the Health and Safety Research Division of Oak Ridge National Laboratory to determine whether the existing radiological status of the property and adjacent area is consistent with current health guidelines and radiation protection practices. On-site indoor radon daughter and radon concentrations exceeded both the U.S. Surgeon General's Guidelines in Title 10, *Code of Federal Regulations*, Part 712 (10 CFR Part 712) and the Nuclear Regulatory Commission's maximum permissible concentration limits for radon (10 CFR Part 20) in all structures surveyed. Off-site structures showed concentrations of radon and radon daughters at or only slightly above background levels, except for one site where the radon levels were found to be above the 10 CFR Part 20 guidelines. These results indicate the need for more extensive radon and radon daughter measurements in structures both on and off the site over periods as suggested in 10 CFR Part 712. Outdoor radon and radon daughter concentrations, measured both on and off the site, were well below the guidelines, and the data give no indication of significant radon transport from the site. However, due to weather conditions at the time of the outdoor survey, these results may be low, and further investigations should be conducted to substantiate these results.

INTRODUCTION

At the request of the Department of Energy (DOE), then the Energy Research and Development Administration (ERDA), a comprehensive radiological survey of the former Middlesex Sampling Plant was initiated in March, 1976. This plant, located in Middlesex, New Jersey, served as a uranium ore sampling plant for Belgian Congo ore in the 1940's and early 1950's. The sampling facility was decommissioned in the mid-1950's, and sampling was shifted to other locations. Subsequent to decontamination, the site was surveyed in 1967 prior to release by the Atomic Energy Commission. Due to the lack of complete documentation on the radiological status of the facility after decontamination, and the concern of DOE to maintain radiation exposure to a level as low as reasonably achievable (ALARA), a detailed survey of the site and surrounding area was undertaken to determine the levels of residual contamination on the original property and the extent of any off-site contamination. The results of these surveys could then be compared to the guidelines (10 CFR Part 712) based on recommendations of the U.S. Surgeon General (Appendix II) to determine the need for remedial action in the Grand Junction, Colorado, area. Because no generally applicable guidelines have been promulgated for this type of radioactive contamination, those in 10 CFR Part 712 are used to judge the acceptability of radon daughter exposures.

Since the beginning of the surveys in 1976, several investigations have been conducted at Middlesex.[1-3] These surveys included measurements of alpha contamination levels and beta-gamma dose rates in buildings and in other areas at and near the site; radon and radon daughter concentrations in buildings and outdoors at locations within the facility boundaries and in areas off the site; external gamma radiation levels at the site and on property in the Middlesex area; and radium concentrations in soil at the site, on adjacent property, in drainageways carrying runoff from the site, and at particular locations in the surrounding residential areas. The purpose of this report is to present the results of the radon and radon daughter measurements completed to date. These data were collected by personnel from the Health and Safety Research Division of Oak Ridge National Laboratory (ORNL) during the original survey in March, 1976, and subsequent return trips during March and May, 1976; May and November, 1978; and January, 1979. In addition, radon monitoring was conducted during the 1976 surveys, in February, 1978, and during December, 1978-March, 1979, by the Environmental Measurements Laboratory (EML), formerly the Health and Safety Laboratory (HASL). Some of the data collected by EML are included in this document.

SITE DESCRIPTION

The former Middlesex Sampling Plant is located on the outskirts of Middlesex, New Jersey (Fig. 1). The site is bounded by a railroad to the north, a water drainage system and woods to the south, several industrial concerns and a few homes to the east and west. The major residential areas of Middlesex extend to the north across the railroad tracks and west of the former plant site.

The site proper consists of six buildings located in a fenced area depicted schematically in Fig. 2. The major structures within the complex are the former warehouse and process building (Bldg. A) and the administration building (Bldg. F). The site is now occupied by the Sixth Motor Transport Battalion of the U.S. Marine Corps, and it serves as a reserve training center.

MEASUREMENT TECHNIQUES

Radon and radon daughter measurements made during the field surveys at the Middlesex site utilized both grab sample and continuous monitoring techniques. In the surveys conducted by ORNL staff, indoor and outdoor radon concentrations, both on and off the site, were determined using a continuous measurement technique developed by Wrenn et al.[4] Although this detector, commonly referred to as a Wrenn chamber, typically measures radon concentrations continuously over periods of 24 hr or more, the concentrations are recorded at much shorter intervals (approximately 30 min). Because the measurement technique depends upon diffusion of radon into the detection chamber (Appendix I), radon and radon daughters from previous measurement intervals may remain within the chamber for the next counting period. Hence, each reading actually represents a concentration which has been integrated over a period of 2 to 4 hr. This integrating tendency of the Wrenn chamber acts to smooth out extreme variations in the actual radon concentrations caused by short-term changes such as those resulting from variations in room ventilation rate. The results of a typical 24-hr radon measurement, showing the "smoothing" tendencies of this technique, are illustrated in Fig. 3.

The Wrenn chamber is normally used for indoor radon measurements, and it shows moisture dependency. For this reason, during outdoor measurements, the detectors are protected from direct exposure to inclement weather. However, this arrangement does restrict the air movement as compared with actual outdoor conditions; and as a result, it may produce higher radon concentrations than would normally be experienced.

For the measurement of radon daughters in air, the ORNL survey utilized an alpha spectrometry technique refined by Kerr.[5-6] In this measurement technique, particulate ^{222}Rn daughters attached to airborne dust are collected on a membrane filter (maximum pore size of 0.4 μm) using an integral pump arrangement. Sampling times of 5 to 10 min are used, with flow rates ranging from 12 to 16 liters per minute. The filter is then counted using the alpha spectrometry method described in Appendix I. From one integral count of the ^{218}Po alpha activity and two integral counts of the ^{214}Po activity, the concentrations (picocuries per liter) of ^{218}Po, ^{214}Pb, and ^{214}Bi (RaA, RaB, and RaC, respectively) can be determined. A technique has also been developed to measure ^{219}Rn (actinon) daughter concentrations in air (Appendix I), and it was utilized by the ORNL survey team during the 1978 survey. The results obtained using this revised technique indicated that ^{219}Rn daughter concentrations were insignificant. Hence, data are reported only for ^{222}Rn and its daughters.

Additional radon and radon daughter measurements, conducted with the assistance of EML, were obtained using Lucas flasks for instantaneous ^{222}Rn concentrations (Appendix I); and continuous measurement techniques[7-8] were used for determination of radon and radon daughter concentrations. In order to measure radon emanation from surfaces on the site and on adjacent property, a charcoal canister technique developed by EML[9] was used. The quantity of radon emanating from a surface gives an indication of the ^{226}Ra level in the soil or other material underlying the measurement point. Several variables, including porosity of the soil, moisture content, ambient temperature and pressure affect the measured values. Therefore, this technique should be regarded as only an indication of the relative magnitude of the source of radon at any particular point.

In an analysis of the results of radon and radon daughter measurements, it should be noted that the measurements are only an indication of concentrations present over the sampling period. Results of instantaneous readings or even continuous sampling over a period of weeks cannot be extrapolated to predict average annual conditions at a particular location. This is due to the large variation in radon concentrations which result from changes in atmospheric and ventilation conditions over the period of a year.

SURVEY RESULTS

Results of the investigations conducted at the former Middlesex Sampling Plant and the surrounding area are presented in the following sections. The presentation has been divided into measurements of indoor radon and radon daughter concentrations, and outdoor radon emanation, radon and radon daughter concentrations.

Indoor Measurements

Measurements of radon and radon daughter concentrations inside buildings at the Middlesex site, in structures adjacent to the site, and in dwellings in the Middlesex area were obtained by ORNL and EML during the initial survey in March-May, 1976. Background levels of these radionuclides were measured in dwellings in the Middlesex area (within 50 miles of Middlesex, New Jersey), and the results are presented in Table 1.[10] The average background concentration of ^{222}Rn in cellars was determined to be 2.7 pCi/liter, and the average radon daughter concentration in dwellings (including cellars and upper levels of homes) was 0.009 WL.*

Radon and radon daughter concentrations in air were measured during the initial site visit in the process building, boiler shop, garage, and administration building located at the Middlesex site. Short-interval measurements of the radon daughter concentrations during the normal working day in the former process building (Fig. 4) ranged from 0.003 WL to 0.10 WL, with the highest concentration being measured on the lower level (Table 2). Continuous radon daughter measurements by EML over a period of 6 days on the lower level of the process building showed a maximum concentration of 0.15 WL (Table 3). The radon concentration in buildings on the site ranged from 0.28 to 31 pCi/liter from Lucas flask measurements, and from 2.4 to 29 pCi/liter for continuous measurements as presented in Table 3. The highest concentrations were again found in the former process building, lower level.

Off-site measurements during this time frame included two residences and one commercial building adjacent to the site as shown in Fig. 5. The radon concentration in air in these structures (Lucas flask measurements) ranged from 0.2 to 0.6 pCi/liter; and the continuous concentration measurement, integrated over a period of 6 days, was

*A working level (WL) is defined as any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.

0.5 pCi/liter. The radon daughter concentration in the dwellings did not exceed 0.004 WL, and the radon daughter concentration in the commercial establishment was found to be 0.014 WL.

During 1978, personnel from EML resumed monitoring at the Middlesex site.[11-12] Initial measurements were centered in the administration building to investigate the significance of the high radon concentration near the building sump. Radon concentrations determined by continuous monitoring are shown on the floor plan of the building in Fig. 6. The upper figures represent averages of several week-long measurements at each location from February 9 to May 12, 1978, except for location A-10 where only one measurement was made. To test the hypothesis that the sump was the source of the elevated radon concentrations in this building, an exhaust fan was installed in the pipe chase at the location shown in the figure. The fan expelled air from the chase (and hence the sump) for two weeks (May 16 to June 1) while additional radon measurements were obtained. The reduced concentrations are shown as the middle figure at each location. Results of additional measurements made after the fan was shut off, during the period June 1 to July 27, are shown as the bottom numbers. The range of measured radon concentrations prior to the ventilation was from 1.1 to 15 pCi/liter, the range during the ventilation procedure was determined to be 0.5 to 2.6 pCi/liter, and afterwards it varied from 2.0 to 20 pCi/liter. Fan operation resulted in 75 to 95% reduction in radon concentration in the building.

As a result of the observed effectiveness of fan operation in reducing the concentration of radon in the adminstration building, Navy personnel installed a fan in the pipe chase for more permanent operation which began December 26, 1978. Radon measurements in the administration building were made by EML and ORNL staff members before and after December 26. The EML data[12] in Table 4 (see Fig. 6 for measurement locations) show reductions in concentration in the range 96 to 77% with an average reduction (6 locations) of 84%. Results of the ORNL measurements summarized in Table 5 also show a marked reduction in radon concentration following the initiation of fan operation, especially in rooms A-4 and A-6 (supply office and day room). The reduction in the other two rooms is less drastic but it is significant.

The radon concentration in the carpenter shop of the process building was measured by ORNL personnel during the period November 6, 1978 to January 9, 1979, using the continuous monitoring technique. The overall average radon concentration for the 24-hr averages during the period of the measurements recorded in Table 5 was 25 pCi/liter before the fan operation and 28 pCi/liter after. The corresponding daytime averages were 28 pCi/liter before and 29 pCi/liter after fan operation.

In addition to these measurements, EML personnel conducted continuous radon measurements in the former process building.[11] From one set of time-integrated measurements, the range of radon concentrations was 16 to 28 pCi/liter on the first floor, and 1.9 to 22 pCi/liter on the second floor. These compare reasonably well with the ORNL data obtained in 1976 in the same building (Table 3).

During the May, 1978, survey, elevated gamma radiation levels at a location in the town of Middlesex were discovered by an aerial radiation survey of the sampling plant and vicinity conducted by the Washington Aerial Measurements Department of EG&G.[13] The subsequent ground survey located the anomaly at property owned by the Church of Our Lady of Mount Virgin, located on Harris Avenue in Middlesex. This property is shown in relation to the sampling plant in Fig. 7. Some nearby residents recall that, in about 1947, soil was moved from the sampling plant and was used as fill dirt for what is presently the lawn of the church rectory.[2] A detailed radiological survey was conducted at this location, including radon monitoring in the rectory basement and a bedroom on the first floor. Continuous radon measurements, using Wrenn chambers, were made for 11 days in rooms 2 and 9 in the rectory basement, and for 4 days in room 9 on the street level (Fig. 8).

The results of the radon measurements are presented in Tables 6 and 7. Radon concentrations in room 2 of the basement averaged approximately 21 pCi/liter, and ranged from 2 to 48 pCi/liter. Concentrations of radon in room 9, located closer to the basement sump, averaged 31 pCi/liter over the 10-day period and ranged from approximately 3 to 92 pCi/liter for single measurements. As was noted in the survey of the administration building at the sampling plant, the building sump was identified as a major source of radon and radon daughters in the rest of the dwelling. On the street level, in room 9, radon concentrations varied from 0.03 to 2.7 pCi/liter for a single reading and averaged approximately 1 pCi/liter over the 4 days of the survey. It should be noted that the street level of the rectory was well ventilated (doors and windows open) during the survey, and hence, the radon concentrations measured during this time frame may be significantly lower than the average annual concentration in this part of the structure.

Outdoor Measurements

Measurements of radon emanation rates of various surfaces in and around the Middlesex Sampling Plant site were obtained during the March, 1976, survey. These results have been reported previously.[1] Outdoor radon and radon daughter concentrations were obtained both on the site and off the site during the May, 1978, investigations. Background levels of outdoor radon daughter concentrations based on measurements taken within 50 miles of Middlesex (Table 1) averaged 0.002 WL.[10]

Radon emanations from various surfaces on and in the vicinity of the site were measured by EML during the initial (1976) survey using a charcoal canister technique at locations identified in Fig. 9.[11] The results of these measurements are given in Tables 8 and 9. The average radon emanation rate for all measurements at outdoor locations on and immediately adjacent to the sampling plant was 3.2 pCi/m^2-sec. Background measurements taken at locations some distance from the Middlesex site, but close enough to be representative of it, showed an average emanation rate of 0.45 pCi/m^2-sec. The average worldwide background emanation rate is reported[14] to be 0.43 pCi/m^2-sec, with some background values within the United States reported[14] to be as high as 1.4 pCi/m^2-sec.

Outdoor radon daughter concentrations were measured by the ORNL survey team during May, 1978, utilizing the alpha spectrometry method described previously. Measurements were made near the former process building at the sampling plant, at an industrial establishment (Wood Industries) west of the site, in the parking lot of the Middlesex Municipal Building, and at the Parker School of Middlesex in order to observe the extent of any off-site airborne contamination from the site. The locations of these buildings in relation to each other are shown in Fig. 6. Ten-minute samples were taken at each location at least once a day, over a 4-day period. The results of these measurements are presented in Table 10. The concentration of radon daughters in air ranged from less than 0.01 WL to 0.02 WL, the highest occurring at the process building. Considering the accuracy limits of the detection system and the windy conditions during the sampling period, the difference between the average concentration on the site and that off the site is not considered significant.

Outdoor radon concentrations were determined by continuous measurement using Wrenn chambers on the rooftops of the buildings described above (Fig. 6). Two Wrenn chambers were used on the roof of each building to measure the radon concentration in air at those locations continuously over a period of 10 days. The results of this survey are presented in Table 11. The radon concentrations obtained from the two detectors were averaged over each counting interval. Minimum and maximum values of the averaged interval values are shown in Table 11. These 30-min average results were then averaged over a 24-hr period to yield the daily overall average. The radon concentration on the site (roof of process building) ranged from 0.01 to 0.58 pCi/liter, and the average was 0.14 pCi/liter over an 8-day period. Off-site measurements ranged from less than 0.01 pCi/liter up to 0.32 pCi/liter. The averages over the survey period were 0.06, 0.04, and 0.06 pCi/liter for the

Wood Industry, Municipal building, and Parker School locations, respectively. Again, the differences observed in the overall averages may not be significant due to the windy conditions during the survey period and to the limitations of the detection system.

SUMMARY AND CONCLUSIONS

Several radiological surveys of the former Middlesex Ore Sampling Plant and surrounding area were conducted during 1976-1979. In addition to other measurements, surveys of the indoor and outdoor radon and radon daughter concentrations both on the site (the former Sampling Plant site) and in dwellings and commercial establishments off the site were completed. The results of these investigations have identified levels of radioactive contamination above background at the sampling plant site, at locations immediately adjacent to the site, and at one location away from the site. This contamination is assumed to be the result of natural and human assisted spread of pitchblende ore residues from the original ore-handling activities.

The contamination potential at the Middlesex site is similar to, although much less than, that encountered at Grand Junction, Colorado, where radium-bearing uranium mill tailings were used for private purposes in construction of residences and commercial structures. Due to the situation at Grand Junction, the state of Colorado requested the U. S. Surgeon General to develop a set of guidelines for use in considering the need for remedial action in such cases. These guidelines were adopted by the Department of Energy (formerly ERDA) as the basis for the Grand Junction Remedial Action Criteria, which have been codified as 10 CFR Part 712 (Appendix II).

In considering the need for remedial action in structures where radon daughter concentrations exceed background, it is recommended in 10 CFR Part 712 that indoor radon daughter concentrations be determined by "(1) averaging the results of six air samples each of at least 100 hours duration, and taken at a minimum of 4 week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission." For structures other than schools and residences, an observed average indoor radon daughter concentration level of 0.03 WL or greater above background would qualify the structure for consideration by the DOE for the need for remedial action. For schools and residences, this level has been established as 0.01 WL.

The Nuclear Regulatory Commission has provided a guideline for the maximum permissible concentration of radon in air (MPC_a) for exposure to the general public in 10 CFR Part 20, Appendix B. This guide sets an upper limit on the concentration of radon in air of 3 pCi/liter (or 0.033 WL) averaged over a year. This concentration guideline can be utilized for indoor or outdoor measurements.

Radon and radon daughter concentrations in the process building and administration building at the sampling plant site exceeded the suggested guidelines for exposure of the general public, as measured during the March, 1976, and February, 1978, surveys. Concentrations as high as 29 pCi/liter of radon and up to 0.15 WL of radon daughters were observed in the process building.[11] The administration building contained areas with concentrations as high as 15 pCi/liter of radon, although it was found by EML that this concentration could be reduced significantly by use of a fan to ventilate the utility pipe chase under the building.[12]

Outdoor radon and radon daughter concentrations measured at the sampling plant were well below the recommended levels, although the radon emanation rates from various surfaces at the site were 7 to 8 times higher than background in the area. These outdoor radon concentrations may have been low due to windy conditions during the measurement period. Off-site, outdoor radon and radon daughter concentrations were also well below both the Surgeon General's Guidelines and 10 CFR Part 20 and, within the accuracy of the measurement techniques, indicated little or no off-site transport of radon.

Four dwellings off the site were surveyed for levels of indoor radon and radon daughters. Three are in areas adjacent to the site, and the fourth is located in a residential area of Middlesex (rectory of the Church of Our Lady of Mount Virgin). The measured radon and radon daughter concentrations in the three structures adjacent to the site and in a bedroom on the first floor of the rectory were all below guidelines during the measurement period, although the concentrations were often above background. However, the average daily radon concentration measured in the rectory basement ranged from 5.5 to 53 pCi/liter, with a maximum single reading of 92 pCi/liter. These results indicate that a potential hazard from radon and its progeny could exist in the structure that can be reduced by dilution ventilation or by removing contaminated soil from the outside basement walls.

Part of the surveys conducted in the Middlesex area were made during warm seasons of the year when structures were generally well ventilated. Radon concentrations much higher than those measured could be expected under colder, less ventilated conditions. Furthermore, if the criteria in 10 CFR Part 712 are to be applied to this site, more extensive ^{222}Rn daughter sampling, should be initiated in order to determine the annual average indoor concentration of radon daughters.

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ORNL-Photo 1939-77-A

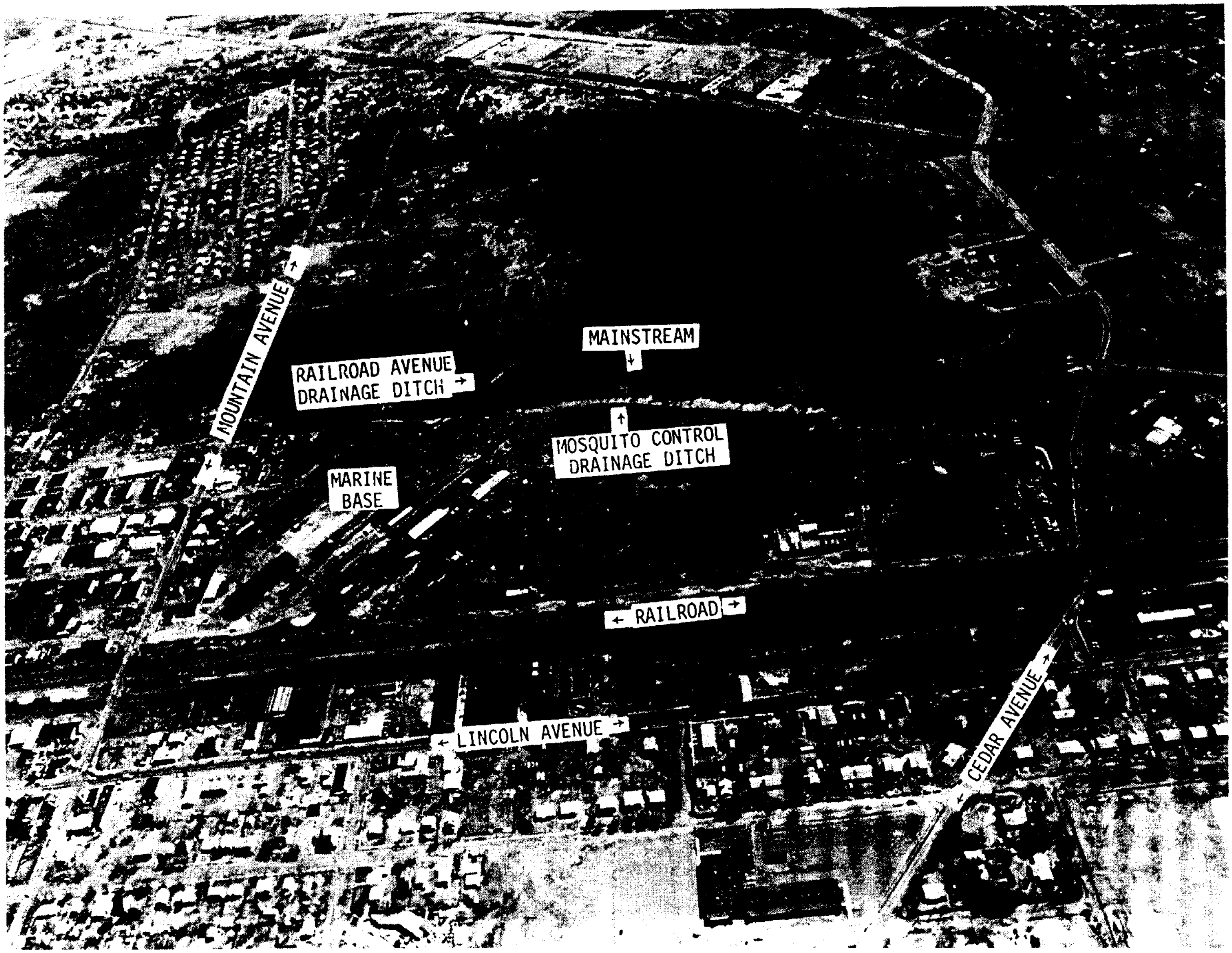

Fig. 1. Aerial view of the Middlesex Sampling Plant and surrounding area.

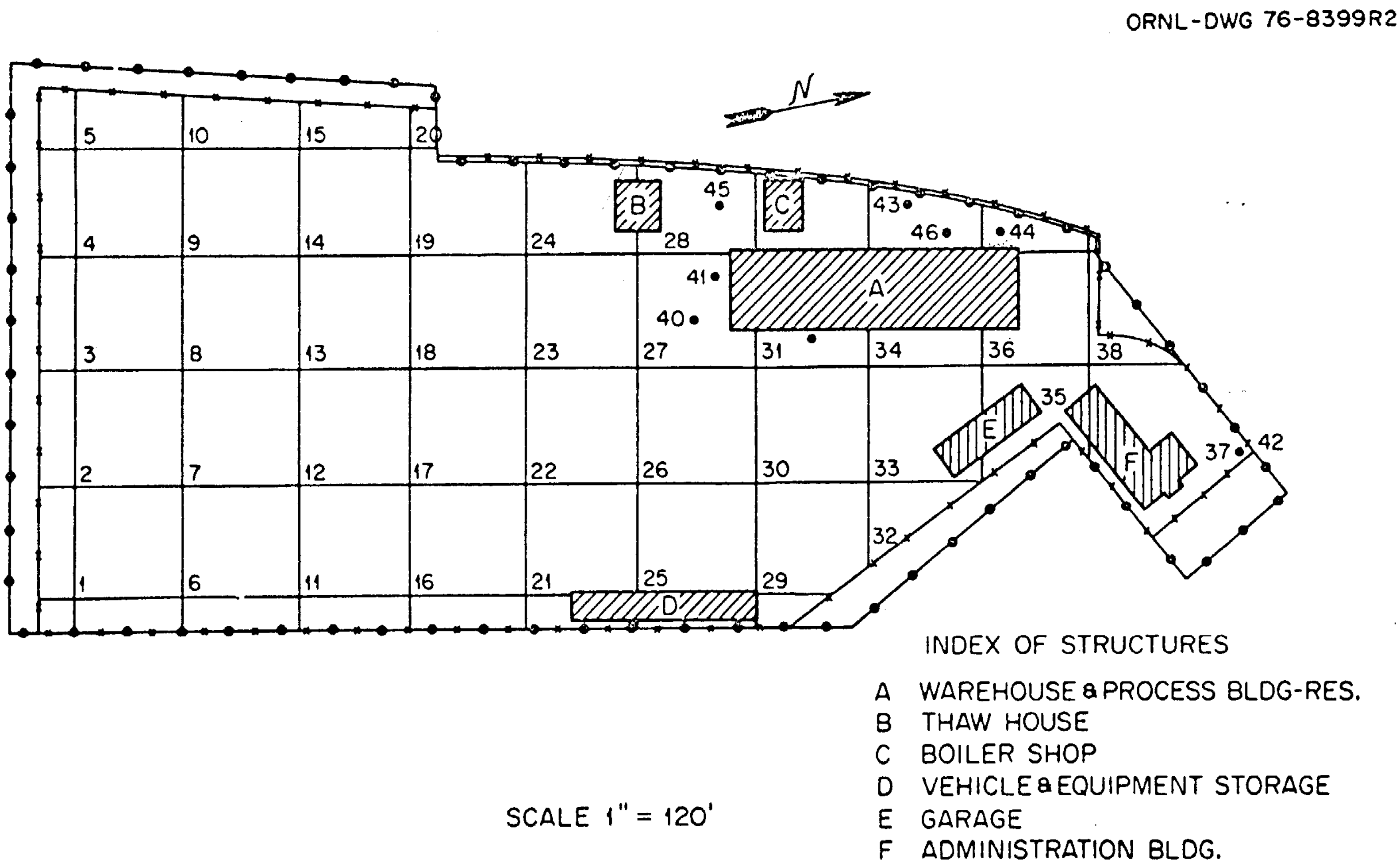

Fig. 2. Grid used for locating sampling and measurement points.

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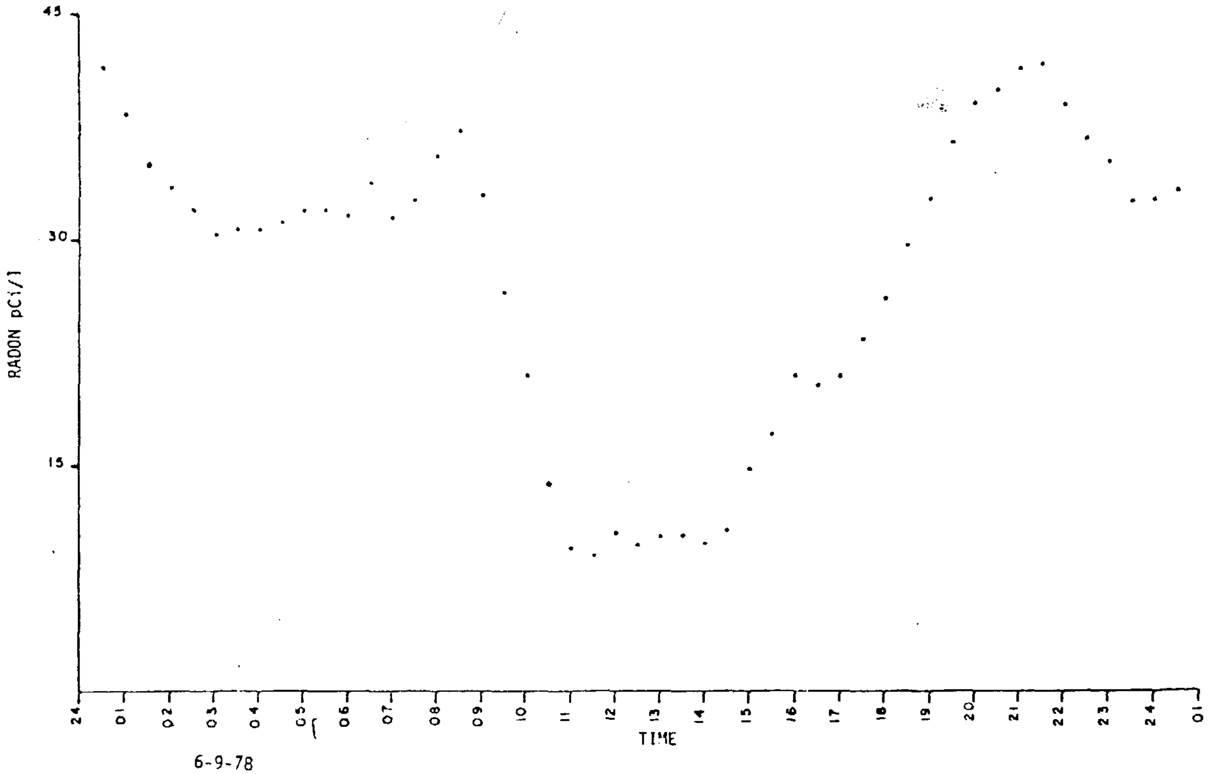

Fig. 3. Typical diurnal variation of radon concentration in the rectory of Our Lady of Mount Virgin, Middlesex, New Jersey.

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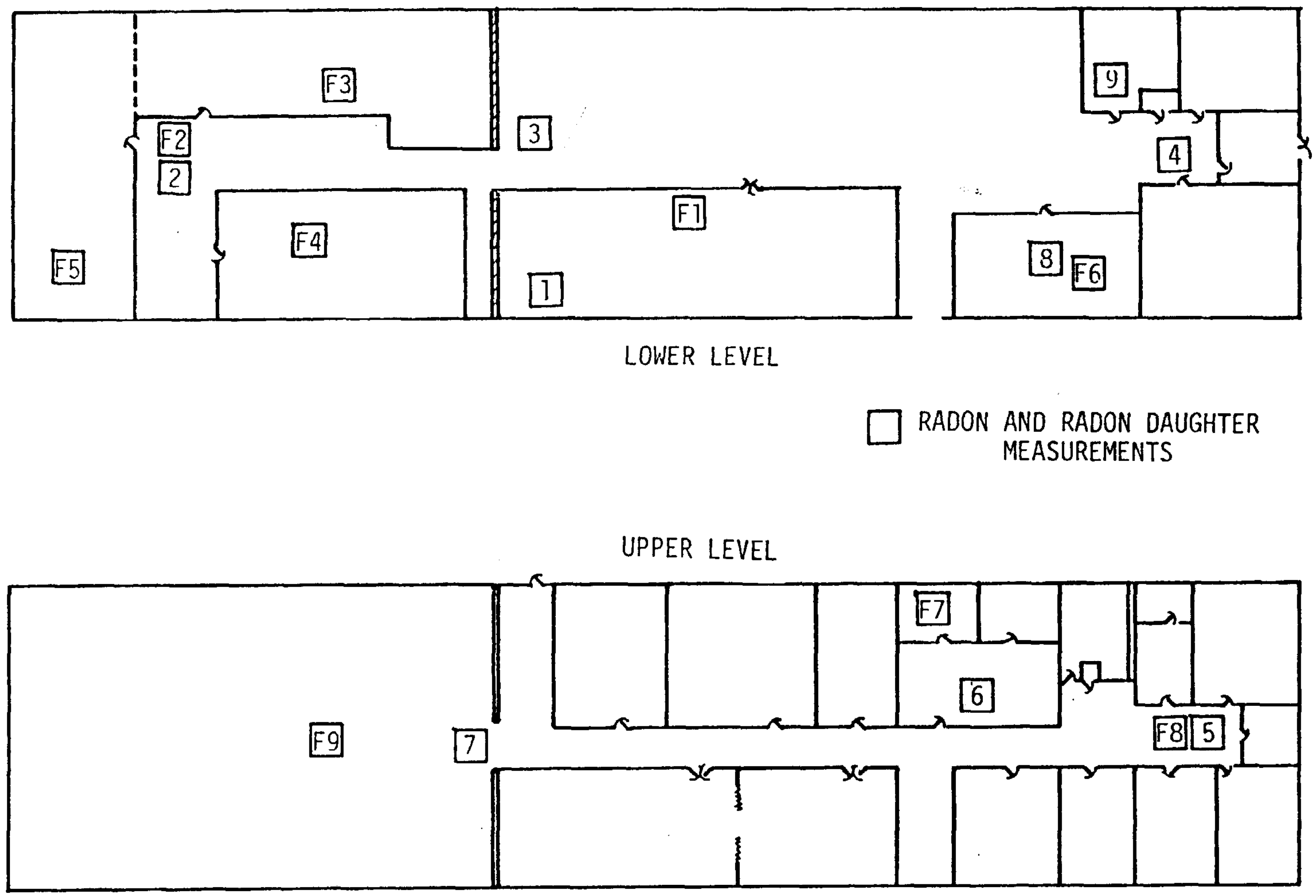

Fig. 4. Locations of radon and radon daughter sampling points in the process building.

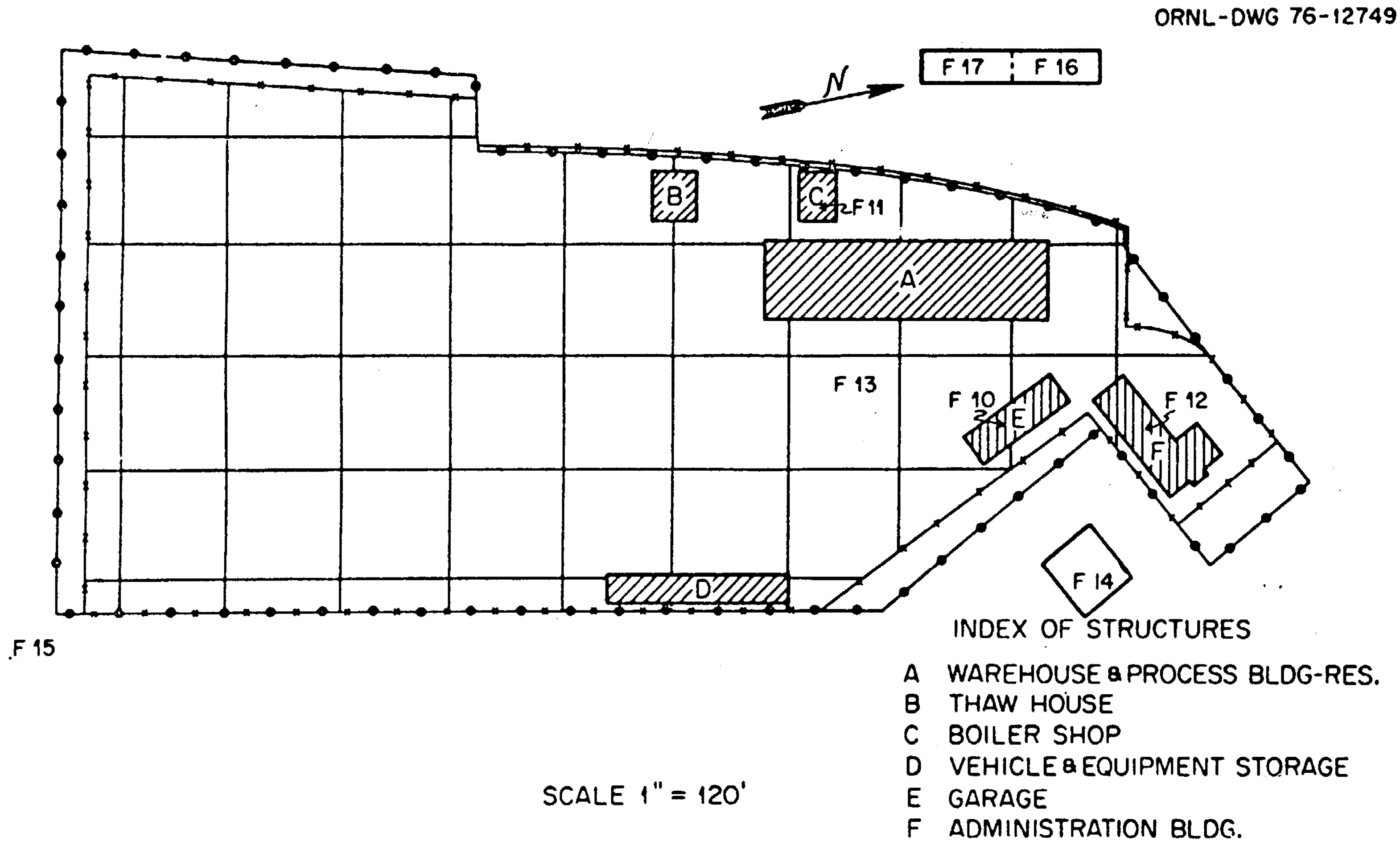

Fig. 5. Locations of radon and radon daughter sampling points on the site and on adjacent property.

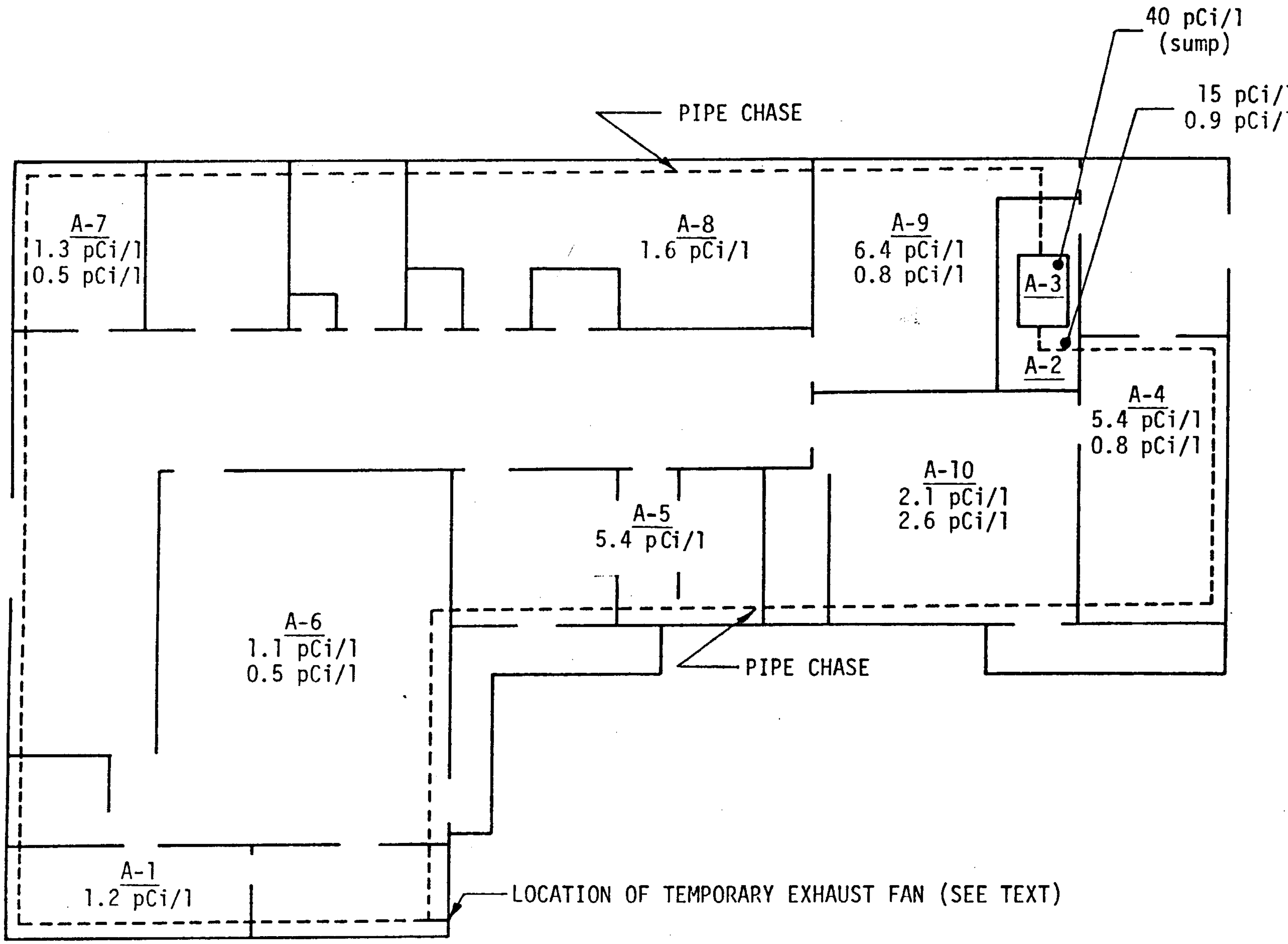

Fig. 6. Locations of radon monitors in the administration building. Source: Memo from A. J. Breslin, Director, Aerosol Studies Division, Environmental Measurements Laboratory, New York, to William E. Mott, Director, Division of Environmental Control Technology, Department of Energy, Washington, D.C., June 12, 1978.

ORNL-Photo 5153-79

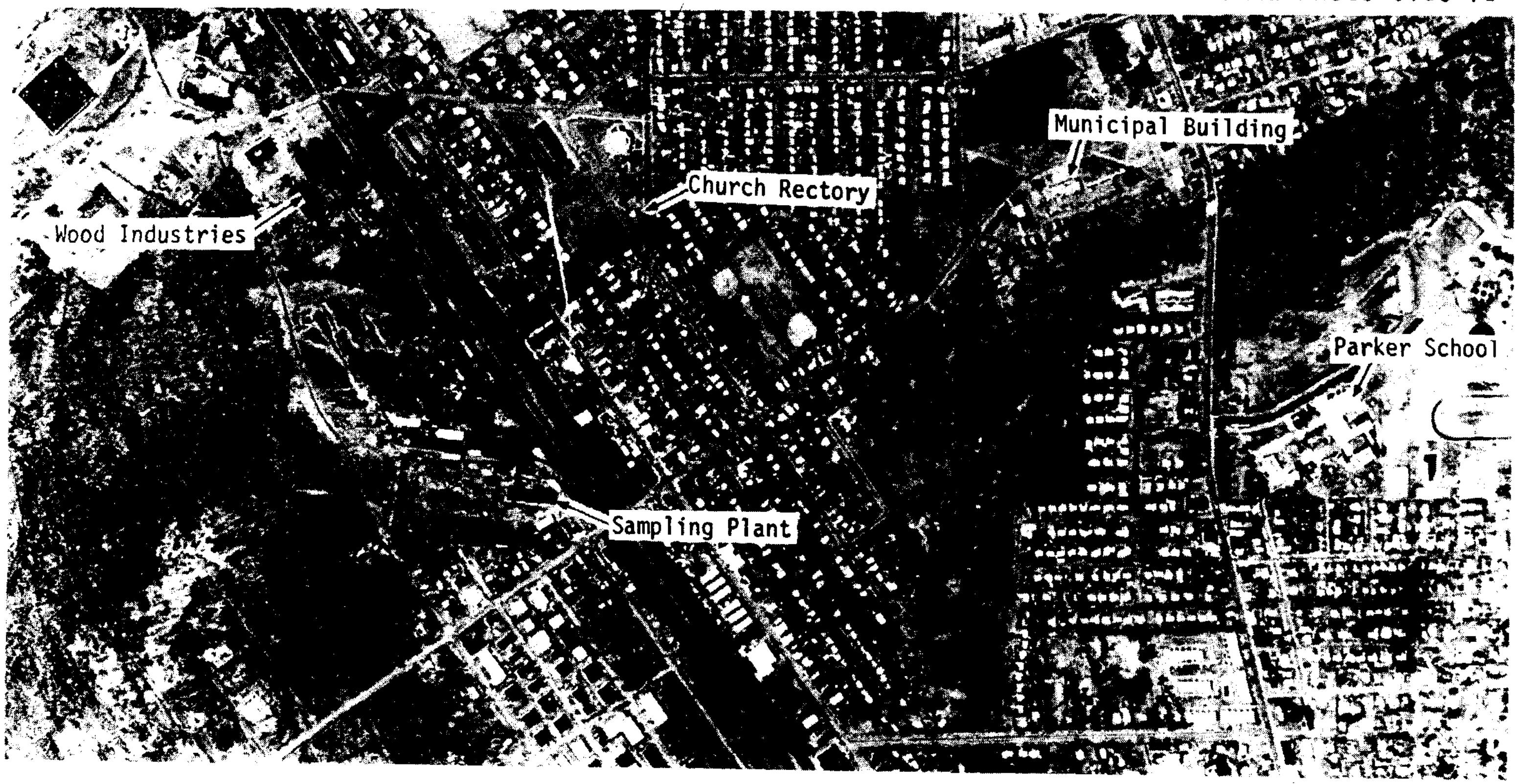

Fig. 7. Aerial view of Middlesex, New Jersey.

ORNL-DWG 79-19510

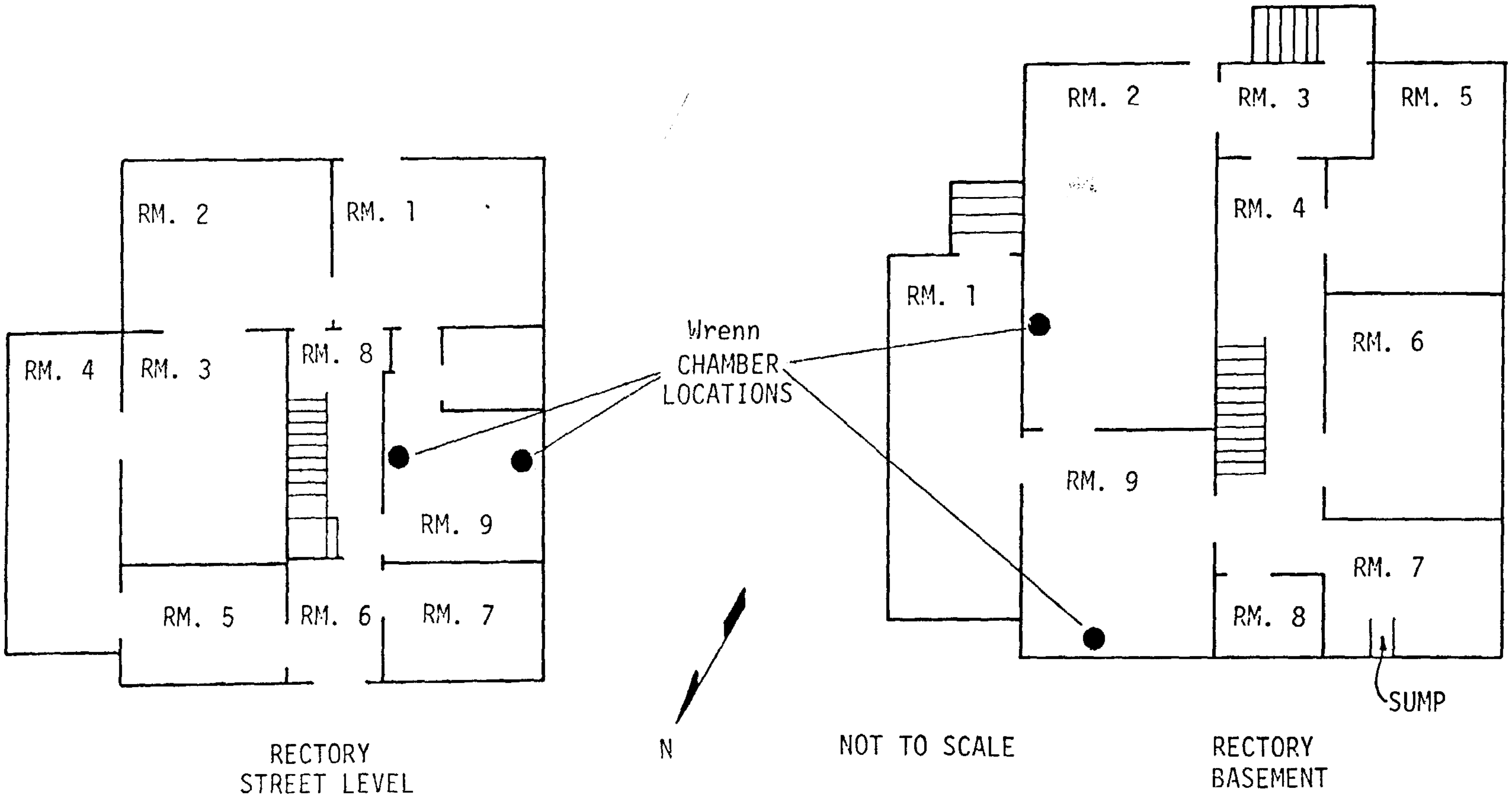

Fig. 8. Locations of radon sampling points in the rectory of Our Lady of Mount Virgin.

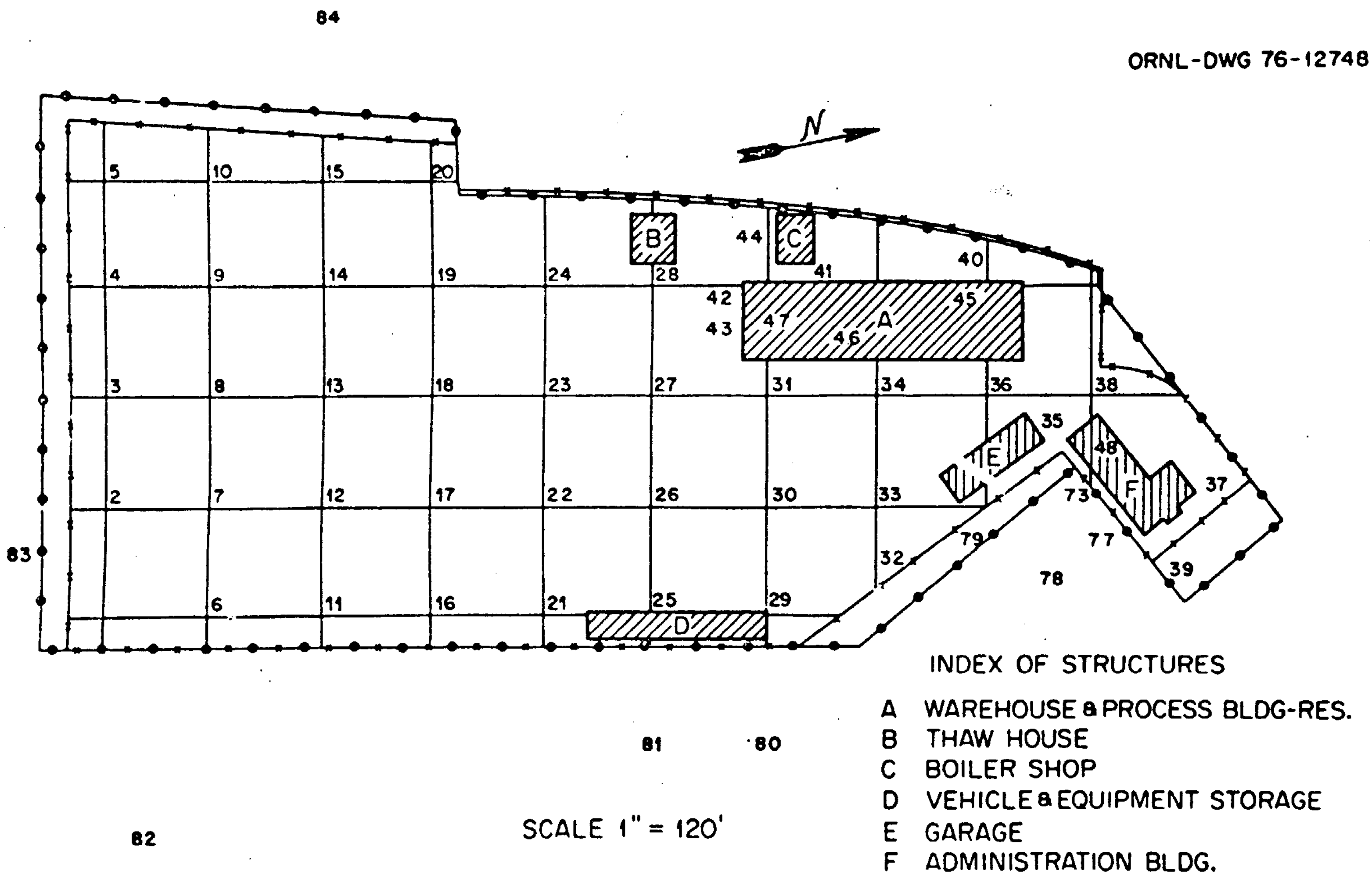

Fig. 9. Locations of radon emanation measurements.

Table 1. Background level measurements of ^{222}Rn and ^{222}Rn daughter concentrations in and around dwellings in the Middlesex area[a]

Location	Concentration			No. of measurements
	Minimum	Maximum	Average	
^{222}Rn (pCi/liter)				
Cellars	0.72	6.0	2.65	31
^{222}Rn daughters (WL)[b]				
Cellars	0.002	0.040	0.013	56
First Floors	0.002	0.026	0.006	56
In dwellings[c] (WL)	0.002	0.40	0.009	112
Outdoors (WL)	0.0015	0.0026	0.002	5

[a]All measurements were made within 50 miles of Middlesex, New Jersey. Individual measurements represent weekly average concentrations. The data were obtained by EML personnel (Ref. 10).

[b]A working level (WL) is any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.

[c]Cellars, first floors, second floors, and garages.

Table 2. Indoor radon daughter concentrations at sampling plant locations[a]

Location[b]	Description	Radionuclide	Concentration pCi/liter	Concentration Working levels
1	Lower level process bldg. Shop	Ra-A	20.3	
		Ra-B	9.1	
		Ra-C	7.5	
		Total	36.9	0.10
2	Lower level process bldg. South end	Ra-A	17.9	
		Ra-B	10.1	
		Ra-C	10.3	
		Total	38.3	0.10
4	Lower level process bldg. North end hall	Ra-A	7.4	
		Ra-B	2.2	
		Ra-C	3.9	
		Total	13.5	0.03
6	Upper level process bldg.	Ra-A	8.4	
		Ra-B	4.1	
		Ra-C	3.7	
		Total	16.2	0.04
7	Upper level process bldg. Gymnasium	Ra-A	5.6	
		Ra-B	4.3	
		Ra-C	3.3	
		Total	13.2	0.04
	Administration bldg.	Ra-A	1.8	
		Ra-B	0.1	
		Ra-C	0.1	
		Total	2.0	0.003

[a]Determined using spot sample spectrometry technique (refs. 5 and 6).

[b]See Fig. 4.

Table 3. Radon and radon daughter measurements in and around sampling plant buildings during March-May, 1976

Location[a]	Radon concentration (pCi/liter) Flask	CRIS[b]	Radon daughter concentration (WL)
F1	23	29[c]	0.15[c]
	18		
	8.5	19[d]	0.14[d]
F2	31		
	4.4		
F3	7.0		
F4	12		
F5	16		
F6	4.4		
F7	13	12[c]	0.090[c]
F8	3.1		
F9	19		
F10	0.28		
F11	0.60		
F12	0.26	2.4[c]	0.016[c]
F13	0.02		
	0.25		
F14	0.4	0.5[d]	0.0040[d]
F15	0.2	0.5[d]	0.0032[d]
F16	0.5		0.014[d]
F17	0.6		

[a]See Figs. 4 and 5.

[b]Measurement integrated over the period 4/9/76-4/15/76.

[c]Measurement integrated over the period 5/12/76-5/18/76.

[d]Cumulative radon integrating sampler.

Table 4. Effect of fan operation on the radon concentration in the administration building - EML data[a]

Room	Concentration (pCi/liter)		% Reduction
	Before fan[b]	After fan[c]	
A-1	2.2	0.5	77
A-2	14	0.5	96
A-4	3.8	*d*	
A-6	2.6	*d*	
A-7	2.9	0.5	83
A-8	3.5	0.7	80
A-9	5.4	0.9	83
A-10	5.5	0.8	85

[a]Reference 12.

[b]Measurements made during 10/6/78 to 12/29/78.

[c]Measurements made during 12/29/78 to 3/2/79.

[d]Not determined.

Table 5. Effect of fan operation on the radon concentration in the administration building - ORNL data

Room[a]	Average concentration (pCi/liter) Before fan[b]	After fan[c]	% Reduction
A-1			
24 hr	0.34	0.21	38
day[d]	0.48	0.24	50
A-4			
24 hr	1.3	0.16	88
day[d]	1.3	0.10	92
A-5			
24 hr	0.31	0.16	48
day[d]	0.28	0.12	57
A-6			
24 hr	1.0	0.14	86
day[d]	1.0	0.10	90

[a]Room A-1 is designated the main office; room A-4, the supply office; room A-5, the shower; and room A-6, the day room.

[b]Measurements made during 12/19/78 to 12/25/78.

[c]Measurements made during 12/26/78 to 1/9/79 except for rooms A-4 and A-6 where data were lost for most of the period 12/26/78 to 1/3/79.

[d]Day average is for the hours 7 a.m. to 3 p.m.

Table 6. Radon concentrations in the rectory basement

Date	Room No.	Concentration (pCi/liter) Minimum	Maximum	Average	No. of measurements
6/2/78	9	2.8	11.5	7.8	26
	2	2.0	9.1	5.5	26
6/3/78	9	11.5	23.3	16.7	48
	2	6.1	13.9	9.1	47
6/4/78	9	19.6	62.4	30.9	48
	2	11.1	31.1	19.7	48
6/5/78	9	13.8	33.7	19.2	48
	2	11.6	22.6	15.5	48
6/6/78	9	23.9	72.9	53.2	48
	2	25.5	47.8	34.8	48
6/7/78	9	4.9	61.1	36.4	48
	2	3.7	38.5	23.5	48
6/8/78	9	16.0	55.6	38.9	48
	2	11.7	37.2	27.0	48
6/9/78	9	9.9	41.8	27.4	47
	2	4.5	28.8	18.9	47
6/10/78	9	14.1	77.9	33.7	48
	2	8.3	32.8	19.8	48
6/11/78	9	10.3	92.0	49.3	46
	2	2.4	42.6	25.4	48
6/12/78	2	21.3	37.6	28.4	23
Total Av.	9			31.4	455
	2			20.7	479

Table 7. Radon concentrations in room 9, first level of the rectory

Date	Concentration (pCi/liter)			No. of measurements
	Minimum	Maximum	Average	
6/13/78	0.1	1.3	0.5	26
6/14/78	0.03	1.2	0.5	48
6/15/78[a]	0.1	1.5	0.8	24
	0.6	1.5	1.0	12
6/16/78	0.4	2.7	1.1	32
	0.3	2.5	1.2	32
Total average			0.9	174

[a]Two Wrenn chambers were utilized in room 9 on 6/15-6/16.

Table 8. Radon emanation rates from various surfaces at the Middlesex site[a]

Location[b]	Emanation rate (pCi/m^2-sec)	Surface	Location[b]	Emanation rate (pCi/m^2-sec)	Surface
1	1.6	Soil	26	0.24	Paved
2	5.8	Paved	27	31.	Hard soil
3	0.33	Paved	29	0.18	Paved
4	0.11	Paved	30	0.47	Paved
5	0.59	Paved	31	8.9	Gravel
6	2.7	Paved	32	0.63	Paved
7	0.63	Paved	33	0.11	Paved
8	1.9	Paved	34	0.25	Gravel
9	0.96	Paved	35	1.9	Hard soil
10	6.2	Paved	36	0.13	Paved
11	1.6	Paved	37	3.1	Grass
12	1.6	Paved	38	6.2	Grass
13	1.2	Paved	38	12.	Grass
14	0.21	Paved	38	4.5	Paved
15	0.36	Paved	39	7.7	Grass
16	4.2	Paved	39	10.	Grass
17	3.5	Paved	40	1.3	Paved
18	1.7	Paved	41	0.72	Paved
19	0.81	Paved	42	1.1	Gravel
20	0.13	Paved	43	6.9	Gravel
21	0.76	Paved	44	0.63	Paved
22	1.1	Paved	45	0.19	Concrete floor
23	0.52	Hard soil	46	0.27	Concrete floor
24	10.	Hard soil	47	0.37	Concrete floor
25	0.05	Paved	48	0.01	Tile floor

[a]Determined using a charcoal canister technique (ref. 10).

[b]See Fig. 8.; No data collected at Station 28.

Table 9. Radon emanation rates from surfaces off the site

Location[a]	Emanation rate (pCi/m^2-sec)	Surface
77	2.4	Grass
78	5.4	Grass
78	6.5	Grass
79	7.	Loose soil
80	0.53	Packed soil
81	0.98	Soil
82	0.36	Grass
83	1.9	Swampy
84	2.1	Loose soil
85[b]	0.35	Soil
86[b]	0.16	Gravel
87[b]	0.43	Sandy soil
88[b]	0.28	Soil
89[b]	0.81	Grass
90[b]	0.10	Soil
91[b]	0.54	Grass
92[b]	0.93	Soil

[a]See Fig. 9.

[b]Locations 85-92 are remote to Middlesex Sampling Plant and are not shown on Fig. 9. Flux measurements at these locations may be interpreted as background for the Middlesex area.

Table 10. Outdoor radon daughter concentrations

Date	Time	Location	Concentration (pCi/liter) RaA	RaB	RaC	Total	Working level
5/19/78	9:10	Process Bldg.	0.11	0.04	0.07	0.22	0.001
	10:15	Wood Ind.	0.03	0.05	0.05	0.13	<0.001
	11:00	Parker School	<0.01	0.05	0.04	0.09	<0.001
	11:40	Municipal Bldg.	0.06	0.02	0.07	0.15	<0.001
	15:55	Process Bldg.	0.03	0.01	0.05	0.09	<0.001
	16:40	Wood Ind.	0.06	0.02	0.04	0.12	<0.001
5/20/78	8:30	Process Bldg.	0.11	0.14	0.12	0.37	0.001
	9:45	Wood Ind.	0.11	0.08	0.18	0.37	0.001
	10:45	Parker School	0.09	0.12	0.07	0.28	0.001
	11:30	Municipal Bldg.	0.08	0.06	0.07	0.21	0.001
	13:20	Process Bldg.	0.09	0.11	0.02	0.22	0.001
	14:10	Wood Ind.	0.02	0.03	0.04	0.09	<0.001
	15:20	Parker School	0.02	0.08	0.02	0.12	<0.001
	16:20	Municipal Bldg.	0.06	0.05	0.03	0.14	<0.001
5/21/78	8:28	Process Bldg.	0.13	0.14	0.09	0.36	0.001
	9:15	Municipal Bldg.	0.07	0.10	0.03	0.20	0.001
	10:05	Parker School	0.13	0.07	0.06	0.26	0.001
	10:45	Wood Ind.	0.06	0.08	0.04	0.18	0.001
	11:30	Process Bldg.	0.08	0.03	0.06	0.17	0.001
	13:25	Municipal Bldg.	0.04	0.06	0.06	0.16	<0.001
	14:28	Parker School	0.05	0.01	0.07	0.13	0.001
	15:05	Wood Ind.	0.04	0.02	0.05	0.11	<0.001
	15:55	Process Bldg.	0.03	0.01	0.03	0.07	<0.001
	16:40	Municipal Bldg.	0.02	0.02	0.02	0.06	<0.001
	17:23	Parker School	0.02	<0.01	0.03	0.05	<0.001
5/22/78	8:30	Process Bldg.	0.05	0.06	0.05	0.16	0.001
	9:45	Wood Ind.	0.04	0.01	0.05	0.10	<0.001
	10:30	Municipal Bldg.	0.04	0.02	0.04	0.10	<0.001
	11:20	Parker School	0.01	0.04	0.01	0.06	<0.001
	13:00	Process Bldg.	0.03	0.05	<0.01	0.09	<0.001
	14:05	Wood Ind.	<0.01	0.02	0.01	0.04	<0.001
	14:50	Municipal Bldg.	0.01	0.01	0.03	0.05	<0.001
	15:40	Parker School	0.05	0.07	<0.01	0.13	<0.001
	16:55	Process Bldg.	0.04	0.03	0.03	0.10	<0.001
5/23/78	8:30	Process Bldg.	0.21	0.21	0.13	0.55	0.002
	9:18	Municipal Bldg.	0.07	0.10	0.02	0.19	0.001
	10:25	Parker School	0.05	0.04	0.03	0.12	<0.001
	11:30	Wood Ind.	0.06	<0.01	0.06	0.13	<0.001
Average		Process Bldg.				0.22	0.001
		Municipal Bldg.				0.14	<0.001
		Parker School				0.14	<0.001
		Wood Ind.				0.14	<0.001

Table 11. Outdoor radon concentrations

Date	Location	Average concentration (pCi/liter)[a] Minimum	Maximum	Daily overall average (pCi/liter)	No. of measurements
5/15/78	Process Bldg.	0.05	0.20	0.13	10
	Municipal Bldg.	<0.01	0.02	0.01	15
5/16/78	Process Bldg.	0.05	0.24	0.13	27
	Wood Ind.	<0.01	0.07	0.02	26
	Municipal Bldg.	<0.01	0.11	0.02	28
5/17/78	Process Bldg.	0.04	0.22	0.12	39
	Wood Ind.	<0.01	0.09	0.04	48
	Municipal Bldg.	<0.01	0.15	0.03	48
5/18/78	Process Bldg.	0.02	0.34	0.16	42
	Wood Ind.	<0.01	0.10	0.02	47
	Municipal Bldg.	<0.01	0.08	0.03	47
	Parker School	<0.01	0.11	0.05	25
5/19/78	Process Bldg.	0.06	0.39	0.20	28
	Wood Ind.	<0.01	0.13	0.02	48
	Municipal Bldg.	0.01	0.16	0.06	48
	Parker School	<0.01	0.13	0.06	48
5/20/78	Process Bldg.	0.01	0.26	0.11	24
	Wood Ind.	0.01	0.23	0.10	47
	Municipal Bldg.	0.02	0.22	0.08	48
	Parker School	<0.01	0.26	0.09	48
5/21/78	Process Bldg.	0.04	0.26	0.11	25
	Wood Ind.	<0.01	0.15	0.05	48
	Municipal Bldg.	<0.01	0.14	0.03	48
	Parker School	<0.01	0.15	0.03	46
5/22/78	Process Bldg.	0.05	0.58	0.16	25
	Wood Ind.	0.01	0.16	0.06	48
	Parker School	<0.01	0.19	0.06	47
5/23/78	Wood Ind.	0.02	0.30	0.13	35
	Parker School	<0.01	0.32	0.09	47
5/24/78	Parker School	<0.01	0.10	0.04	17
Average	Process Bldg.			0.14	220
	Wood Ind.			0.06	347
	Municipal Bldg.			0.04	302
	Parker School			0.06	326

[a]Average concentration of two Wrenn chamber measurements.

APPENDIX I

APPENDIX I

TECHNIQUES FOR THE MEASUREMENT OF RADON AND RADON DAUGHTERS IN AIR

Wrenn Chambers

The Wrenn Chamber (Fig. I-A) operates on the principle that RaA ions are positively charged. Radon is allowed to diffuse through a foam rubber covered, hemispherically shaped metal screen, which filters radon daughters. As radon decays, after diffusing into the cavity, RaA ions are attached to a thin aluminized mylar film which is stretched over a zinc sulfide scintillation detector (Fig. I-B). The potential between this aluminized mylar film and the hemispherically shaped wire screen (Fig. I-C) creates a strong electric field which serves to attract the charged ions. The ions thus attracted remain on the surface of the mylar film and continue their radioactive decay to other radon daughters. The principal radiation detected by a radon monitor of this type is the alpha particles from RaA and RaC'.

The Wrenn Chambers are calibrated through a series of measurements in an enclosure containing radon. Comparisons are made between these measurements and a series of measurements of the radon concentration using Lucas cells (described below). A sample of air is withdrawn from the enclosure into a Lucas cell for this purpose.

Lucas Chamber

A Lucas Chamber (Fig. I-D) consists of a 95-ml glass flask, coated inside with a uniform layer of zinc sulfide. For measurements of radon concentration in the air, the flask is evacuated to a pressure of 50 microns. The flask is then taken to a location where a sample is desired and the collection valve is opened. After collection of air in the flask, sample counting is delayed 3 to 4 hours to allow the radon daughters to attain equilibrium. Alpha particles from the radon daughters produce scintillations in the zinc sulfide. The sample is normally

ORNL-Photo 5199-78

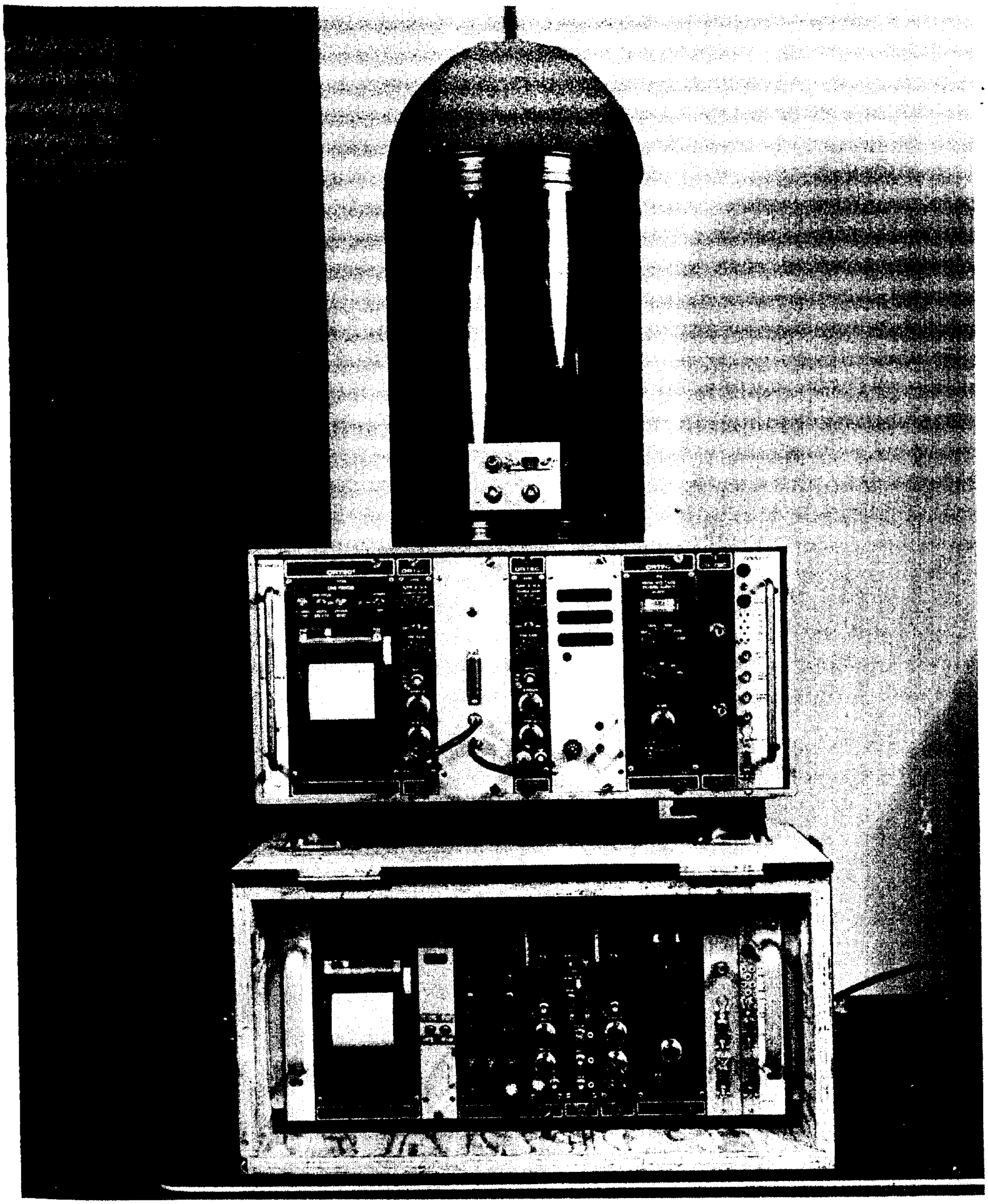

Fig. I-A. View of Wrenn chamber detector and control unit.

ORNL-Photo 0867-78

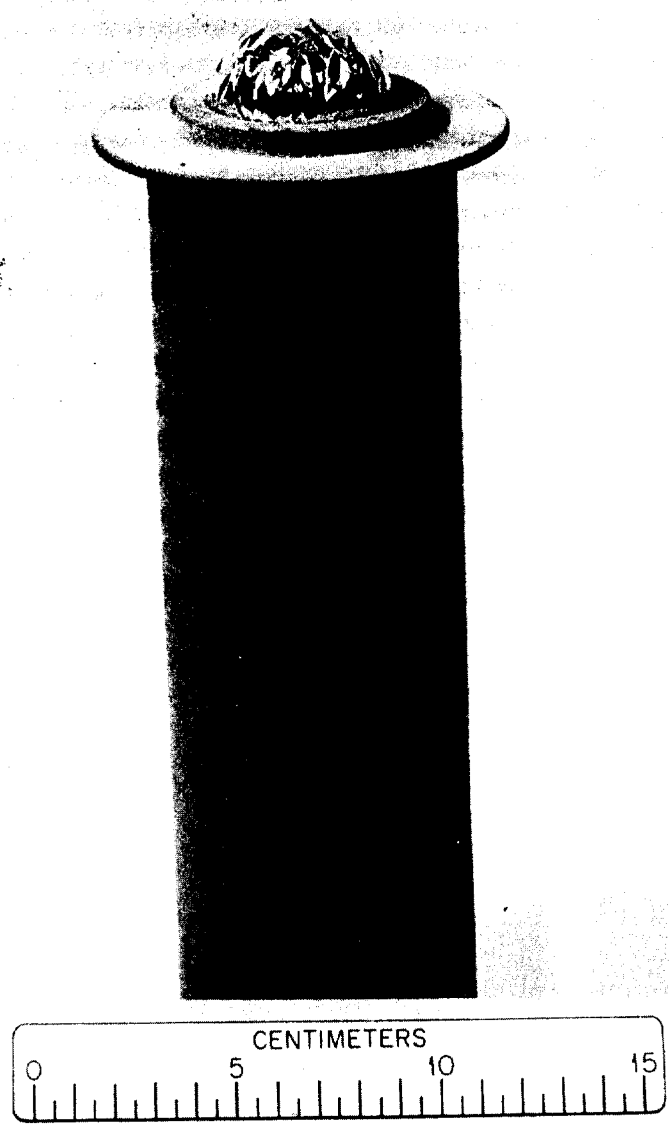

Fig. I-B. View of mylar covered ZnS detector.

ORNL-Photo 0686-78

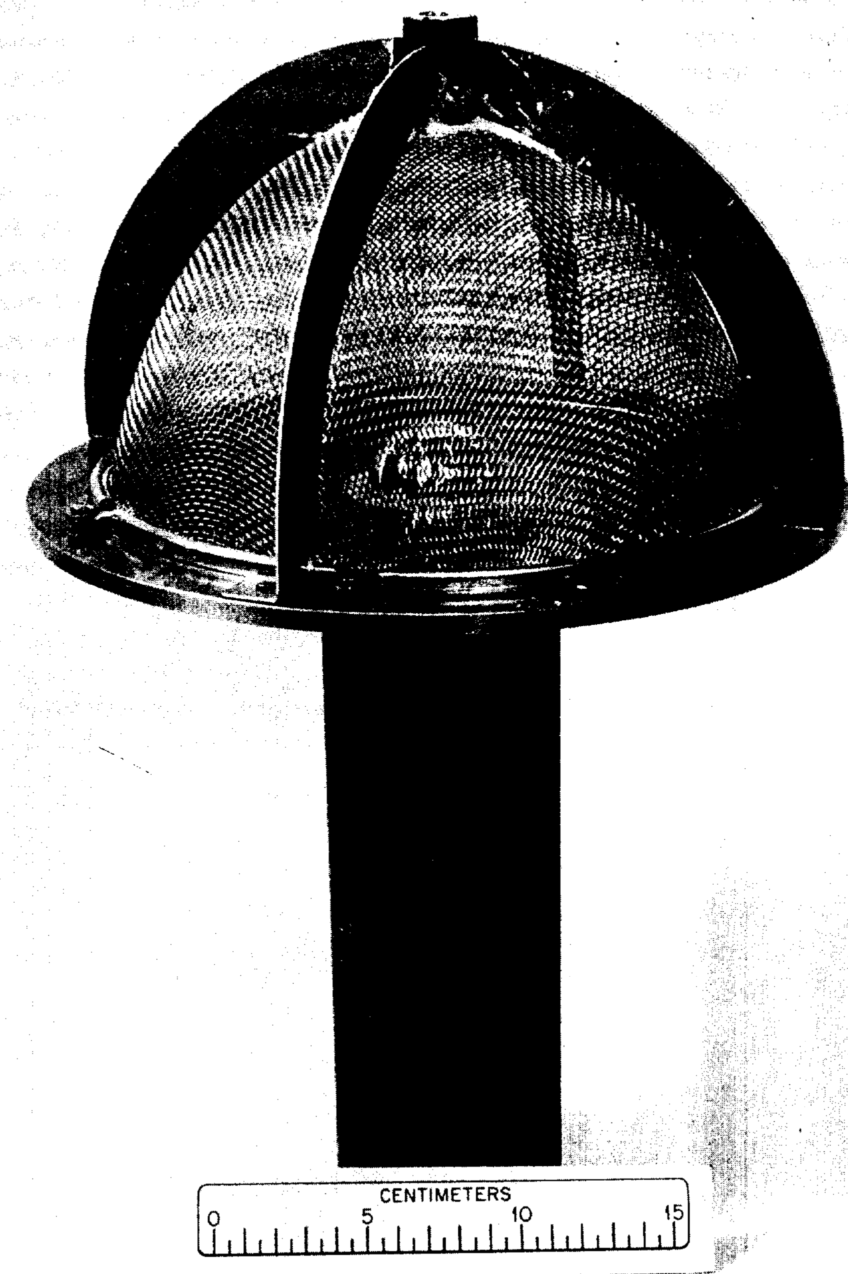

Fig. I-C. View of mylar covered ZnS detector inside ground screen.

ORNL-Photo 1083-78

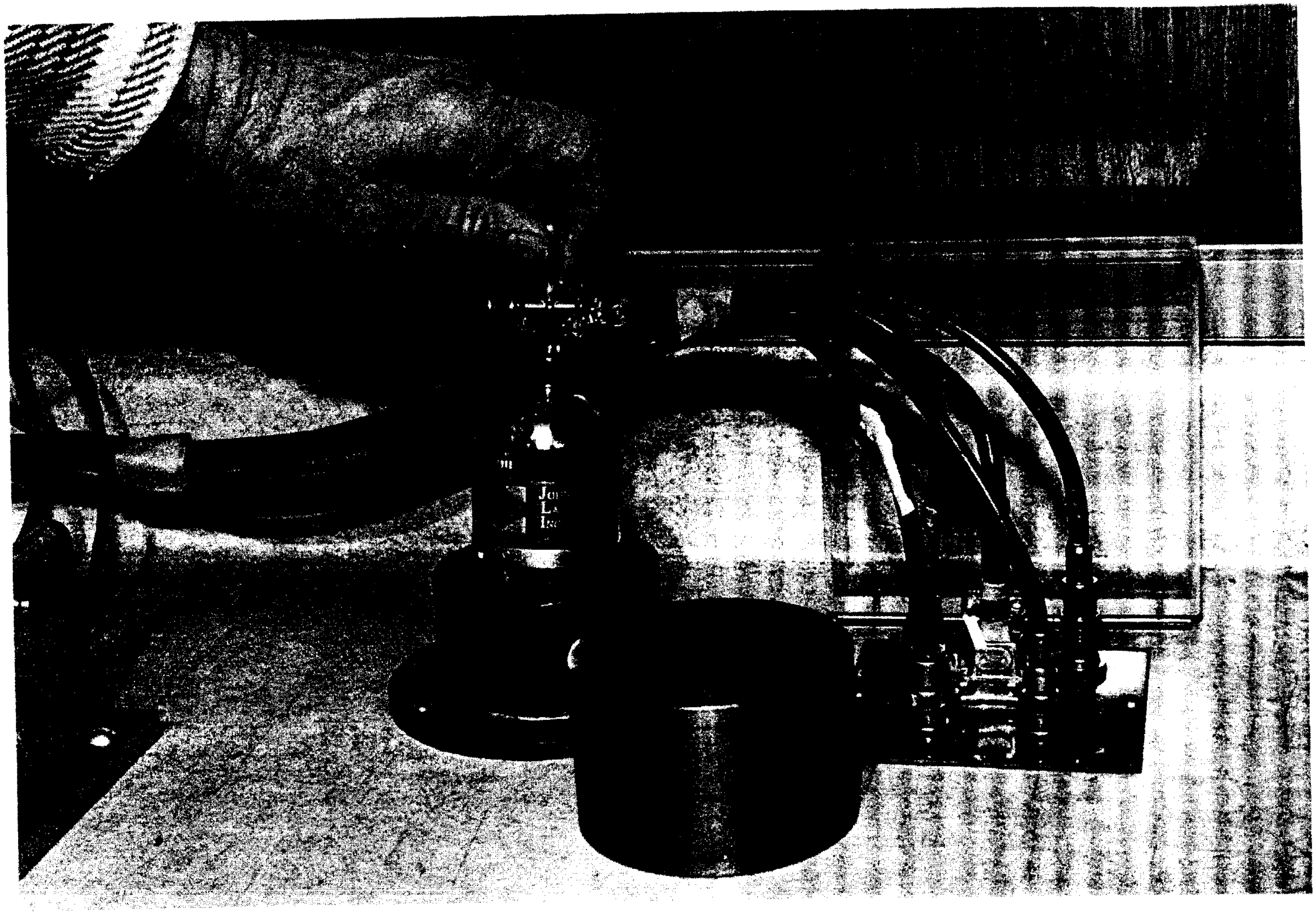

Fig. I-D. Lucas chamber.

counted with a photomultiplier tube assembly. After the sample has been counted, the flask is again evacuated to 50 microns to prevent contamination.

Technique for the Measurement of ^{222}Rn Progeny Concentrations in Air

An alpha spectrometry technique has been refined by Kerr(I-1, I-2) for the measurement of ^{222}Rn progeny concentrations in air. From one integral count of the ^{218}Po alpha activity and two integral counts of the ^{214}Po alpha activity, the concentrations in air of ^{218}Po, ^{214}Bi and ^{214}Pb may be calculated.

Particulate ^{222}Rn daughters attached to airborne dust are collected on a membrane filter with a pore size of 0.4 microns. A sampling time of 5-10 minutes and a flow rate of 12-16 LPM are used. This filter sample is then placed under a silicon surface barrier detector and counted. The detector and counting system used for radon daughter measurements are shown in Fig. I-E. Usually, counting of this kind is performed with a vacuum between the sample and the detector which requires a complicated sample holder and time-consuming sample changing methods. Experiments at this laboratory have shown that ease in sample handling is obtained with little loss in resolution when helium is used as a chamber fill gas.(I-3) In this counter, helium is flowed between the diode and the filter sample, which are separated by a distance of 0.5 cm. One integral count of the ^{218}Po alpha activity is obtained from 2 to 12 minutes, and two integral counts of the ^{214}Po activity are obtained from 2 to 12 minutes and 15 to 30 minutes, respectively. All counting intervals are referenced to $t = 0$ at the end of sample.

The equations describing the ^{222}Rn progeny atoms collection rates on the filter are of the form

$$\frac{dn_i(t)}{dt} = C_i v + \lambda_{i-1}(t) - \lambda_i n_i(t), \qquad (1)$$

ORNL-Photo 1081-78

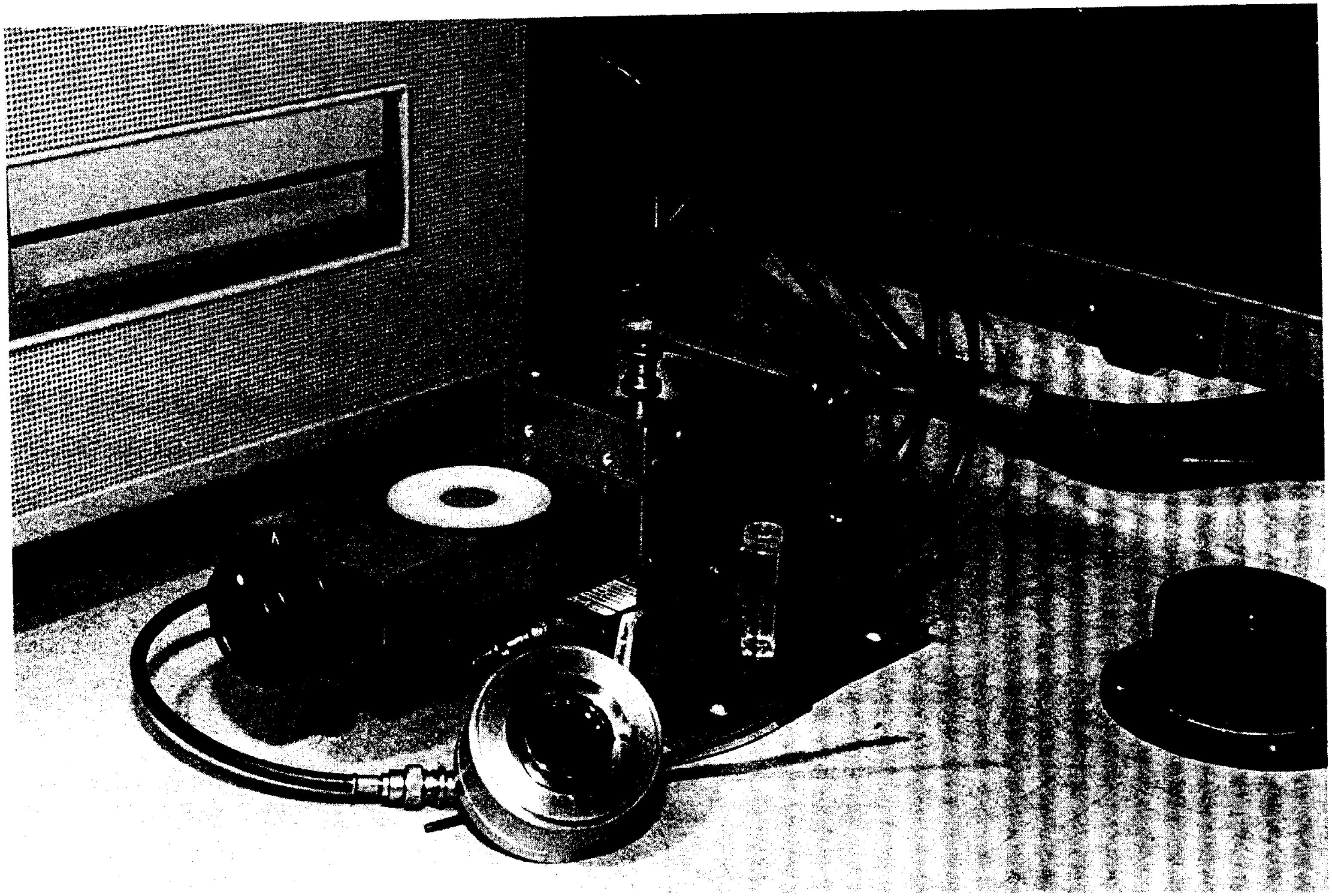

Fig. I-E. Alpha spectrometer used to assess radon daughter concentrations.

where

n_i = number of the i^{th} species of atom on the filter as a function of time,

λ_i = radioactive decay constant of the i^{th} species (min^{-1}),

C_i = concentration of the i^{th} species (atoms l^{-1}), and

v = air sampling flow rate (liters min^{-1}).

The solution of Eq. (1) is of the form

$$y = e^{ax} [y_0 = \int F(x)\ e^{ax} dx].$$

From the general form of the solution, specific equations can be obtained describing the number of each ^{222}Rn decay product collected on the filter as a function of time. Also by letting $v = 0$ in Eq. (1), a set of equations describing the decay on the filter of each ^{222}Rn progeny can be obtained. The equations describing the decay of ^{222}Rn progeny on the filter can be integrated and related to the integral counts obtained experimentally. Values for the total activities of ^{218}Po, ^{214}Pb, and ^{214}Bi on the filter at the end of sampling are obtained by applying matrix techniques. The airborne concentrations are obtained by solving the equations describing the atom collection rates on the filter. A computer program has been written to perform these matrix operations, to calculate the air concentrations of the radon progeny, and to estimate the accuracy of the calculated concentrations.

As described in reference I-4, during investigations utilizing this alpha spectrometry technique at another site, daughters of ^{219}Rn (actinon) were discovered during the counting procedure. The presence of these progeny, primarily a result of contamination with uranium ore raffinates, in observable and sometimes rather high concentrations could result in large errors in the calculation of ^{222}Rn daughter concentrations using the previously described method. Hence, a revised procedure has been developed[I-5] to determine the daughter concentration of both radon isotopes. This technique is based on a similar filter counting procedure, utilizing measurements over two additional energy regions.

REFERENCES FOR APPENDIX I

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APPENDIX II

SURGEON GENERAL's GUIDELINES

Part 712

Grand Junction Remedial Action Criteria

Federal Register, Vol. 41, No. 253, pp. 56777-8
Thursday, December 30, 1976

PART 712 - GRAND JUNCTION REMEDIAL ACTION CRITERIA

712.1 Purpose

(a) The regulations in this part establish the criteria for determination by ERDA of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colo., to radiation emanating from uranium mill tailings which have been used as construction-related material.

(b) The regulations in this part are issued pursuant to Publ. L. 92-314 (86 Stat. 222) of June 16, 1972.

713.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colo., under or adjacent to which uranium mill tailings have been used as a construction-related material between January 1, 1951, and June 16, 1972, inclusive.

712.3 Definitions

As used in this part:

(a) "Administrator" means the Administrator of the Energy Research and Development Administration or his duly authorized representative.

(b) "Area of Grand Junction, Colo.," means Mesa County, Colo.

(c) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.

(d) "ERDA" means the Energy Research and Development Administration or duly authorized representative thereof.

(e) "Construction-related material" means any material used in the construction of a structure.

(f) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) Averaging the results of 6 air samples, each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen (mR)" means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-218), Radium C (bismuth-214), and Radium C (polonium-214).

(k) "Remedial action" means any action taken with a reasonable expectation of reducing the radiation exposure resulting from uranium mill tailings which have been used as construction-related material in and around structures in the area of Grand Junction, Colo.

(l) "Surgeon General's guidelines" means radiation guidelines related to uranium mill tailings prepared and released by the Office of the U.S. Surgeon General, Department of Health, Education and Welfare on July 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium mill operation involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

712.4 Interpretations

Except as specifically authorized by the Administrator in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of ERDA other than a written interpretation by the General Counsel will be recognized to be binding upon ERDA.

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Energy Research and Development Administration, Washington, D.C. 20545.

712.6 General radiation exposure level criteria for remedial action

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommend the following graded action levels for remedial action in terms of external gamma radiation level (EGR) and indoor radon daughter concentration level (RDC) above background found within dwellings constructed on or with uranium mill tailings:

EGR	RDC	Recommendation
Greater than 0.1 mR/hr.	Greater than 0.05 WL.	Remedial action indicated
From 0.05 to 0.1 mR/hr.	From 0.01 to 0.05 WL.	Remedial action may be suggested
Less than 0.05 mR/hr.	Less than 0.01 WL.	No remedial action indicated

712.7 Criteria for determination of possible need for remedial action

Once it is determined that a possible need for remedial action exists, the record owner of a structure shall be notified of that structure's eligibility for an engineering assessment to confirm the need for remedial action and to ascertain the most appropriate remedial measure, if any. A determination of possible need will be made as a result of the presence of uranium mill tailings under or adjacent to the structure, one of the following criteria is met:

(a) Where ERDA approved data on indoor radon daughter concentration levels are available:

(1) For dwellings and schoolrooms: An indoor radon daughter concentration level of 0.01 WL or greater above background.

(2) For other structures: An indoor radon daughter concentration level of 0.03 WL or greater above background.

(b) Where ERDA approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/hr. or greater above background.

(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(A) It may be presumed that if the external gamma radiation level is equal to or exceeds 0.02 mR/hr. above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

(B) It should be presumed that if the external gamma radiation level is less than 0.01 mR/hr. above background, the indoor radon daughter concentration level is less than 0.01 WL above background and no possible need for remedial action exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/hr. above background but is less than 0.02 mR/hr. above background, measurements will be required to ascertain the indoor radon daughter concentration level.

(2) For other structures: (i) An external gamma radiation level of 0.15 mR/hr. above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiation level/indoor radon daughter concentration level relationship. Decisions will be made in individual cases based upon the results of actual measurements.

712.8 Determination of possible need for remedial action where criteria have not been met

The possible need for remedial action may be determined where the criteria in 712.7 have not been met if various other factors are present. Such factors include, but are not necessarily limited to, size of the affected area, distribution of radiation levels in the affected area, amount of tailings, age of individuals occupying affected area, occupancy time, and use of the affected area.

712.9 Factors to be considered in determination of order or priority for remedial action

In determining the order or priority for execution of remedial action, consideration shall be given, but not necessarily limited to, the following factors:

(a) Classification of structure. Dwellings and schools shall be considered first.

(b) Availability of data. Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in 712.7 will be considered first.

(c) Order of application. Insofar as feasible remedial action will be taken in the order which the application is received.

(d) Magnitude of radiation level. In general, those structures with the highest radiation levels will be given primary consideration.

(e) Geographical location of structures. A group of structures located in the same immediate geographical vicinity may be given priority consideration particularly where they involve similar remedial efforts.

(f) Availability of structures. An attempt will be made to schedule remedial action during those periods when remedial action can be taken with minimum interference.

(g) Climatic conditions. Climatic conditions or other seasonable considerations may affect the scheduling of certain remedial measures.

712.10 Selection of appropriate remedial action

(a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/hr. above background in the case of dwellings and schools and 0.15 mR/hr. above background in the case of other structures.

(b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. ERDA shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

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