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ANL-OHS/HP-83-104



**SURPLUS FACILITIES  
MANAGEMENT PROGRAM**

**RADIOLOGICAL SURVEY  
OF  
CEER RIO PIEDRAS FACILITY  
SAN JUAN, PUERTO RICO**

**June 15-25, 1982**

*Handwritten signature: D. R. ...*



**OCCUPATIONAL HEALTH AND SAFETY DIVISION  
Health Physics Section  
ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS**

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9700 South Cass Avenue  
Argonne, Illinois 60439

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Prepared by

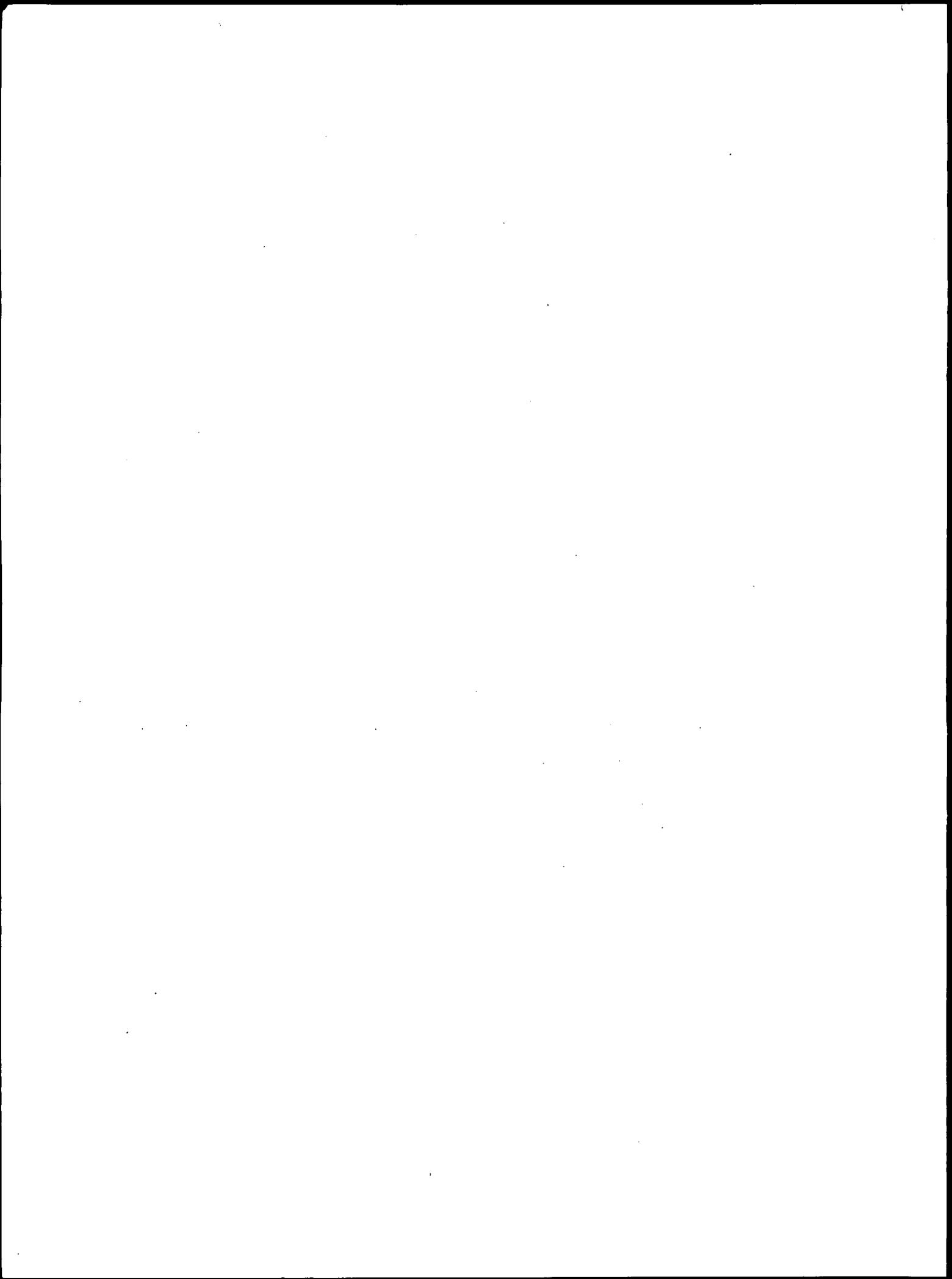
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PREFACE AND EXECUTIVE SUMMARY

In 1961, the Puerto Rico Nuclear Center (PRNC) initiated work with medical applications of radioisotopes in the Bio-Medical Building and associated facilities under an Atomic Energy Commission (AEC) contract. In 1976, the PRNC became the Center for Energy and Environment Research (CEER), and less emphasis was placed on nuclear activities. As a consequence, the U.S. Energy Research and Development Administration (ERDA) agreed that part of the facility should be surveyed, decontaminated as necessary, and released for unrestricted use. The survey and decontamination activities were conducted by CEER personnel.

In June 1982, at the request of the Department of Energy's (DOE) Office of the Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness (ASEP), the Argonne National Laboratory's (ANL) Radiological Survey Group conducted a post-remedial-action survey in support of certification activities to provide an independent review of the success of the remedial decontamination efforts. Results of that survey are reported in this document.

Elevated radiation readings from residual radioactive material were measured at four locations during the course of the survey. Three of the locations (small-area spots) were assumed to be contaminated primarily with  $^{14}\text{C}$ . They exhibited maximum beta readings ranging from 14 k dis/min-100  $\text{cm}^2$  to 96 k dis/min-100  $\text{cm}^2$  as measured with a gas-flow proportional survey meter. Alpha readings taken with the same instrument were indistinguishable from the determined instrument background levels. Low-energy x- and gamma-ray survey instrument readings ranged from 1 k cts/min to 10 k cts/min. The radiation exposure rate measured at contact with a Geiger-Mueller (GM) end window detector survey meter ranged from 0.04 mR/h to 2.5 mR/h. Before the end of the ANL survey, these three spots were cleaned by CEER personnel to the point that no contamination was detectable.

The fourth location exhibiting an elevated radiation reading was on the second floor of the Bio-Medical Building above a first-floor "cave" (a shielded enclosure in which radioactive materials can be handled with remote-controlled manipulators). The cave contained a quantity of the radioactive isotope molybdenum-99 ( $^{99}\text{Mo}$ ) used as a generator of the isotope technetium-99m ( $^{99\text{m}}\text{Tc}$ ), the later being used in diagnostic nuclear medical studies. Work with medical

applications of radioisotopes continues on the first floor of the building. The strength of the  $^{99}\text{Mo}$  source changes due to decay and periodic replacement for further generation of  $^{99\text{m}}\text{Tc}$ . At the time of the survey, the radiation reading, measured with x- and gamma-ray survey instruments on the second floor above the source, was 15 k cts/min for low-energy x- and gamma-rays. The radiation exposure rate measured with the GM end window was 0.05 mR/h. The ambient radiation level at 1 m (3 ft)\* was 60  $\mu\text{R/h}$ . Since this was the only radiation source noted in the area to be released for uncontrolled use, a hazard evaluation was made. For a person working on the second floor directly above this source for 40 hours per week, the yearly dose would be approximately 110 mrem. This is 22% of the 500-mrem yearly whole-body dose commitment for an individual in an uncontrolled area, as specified in the DOE 5480.1, Chapter XI requirements.

Concentrations of long-lived activity and radon progeny, as measured in indoor air samples, were all at the expected background levels.

Based on the findings of the Radiological Survey Group and the action taken by CEER personnel during the course of the survey, it is recommended that the second and third floors and roof of the Bio-Medical Facility, as well as associated facilities (the Shop Building and the Animal House), be released for unrestricted use. It is noted, however, that at the time of the survey, use of radiation sources continued in other areas of the Bio-Medical Building.

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\*When metric units are followed (in parentheses) by English units, the measurements were originally made in English units and then converted into metric. In cases where only metric units are given, the values were either originally given in metric, or resulted from calculations involving numbers previously converted from English into metric.

This survey was performed by the following Health Physics personnel of the Occupational Health and Safety Division, Argonne National Laboratory, Argonne, Illinois: W. H. Smith, K. F. Flynn, R. Rodriguez, and J. D. Thereon.

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RADIOLOGICAL SURVEY  
OF  
CEER RIO PIEDRAS FACILITY  
SAN JUAN, PUERTO RICO

INTRODUCTION

The Atomic Energy Commission (AEC) built the Bio-Medical Life Sciences Research and Training Center in Puerto Rico (Fig. 1) under the 1958 Atoms for Peace Program to enable the Puerto Rico Nuclear Center (PRNC) to serve the Latin American area. The Rio Piedras site was beneficially occupied in 1960 and utilized by the University of Puerto Rico (UPR) in 1961. At that time the Bio-Medical Building had only two floors; a third floor was added in 1971. An exterior view of the building is shown in Figure 2. Floor plans of the second and third floors are shown in Figures 3 and 6, respectively.

Research, education, and training programs in the medical applications of radioisotopes constituted the main activities conducted at this facility. Substantial amounts of radioactive materials were used for nuclear medicine and radiation therapy purposes. In addition, trace amounts of radionuclides were used for radiochemical and terrestrial ecology studies. The principal radioisotopes used at the facility were  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{22}\text{Na}$ ,  $^{32}\text{P}$ ,  $^{45}\text{Ca}$ ,  $^{51}\text{Cr}$ ,  $^{59}\text{Fe}$ ,  $^{60}\text{Co}$ ,  $^{65}\text{Zn}$ ,  $^{75}\text{Se}$ ,  $^{90}\text{Sr}/^{90}\text{Y}$ ,  $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ ,  $^{113}\text{Sn}$ ,  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{137}\text{Cs}/^{137\text{m}}\text{Ba}$ , and  $^{203}\text{Hg}$ . All were beta or positron and/or gamma emitters, with half-lives ranging from 67 hours for  $^{99}\text{Mo}$  to 5730 years for  $^{14}\text{C}$ .

In 1976, the mission of PRNC was modified and it was renamed the Center for Energy and Environment Research (CEER), with more emphasis placed on non-nuclear activities. The U.S. Energy Research and Development Administration (ERDA), a successor agency to the AEC, agreed to transfer the facilities to the UPR and to release some areas of the facility for unrestricted use. The Health and Safety Division personnel for CEER performed radiation surveys and decontamination activities before the release of the Bio-Medical Building, the Shop, and the Animal House. A survey report was published by CEER in 1981.<sup>1</sup>

The Director of Real Estate Management of the Office of Facility Planning and Support for the Department of Energy (DOE), the successor agency to ERDA, in

1981 requested that the Office of Operational Safety of the Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness (ASEP) to review the adequacy of the radiological survey and decontamination report to determine if the radiological condition of the decontaminated portions of the facility was acceptable for unrestricted use. In accordance with the post-remedial-action (certification) responsibilities of the DOE-ASEP, Office of Operational Safety, Public Safety Division, requested that the Argonne National Laboratory (ANL) Radiological Survey Group review the report as part of the post remedial action (certification) activities. As a follow-up, the ANL Radiological Survey Group also conducted a detailed, independent radiological survey at the CEER Facility to assure that the facility had indeed been adequately decontaminated, and to provide associated documentation relevant to the potential certification for unrestricted release of the facility. The survey, the results of which are reported in this document, was conducted during the period June 15 to June 25, 1982. On or about September 30, 1982, the buildings and lands were turned over to the University of Puerto Rico. The first floor of the Bio-Medical Building continues to be used for work with radioisotopes under NRC License No. 52-01946-07. The funds for the facility operations now come from such sources such as the Commonwealth of Puerto Rico and the University of Puerto Rico, as well as from DOE contracts.

The Medical Center of CEER, Rio Piedras, consists of the Bio-Medical Building (1670 m<sup>2</sup>), the Shop Building (mechanical services, 259 m<sup>2</sup>), Animal House (591 m<sup>2</sup>), Storage Facility (37 m<sup>2</sup>) and the Emergency Plant (11.5 m<sup>2</sup>). The layout of these facilities is shown in Figure 1.

## SURVEY AND ANALYTICAL TECHNIQUES

### General

The radiological survey conducted by ANL covered three of the buildings--the Bio-Medical Building (second and third floors and roof), the Shop, and the Animal House. The survey was performed on all accessible floors and walls to a height of 2 m (7 ft) and on a representative selection of accessible overhead structures, such as ceilings, pipes, vents and light fixtures in the three

buildings. Locations of the accessible areas surveyed are indicated in Table 1 and Figures 3 through 8, 10 and 12.

The Storage Facility was not surveyed because it continues to be used to store radioactive waste under NRC License No. 52-01946-07. The Emergency Plant is a small outbuilding containing the emergency generator that supplies the emergency lighting and fire alarm systems in case of power failures. Because it was never involved in any radioactive work, there was no need for a survey of this building. Because work with radioactive materials continues at the Medical Center under NRC license and because the short half-lives of the radioactive materials used in the past, it was decided by the ANL Radiological Survey Group that the grounds did not require any additional survey over that performed by CEER personnel.

### Instrumentation

Five types of survey instruments were used to perform the direct radiological survey investigations. An Eberline FM-4G gas-flow proportional probe, with a detection area of 325 cm<sup>2</sup>, was used with the Eberline PAC-4G-3 electronics to survey the floors. A PAC-4G-3, with a hand-held gas-flow proportional probe having a detection area of 51 cm<sup>2</sup> was used to survey the walls, roof, and areas inaccessible with the floor monitor. An Eberline Model 530 Geiger-Mueller (GM) count rate meter with an Eberline HP-190 end-window probe was used to measure the contact exposure rate (mR/h) of the contaminated areas. An Eberline Pulse Rate Meter, Model PRM-5-3 with a Model PG-2 Low Energy Gamma Scintillation Detector, was used to detect low-energy x-ray and gamma radiation. An Eberline Micro R/h Scintillation Meter, Model PRM-7, was used to detect higher-energy gamma-rays and to determine the general ambient background radiation levels throughout the area surveyed. All five instruments are described in more detail in Appendix 1.

Although <sup>239</sup>Pu and <sup>90</sup>Sr-<sup>90</sup>Y standards were used to calibrate the gas-flow instruments, it should be noted that the numerous isotopes that could be encountered exhibit emission energies differing from those of the standards used in the calibration. Thus, when detecting known isotopes that emit beta energies differing from those of the standards (such as <sup>14</sup>C), a conversion factor for those particular radionuclides was developed to determine the appropriate yield. The methods used to determine the conversion factors are described in Appendix 2. All readings of disintegrations per minute per 100 cm<sup>2</sup> (dis/min-100 cm<sup>2</sup>), as

reported in Table 1, are equated to  $^{14}\text{C}$  unless stated otherwise. Since instrument calibrations were to infinitely-thin flat-plate standards, all reported readings should be regarded as minimal values; no corrections were made for absorption by surface media.

When possible, the isotopes of contamination were identified by performing a gamma-spectral analysis (using an ND-6 portable spectrometer described in Appendix 1) on the contaminated area or item.

### Smear Survey

Dry smears were taken at selected locations throughout the three buildings surveyed. Smears were taken on original structures and components such as walls, floors, pipes, vents, and laboratory benches. All standard smears were taken with Whatman No. 1 filter paper, 4.25 cm in diameter. A standard smear is accomplished by applying moderate pressure by the tips of the first two fingers to the back of the filter paper and then rubbing the paper over the surface. Smears of  $\sim 930 \text{ cm}^2$  ( $1 \text{ ft}^2$ ) were normally taken. A smear of  $100 \text{ cm}^2$  was taken from any area or object that had an instrument reading higher than "normal" background, or if there was excessive dirt or dust in an area.

Three different instruments were used to measure (count) the contamination on the smears. They were first counted in groups of ten using a 10-wire flat-plate gas-flow proportional detector developed at ANL. This instrument detects alpha and beta particles and x- and gamma-rays. Additionally, two smears of each group were removed and counted in the sensitive Nuclear Measurements Corporation  $2\pi$  Internal Gas-Flow Proportional Counters (PC-3A, PC-5, also referred to as PC counters), using an aluminized Mylar cover (Mylar spun top) over the smear paper. Smears were counted in each detector for both alpha and beta-gamma activity. These instruments are described in detail in Appendix 1.

The results of the instrument surveys and smears are given in Table 1, and the locations of elevated instrument readings and smear locations are shown in Figures 3 through 8, 10 and 12.

### Air Samples

Air samples ("grab" samples) were collected with a commercial vacuum cleaner modified at ANL for use as a particulate air-sampling device. A flow rate of 40

cubic meters per hour ( $\text{m}^3/\text{h}$ ) was used. A 10% portion (5 cm in diameter) was removed from the filter medium after collection and counted for both alpha and beta-gamma activity in the PC counter. The counting results were used to determine the concentrations of radon ( $^{222}\text{Rn}$ ), radon progeny, thoron ( $^{220}\text{Rn}$ ), and the presence of any long-lived radionuclides. Information and assumptions used to determine the radon progeny concentrations are presented in Appendix 3; the results are given in Table 2, and the locations where air samples were collected are shown in Figures 3 and 6.

## SURVEY RESULTS

### General

The PAC-4G-3 instrument readings have been normalized to units of disintegrations per minute per 100 square centimeters ( $\text{dis}/\text{min}-100 \text{ cm}^2$ ) using the factors derived in Appendix 2. The readings are equated to  $^{14}\text{C}$ . The PAC-4G-3 readings are reported in net disintegration rates; i.e., the background count rates have been subtracted from the gross count rates prior to conversion to  $\text{dis}/\text{min}-100 \text{ cm}^2$ . Since all alpha readings were measured at the background level, it was not necessary to correct for alpha contribution to the beta-gamma readings. Since all the smears gave background readings, the actual  $\text{dis}/\text{min}-100 \text{ cm}^2$  have not been calculated. All smear results are reported as background (BKGD) in Table 1.

The background levels varied somewhat as expected. The average background readings for all instruments used in the survey are given in Appendix 1. The fraction of the surface area accessible for survey varied from room to room. Percentages of the total area that were accessible for survey are indicated in Table 1.

### Instrument and Smear Survey

Measurements indicating radioactivity above background levels were found only at four locations, three on the second floor, and one on the first floor landing of the Bio-Medical Building. The contamination at three of the locations apparently was primarily  $^{14}\text{C}$ . The ND-6 multichannel analyzer system

indicated natural gamma-ray background spectra at each spot. The PAC-4G-3 indicated the radioactivity to be low-energy beta particles which could be absorbed by low density absorbers. The three spots of radioactivity are listed below and in Table 1.

<u>Location</u>	<u>Readings</u>
Main Stair, First-Floor Landing	96 k dis/min-100 cm <sup>2</sup> , <sup>14</sup> C equivalent 10 k cts/min low-energy x and gamma 2.5 mR/h at contact
Room 201	14 k dis/min-100 cm <sup>2</sup> , <sup>14</sup> C equivalent 2 k cts/min low-energy x and gamma 1.3 mR/h at contact
Room 244	19 k dis/min-100 cm <sup>2</sup> , <sup>14</sup> C equivalent 1 k cts/min low-energy x and gamma 0.04 mR/h at contact

The fourth location indicating activity was in Room 250.

Rooms 250 & 250A	0.05 mR/h at contact 60 μR/h at contact 15 k cts/min low-energy x and gamma
------------------	---

A gamma spectral analysis conducted in Room 250 with the ND-6 and a 2"x2" NaI(Tl) detector indicated that the source was <sup>99m</sup>Tc, a decay product of <sup>99</sup>Mo stored in an open-top "cave" (a shielded enclosure) located in the room below. This radiation source was being used for diagnostic nuclear medicine.

The spots of contamination in Room 201 and on the first floor landing were cleaned to the point that no contamination was detectable, and tile was removed from Room 244. No further contamination was then identified in these rooms. Since the <sup>99</sup>Mo source continued to be utilized in operations conducted on the first floor, it was not removed.

Results of the instrument and smear surveys were compared with both the American National Standards Institute (ANSI) Draft Standard N13.12, "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use," and the NRC's "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material" (see Appendix 4). Since carbon-14 was assumed as the contaminant, the surface contamination limits

for carbon-14 were used for comparative purposes. The allowable limit in the ANSI Standard for Group 3 (including carbon-14) activity is 5000 dis/min-100 cm<sup>2</sup> total, of which only 1000 dis/min-100 cm<sup>2</sup> can be removable. These levels may be averaged over 1.0 m<sup>2</sup>, provided the maximum activity in any area of 100 cm<sup>2</sup> is less than three times the limit value. In the NRC Guidelines for beta emitters, the average allowable contamination level is 5000 dis/min-100 cm<sup>2</sup> beta-gamma, with the maximum being 15,000 dis/min-100 cm<sup>2</sup> beta-gamma. Removable contamination is to be less than 1000 dis/min-100 cm<sup>2</sup> beta-gamma. Measurements used for the average may not be averaged over more than 1 m<sup>2</sup>, and the maximum level applies to an area of not more than 100 cm<sup>2</sup>. Also, the average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 mg/cm<sup>2</sup> of total absorber. The ANSI Standard is identical to the NRC Guidelines for Group 3 beta emitters.

#### Air Samples

The results of the analyses of the six air samples collected are given in Table 2. Details for calculating radon (<sup>222</sup>Rn) and thoron (<sup>220</sup>Rn) concentrations and radon progeny Working Levels are given in Appendix 3. Working Levels ranged from 0.0003 to 0.0046 WL. Under the U.S. Surgeon General's Guidelines in 10 CFR 712 (see Appendix 4), concentrations less than 0.01 WL above background do not indicate a need for remedial action. All these concentrations detected in the survey appear to be within the normally expected background range. The radon concentrations ranged from 0.026 to 0.46 pCi/l, and the thoron concentrations were measured at 0.001 and 0.008 pCi/l. These concentrations are well below the concentration guide of 3 pCi/l for radon and 10 pCi/l for thoron as given in the Department of Energy's "Requirements for Radiation Protection" for uncontrolled areas (DOE 5480.1, Chapter XI, see Appendix 4). No long-lived radionuclides were detected on any air sample.

#### DOSE AND POTENTIAL HAZARD EVALUATION

The only potential radiological hazard detected and not removed was the radiation emanating from the <sup>99</sup>Mo source located in a cave on the first floor and detected directly above Room 250. Therefore, for the hazard evaluation, it

was assumed that a person worked a maximum of 40 hours per week at a desk in Room 250 directly above the source.

The maximum exposure rate in Room 250 was measured at 60  $\mu\text{R/h}$  at 1 m, including a 7  $\mu\text{R/h}$  background. Hence, the total annual dose from this source would be:

$$(60 \mu\text{R/h} - 7 \mu\text{R/h})(40 \text{ h/week})(52 \text{ weeks/year})(1 \text{ rem/R}) = 110 \text{ mrem/year.}$$

This is well below the 500 mrem/year dose commitment permitted for an individual in an uncontrolled area as specified in the DOE 5480.1, Chg. 6, Chapter XI "Requirements for Radiation Protection" (see Appendix 4). Therefore, it is judged that this area does not constitute a radiological hazard in terms of external exposure.

#### CONCLUSIONS AND RECOMMENDATIONS

The three locations with elevated readings from spot contamination found on the second floor and on the first floor landing of the Bio-Medical Building were all cleaned to below detectable levels before the ANL Radiological Survey Group left the CEER facility. Radiation was also detected in Room 250 from the sources in the cave on the first floor of the building. However, the estimated yearly dose of 110 mrem that would be received by a person working 40 hours per week in Room 250 is only 22% of the yearly dose commitment allowed for an individual in an uncontrolled area as specified in DOE 5480.1, Chapter XI. No radiation levels above the expected background were measured in the Shop or the Animal House.

Based on these findings, it is recommended that the second and third floors and roof of the Bio-Medical Building, the Shop, and the Animal House be released for unrestricted use.

REFERENCES

1. U.S. Department of Energy. 1981. "Radiological Survey Report for CEER Rio Piedras Facilities." Center for Energy and Environment Research, University of Puerto Rico.

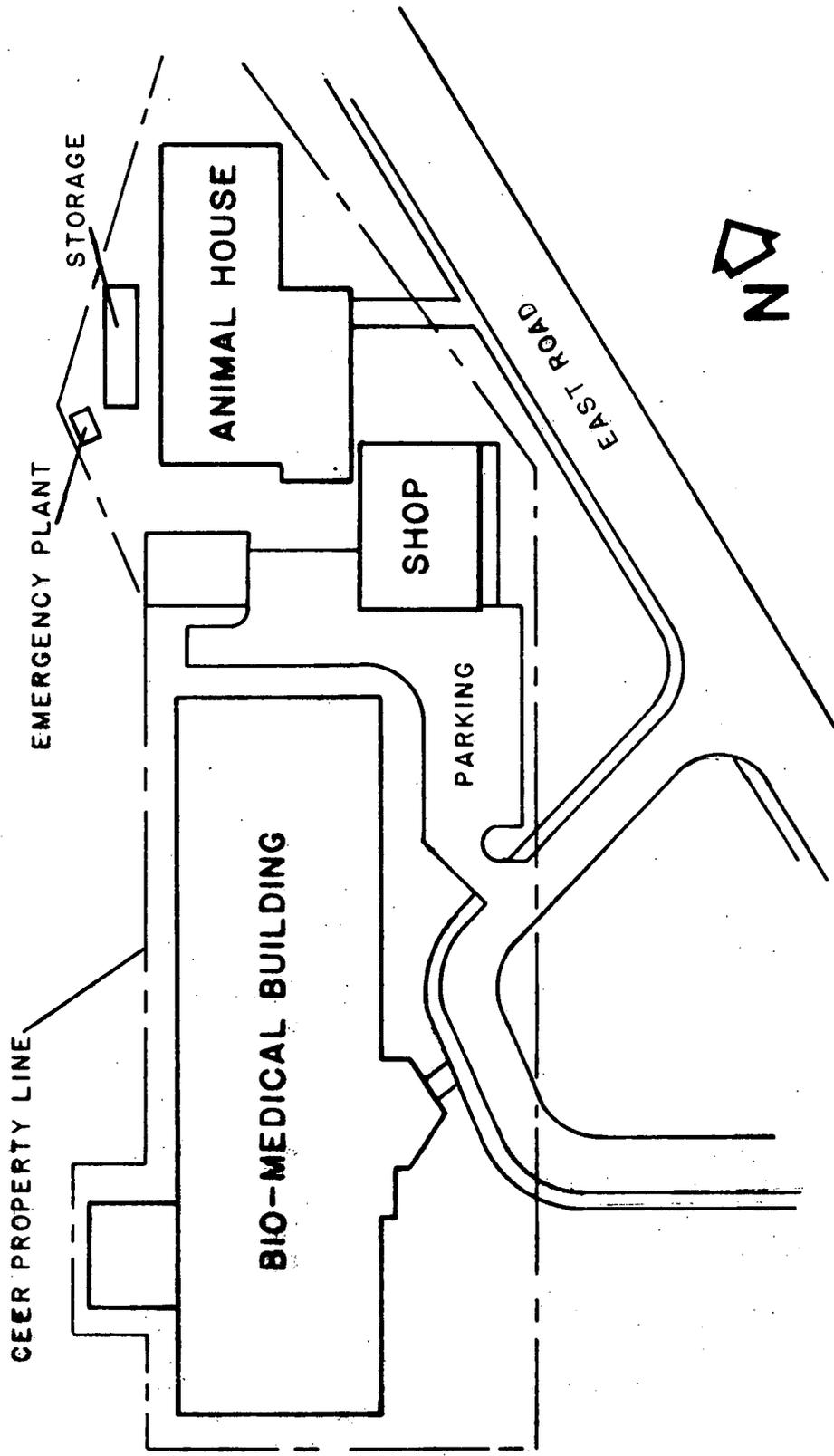


FIGURE 1. CEER RIO PIEDRAS FACILITY

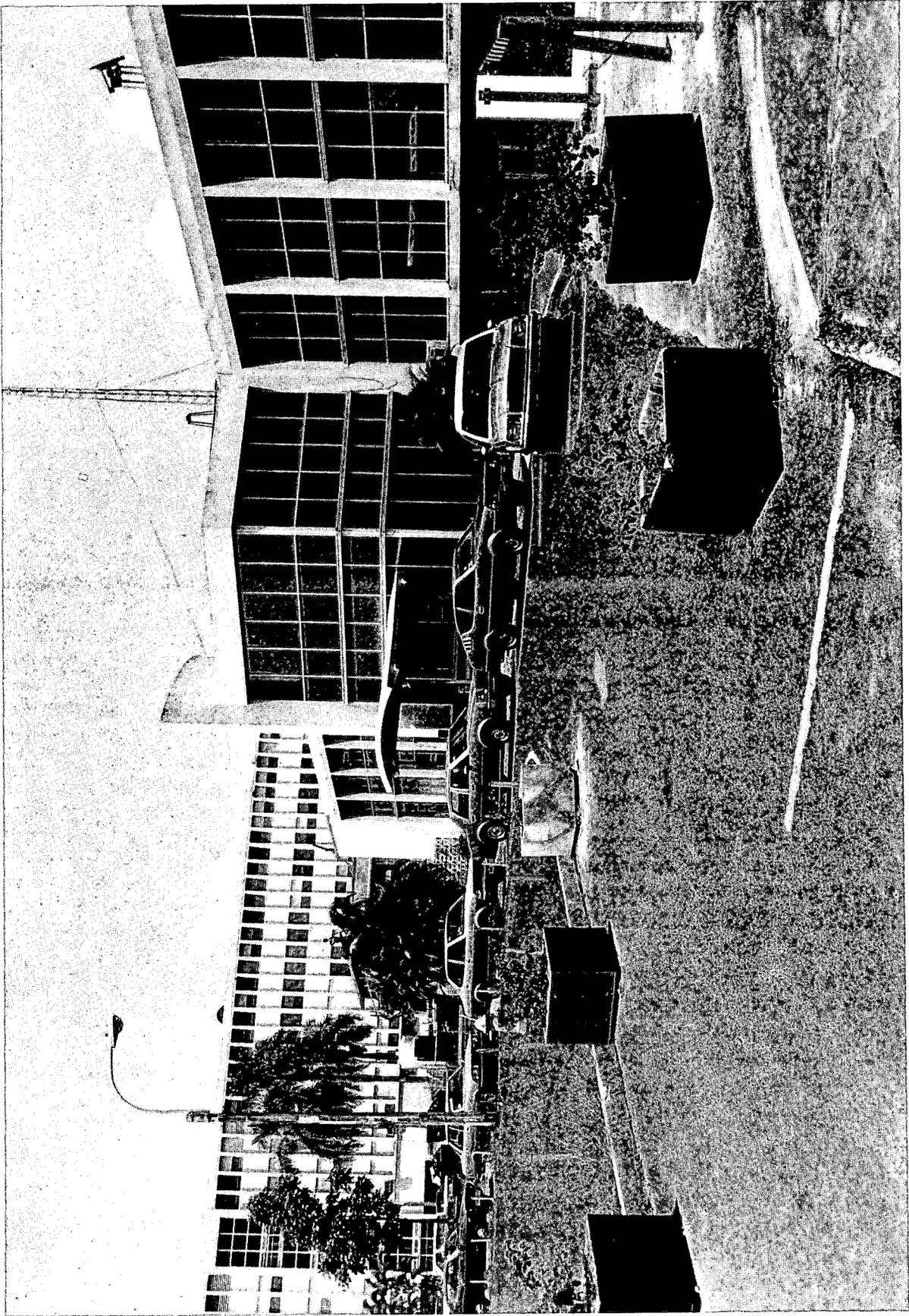


FIGURE 2. BIO-MEDICAL BUILDING, EAST FACE

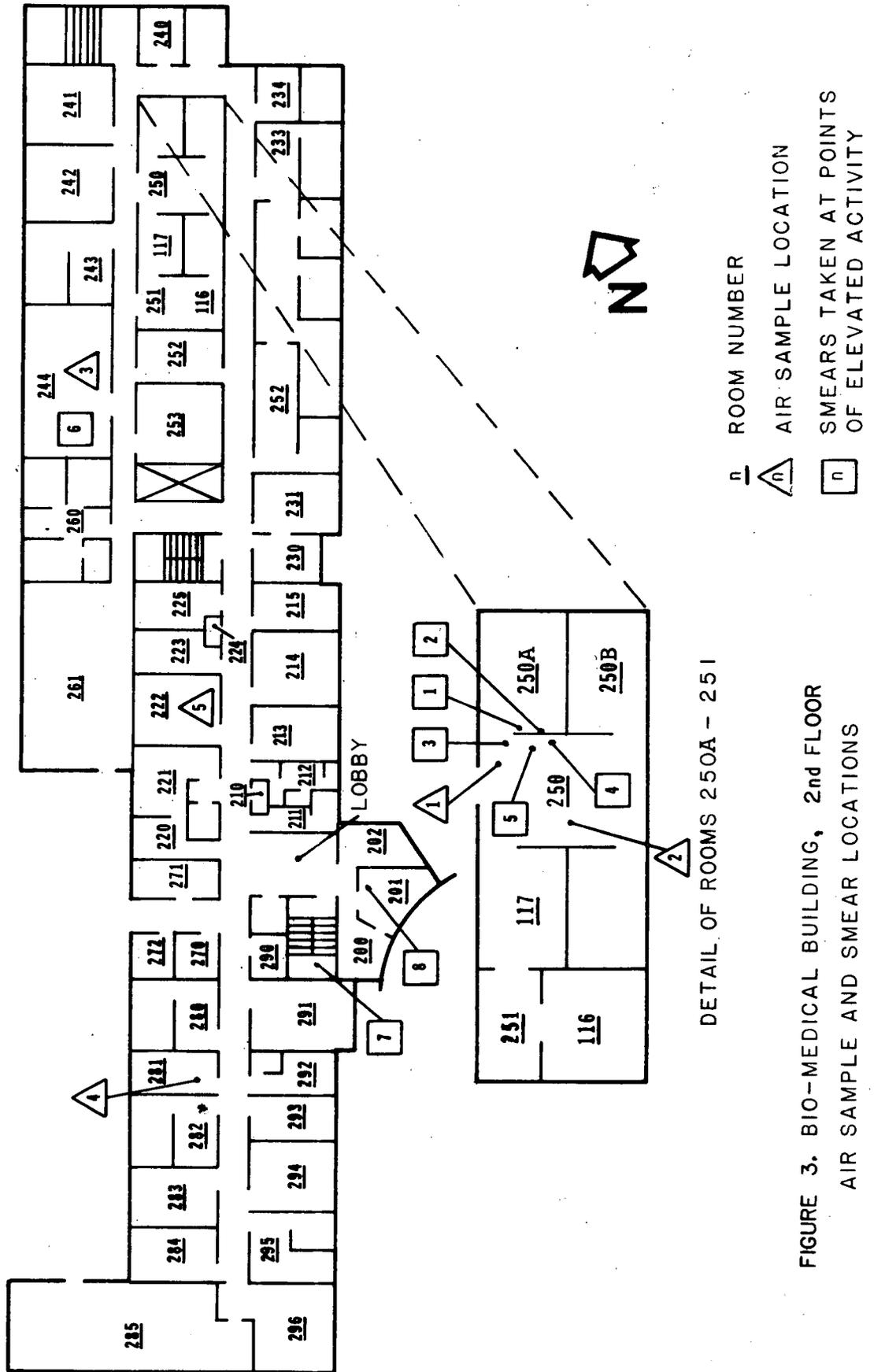
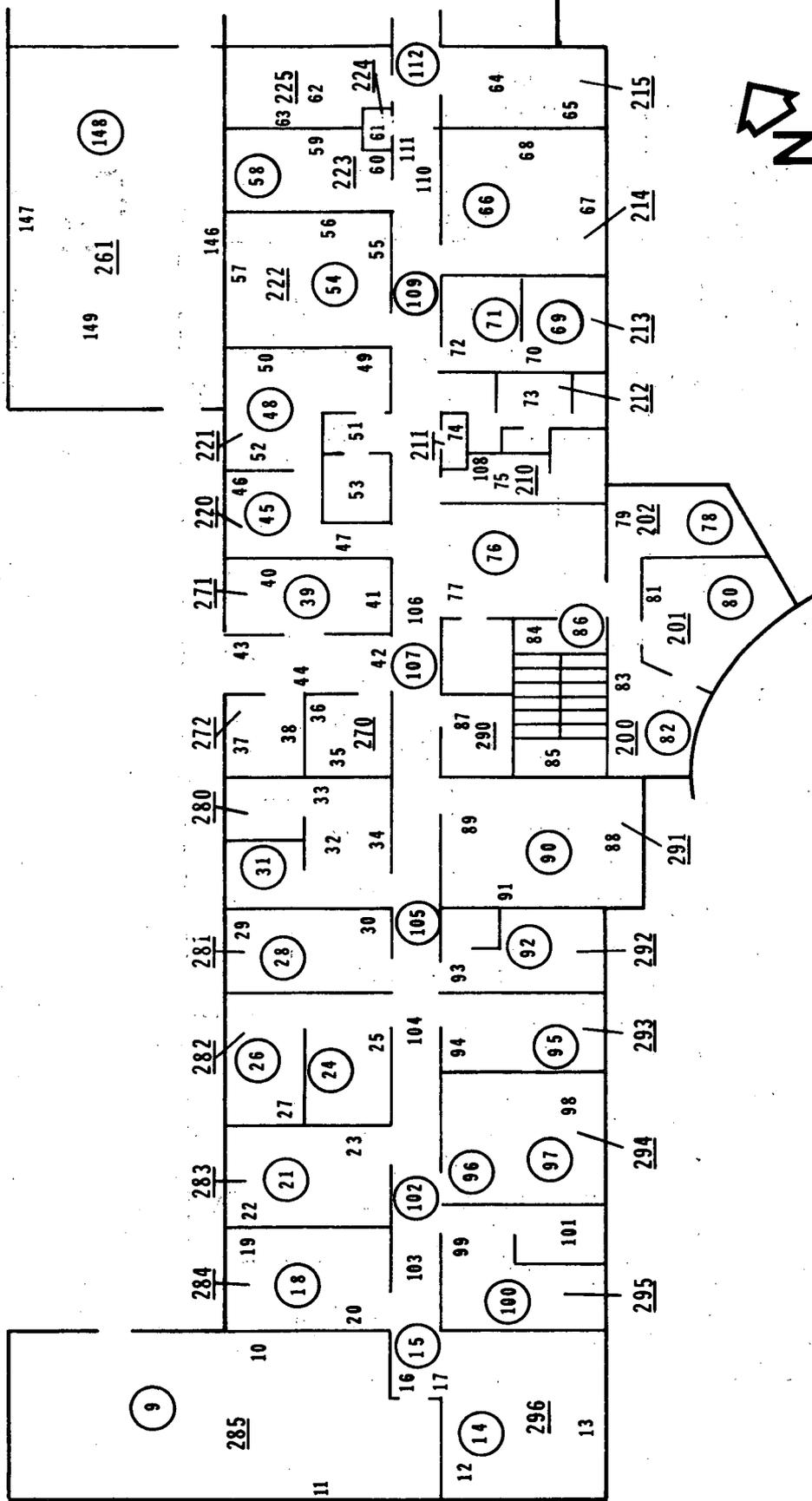
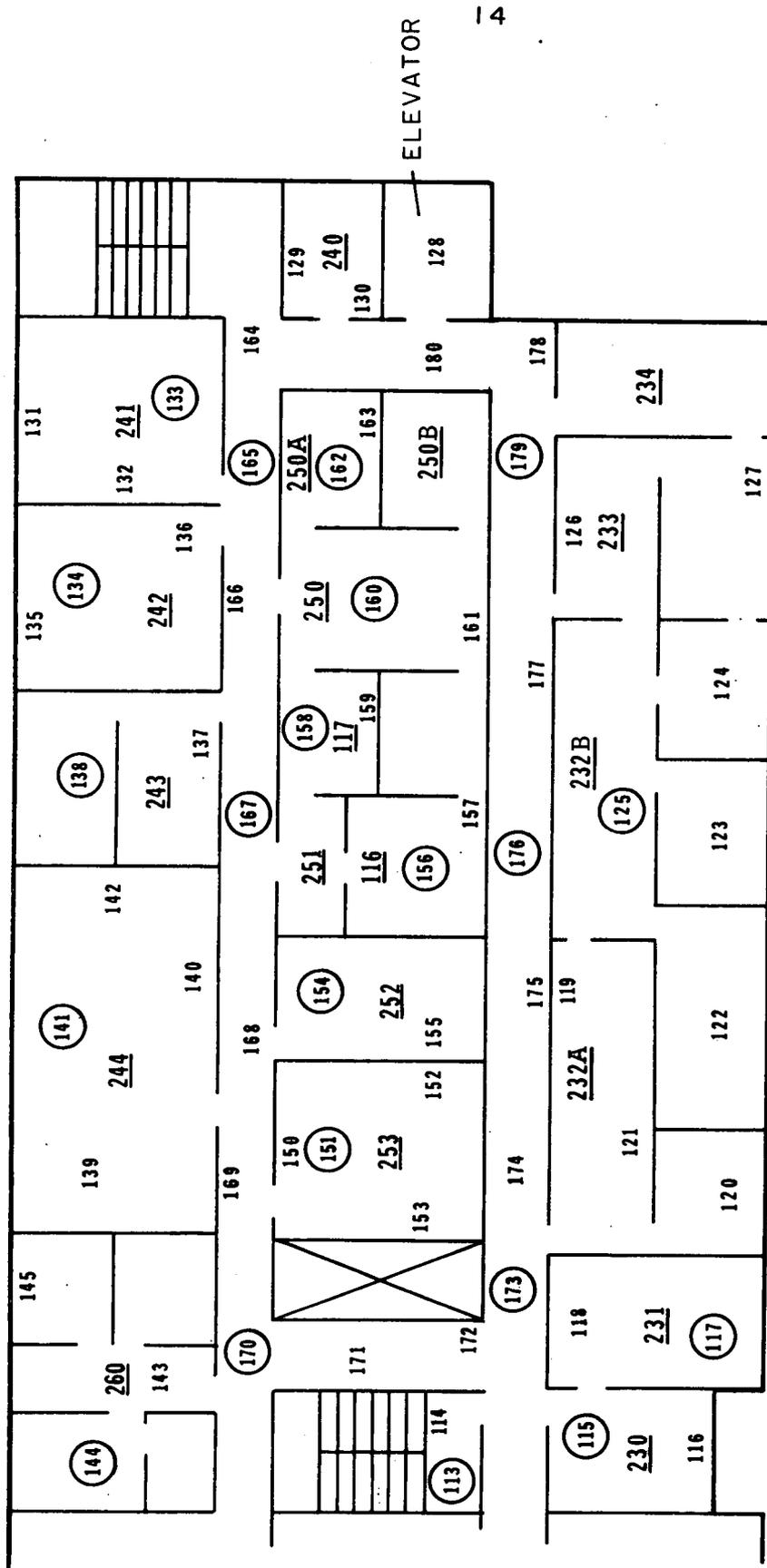


FIGURE 3. BIO-MEDICAL BUILDING, 2nd FLOOR  
AIR SAMPLE AND SMEAR LOCATIONS



- ROOM NUMBER
- SMEAR LOCATION
- OVERHEAD SMEAR LOCATION

FIGURE 4. BIO-MEDICAL BUILDING 2nd FLOOR, SOUTH END SMEAR LOCATIONS



- ROOM NUMBER
- n SMEAR LOCATION
- n OVERHEAD SMEAR LOCATION

FIGURE 5. BIO-MEDICAL BUILDING 2nd FLOOR, NORTH END  
SMEAR LOCATIONS

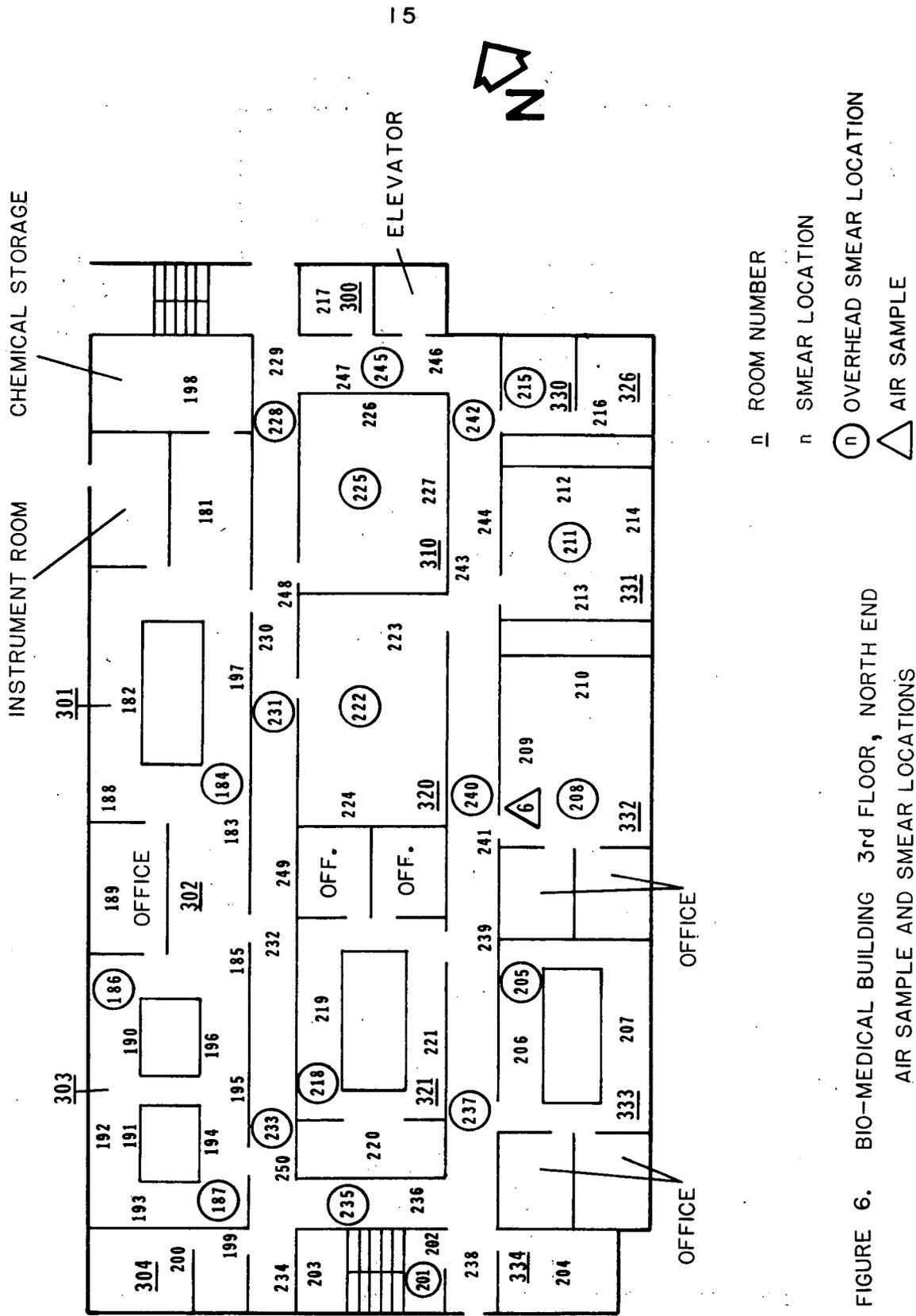
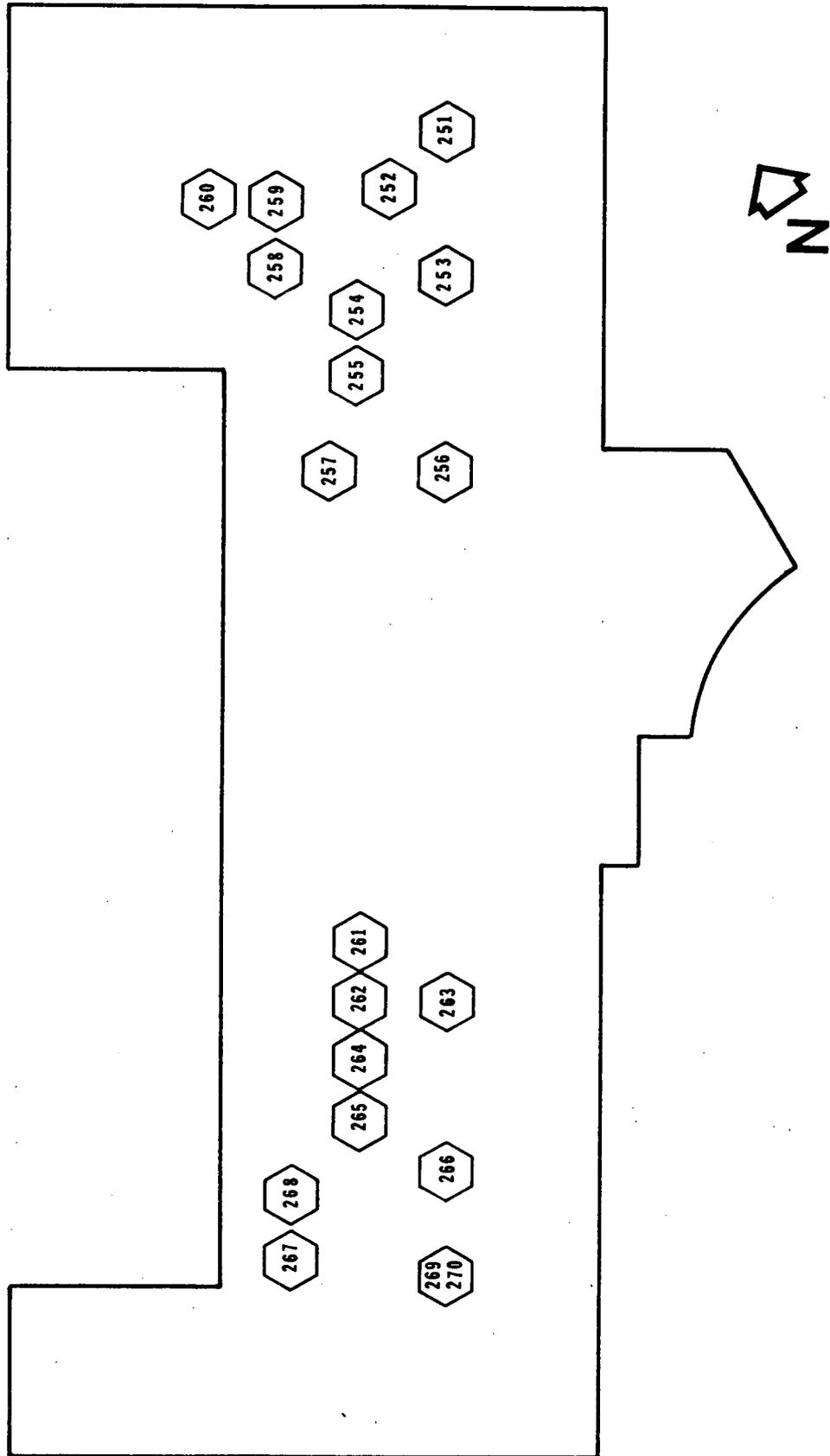
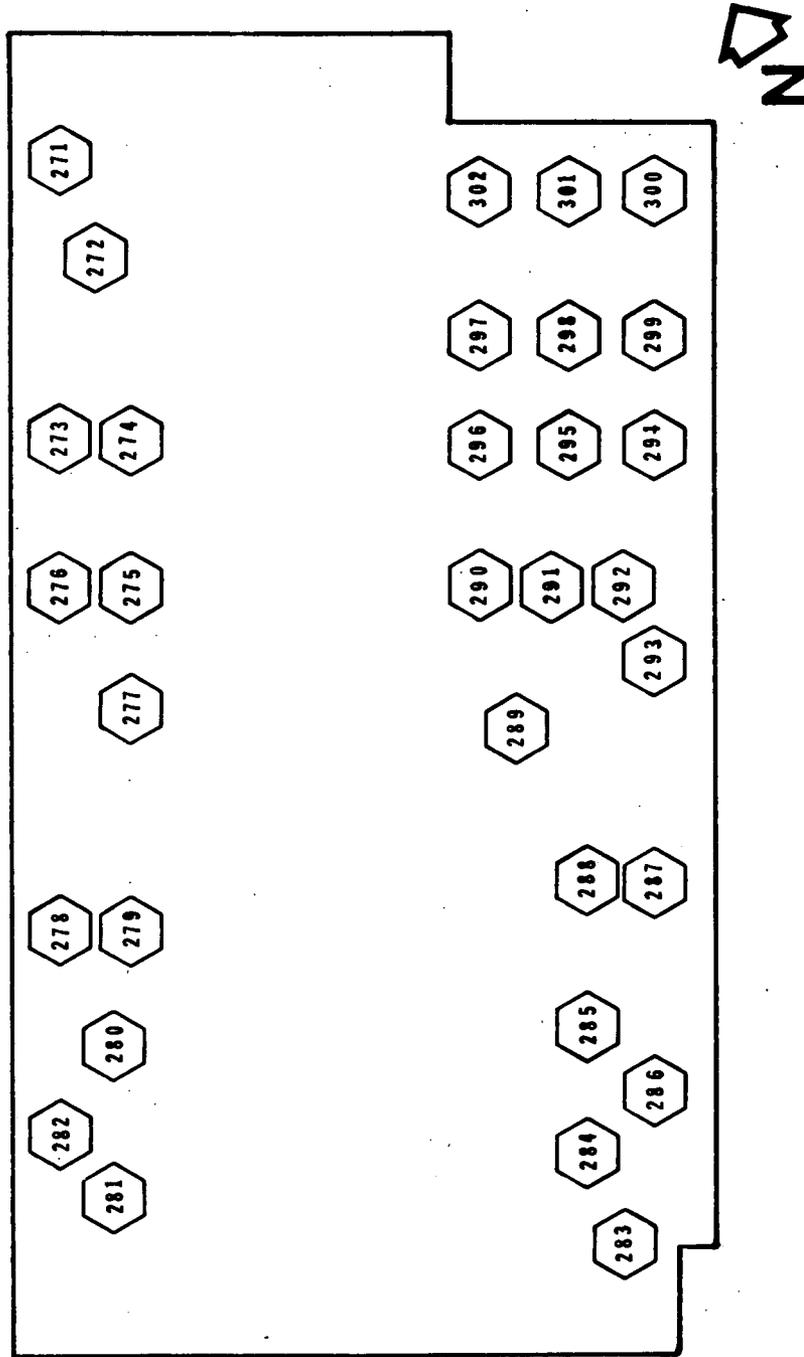


FIGURE 6. BIO-MEDICAL BUILDING 3rd FLOOR, NORTH END  
AIR SAMPLE AND SMEAR LOCATIONS



LOCATION OF SMEARS TAKEN FROM EXHAUST STACKS

FIGURE 7. BIO-MEDICAL BUILDING SOUTH END ROOF EXHAUST STACK SMEAR LOCATIONS



LOCATION OF SMEARS TAKEN FROM EXHAUST STACKS

FIGURE 8. BIO-MEDICAL BUILDING NORTH END ROOF EXHAUST STACK SMEAR LOCATIONS



FIGURE 9. ANIMAL HOUSE, NORTH AND WEST SIDES

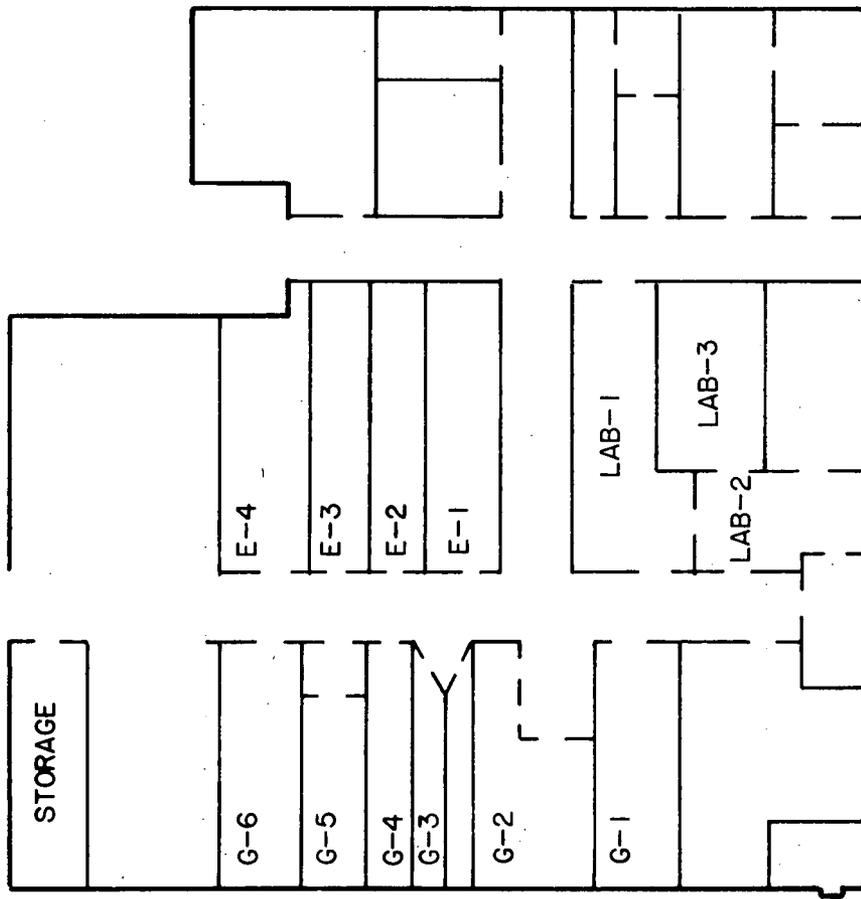


FIGURE 10. ANIMAL HOUSE  
FLOOR PLAN



FIGURE 11. SHOP, SOUTH SIDE

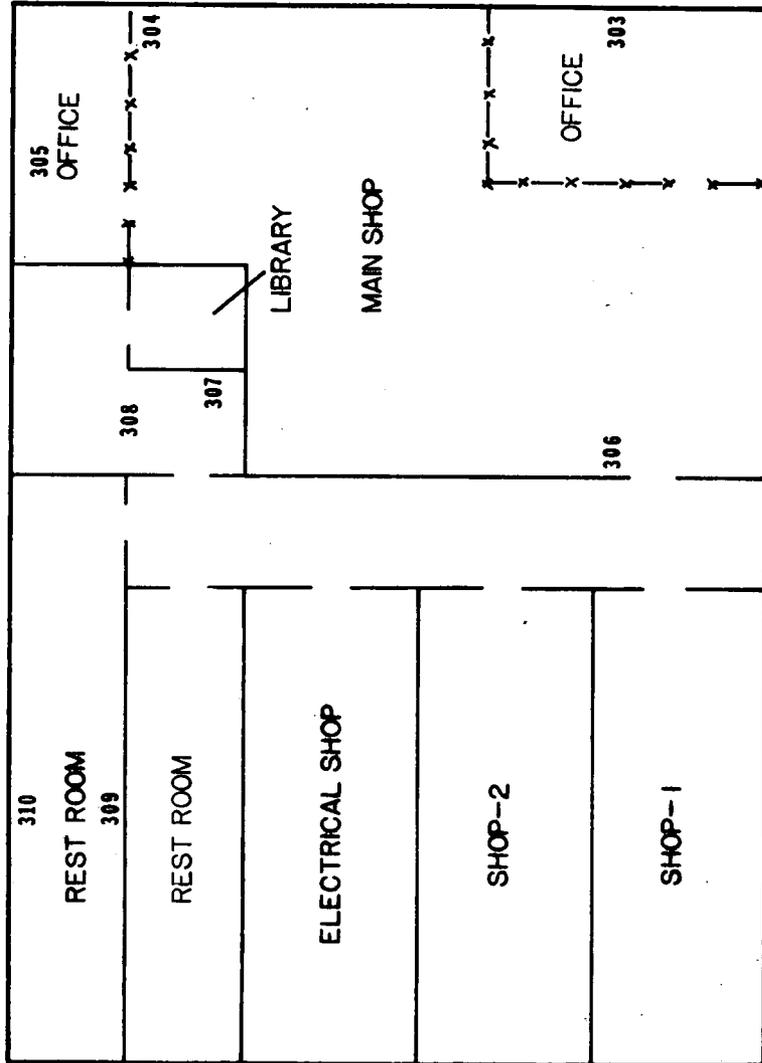


FIGURE 12. SHOP FLOOR PLAN

n SMEAR LOCATION

TABLE 1  
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey	Air Sample (WL)	PAC 4G-3 Direct Readings <sup>a</sup> (dis/min-100 cm <sup>2</sup> )		End Window GM (mR/h) Contact	PRM-7 (μR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm <sup>2</sup> )	Comments
			Beta	Alpha					
Land- ing		NS <sup>b</sup>	96 k	BKGD	2.5	BKGD	400 - 10 k	BKGD	equated to <sup>14</sup> C
200		NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
201		NS	14 k	BKGD	1.3	BKGD	400-2 k	BKGD	equated to <sup>14</sup> C
202		NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
210		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
211		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
212		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
213		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
214		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
215		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
220		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
221		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	

TABLE 1  
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey		Air Sample (WL)	PAC 4G-3 Direct Readings <sup>a</sup> (dis/min-100 cm <sup>2</sup> )		End Window GM (mR/h) Contact	PRM-7 (μR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm <sup>2</sup> )	Comments
	Floor	Wall		Beta	Alpha					
222			0.0014	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
223			NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
224			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
225			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
230			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
231			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
232			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
Elevator			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
233			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
234			NS	BKGD	NRR	NRR	BKGD	BKGD	NST	
240			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
241		80	NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
242		50	NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
243			NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	

TABLE 1  
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey		Air Sample (WL)	PAC 4G-3 Direct Readings <sup>a</sup>		End Window GM (mR/h) Contact	PRM-7 (μR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm <sup>2</sup> )	Comments
	Floor	Wall		Beta	Alpha					
244			0.0004	19 k	BKGD	0.04	BKGD	400-1 k	BKGD	equated to <sup>14</sup> C
250A		80	0.0003	BKGD	-	-	-	BKGD	BKGD	After tile was removed
250B		45	NS	BKGD	BKGD	0.05	5-60 @ contact	5-15 k	BKGD	<sup>99</sup> Mo- <sup>99m</sup> Tc
250		75	0.0003	BKGD	BKGD	NRR	BKGD	1-15 k	BKGD	24
251		80	NS	BKGD	BKGD	NRR	5-60 @ contact	BKGD	BKGD	<sup>99</sup> Mo- <sup>99m</sup> Tc
251, 116A		80	NS	BKGD	BKGD	NRR	BKGD	BKGD	NST	
251, 116B		50	NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
251, 117			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
252		85	NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	

TABLE 1  
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey		Air Sample (WL)	PAC 4G-3 Direct Readings <sup>a</sup> (dis/min-100 cm <sup>2</sup> )		End Window GM (mR/h) Contact	PRM-7 (µR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm <sup>2</sup> )	Comments
	Floor	Wall		Beta	Alpha					
253	80		NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
260	70		NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
261	90		NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
270			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
271			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
272			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
280			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
281			0.0016	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
282			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
283			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
284			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
285			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
290			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
291			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
292			NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	

TABLE 1  
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey	Air Sample (WL)	PAC 4G-3 Direct Readings <sup>a</sup> (dis/min-100 cm <sup>2</sup> )		End Window GM (mR/h) Contact	PRM-7 (µR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm <sup>2</sup> )	Comments
			Beta	Alpha					
293		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
294		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
295		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
296		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
Corridor		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	26
Roof		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
300		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
301		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
302		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
303		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
304		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
Hallways		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
310		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	

TABLE 1  
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey	Air Sample (WL)	PAC 4G-3 Direct Readings <sup>a</sup> (dis/min-100 cm <sup>2</sup> )		End Window GM (mR/h) Contact	PRM-7 (μR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm <sup>2</sup> )	Comments
			Floor	Wall					
320		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
321		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
326		NS	BKGD	NRR	NRR	BKGD	BKGD	NST	
330		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
331		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
332		0.0046	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
333		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
334		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
Roof		NS	BKGD	NRR	NRR	BKGD	BKGD	BKGD	
Mechanical	40	NS	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	
Animal Studies		NS	BKGD	NRR	NRR	BKGD	BKGD	NST	

FOOTNOTES FOR TABLE 1

<sup>a</sup>The Beta Mode Direct Readings and Alpha Mode Direct Readings are taken with PAC instruments (see Appendix 1). The beta mode detects both electromagnetic and particulate radiation. If an area indicated an instrument reading higher than background, a beta mode reading was obtained. The instrument was then switched to the alpha mode, and a reading of the alpha contamination was obtained. In the alpha mode, the instrument only responds to particles with high-specific ionization, such as alpha particles. The beta mode readings were compensated for any alpha contribution by subtracting the alpha mode reading from the beta mode reading.

<sup>b</sup>Not Selected. Locations of air samples were chosen on a selected basis throughout the areas surveyed. "NS" indicates that the room or area was not selected for an air sample.

<sup>c</sup>BKGD = Background. The following are the instrument background readings:

	<u>Beta Mode</u>	<u>Alpha Mode</u>
Floor Monitor	350-400 cts/min-325 cm <sup>2</sup>	0-50 cts/min-325 cm <sup>2</sup>
PAC-4G-3	150-300 cts/min-51 cm <sup>2</sup>	0-50 cts/min-51 cm <sup>2</sup>
PC-3A Counter	47.2±2.3 cts/min*	0.6±0.1 cts/min*
PC-5 Counter	56.7±1.4 cts/min*	0.3±0.1 cts/min*
10-Wire	560.3±5.3 cts/min*	4.7±0.5 cts/min*
PRM-5-3	350-500 cts/min	

GM End Window Detector read 0.01-0.02 mR/h at contact  
μR/h meter reading at 1 m above floor 5-7 μR/h.

<sup>d</sup>NA = Non-Applicable. No contamination was detected above background in the beta mode; therefore, no alpha mode or contact GM End Window survey was necessary.

<sup>e</sup>α = Alpha; βγ = Beta-Gamma (The beta-gamma readings are compensated for any alpha contamination by subtracting the alpha reading from the beta-gamma reading.)

<sup>f</sup>NST = No Smear Taken.

<sup>g</sup>NRR = No Reading Recorded.

<sup>h</sup>Rooms 200-296 are on the second floor of the Bio-Medical Building and Rooms 300-334 are on the third floor.

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\*One standard deviation due to counting statistics.

TABLE 2

RADON DETERMINATIONS

Air Sample Number	Location	Figure	dis/min-m <sup>3</sup>	pCi/ℓ ( <sup>222</sup> Rn)	WL <sup>a</sup>	pCi/ℓ ( <sup>220</sup> Rn)
1	Room 250	3	58	0.026	0.0003	
2	Room 250	3	72	0.033	0.0003	
3	Room 244	3	78	0.035	0.0004	0.0012
4	Room 281	3	352	0.16	0.0016	0.008
5	Room 222	3	309	0.14	0.0014	
6	Room 332	6	1028	0.46	0.0046	

<sup>a</sup> Working Level (WL) is defined as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of  $1.3 \times 10^5$  MeV of potential alpha energy. The numerical value of the WL is derived from the alpha energy released by the total decay through RaC' of the short-lived radon daughter products RaA, RaB, and RaC at radioactive equilibrium with 100 pCi of <sup>222</sup>Rn per liter of air.

## APPENDIX 1

INSTRUMENTATION

## I. PORTABLE RADIATION SURVEY METERS

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 was one of the three primary instruments used for surveying. This instrument is a gas-flow proportional alpha counter which utilizes a propane gas proportional probe, 51 cm<sup>2</sup> (PAC-4G-3) or 325 cm<sup>2</sup> (FM-4G) in area with a thin double-aluminized Mylar window (~ 0.85 mg/cm<sup>2</sup>).

The PAC-4G-3 has three high-voltage positions so that it can be used to distinguish between alpha and beta-gamma contamination. This instrument was initially used in the beta mode. In the beta mode, the detector responds to alpha and beta particles and x- and gamma-rays. When areas indicated a higher count rate than the average instrument background, the beta mode reading was recorded, and the instrument was then switched to the alpha mode to determine any alpha contribution. In the alpha mode, the instrument responds only to particles with high-specific ionization. The PAC instrument is calibrated in the alpha mode with a flat-plate, infinitely thin NBS traceable <sup>239</sup>Pu standard and in the beta mode with a flat-plate, infinitely-thin NBS traceable <sup>90</sup>Sr-<sup>90</sup>Y standard. It is calibrated to an apparent 50% detection efficiency.

B. Beta-Gamma End Window Survey Meter

When an area of contamination was found with a PAC instrument, a reading was taken with an Eberline Beta-Gamma Geiger-Mueller Detector, Model E-530, with an HP-190 detector. This probe has a thin mica end window and is, therefore, sensitive to alpha and beta particles and x- and gamma-rays. A thin piece of aluminum is added to the mica, thus making the window density ~ 7 mg/cm<sup>2</sup>. At this density, the instrument is not sensitive to alpha particles. A maximum reading is obtained with the probe in contact with the area of contamination. In this position, the response (in mR/h) to gamma radiation is generally conservative relative to a determination of mrad/h at 1 cm; however, the response (in mR/h) to beta radiation is nonconservative by a factor of up to about four relative to a determination of mrad/h through 7 mg/cm<sup>2</sup>. This instrument is calibrated with an NBS traceable <sup>137</sup>Cs-<sup>137m</sup>Ba source.

C. Low-Energy Gamma Scintillation Survey Meter

An Eberline Model PRM-5-3 with a PG-2 gamma scintillation detector was used to determine low-energy x and gamma radiation. The PG-2 detector consists of a thin NaI(Tl) scintillation crystal 5 cm in diameter by 2 mm thick. This instrument is calibrated on three separate discriminators for three energy regions using <sup>239</sup>Pu (17 keV), <sup>241</sup>Am (59.5 keV) and <sup>235</sup>U (185.7 keV) sources. During use, the calibration was checked daily with an NBS traceable <sup>137</sup>Cs-<sup>137m</sup>Ba source.

The PRM-5-3 has two modes, the gross mode and the pulse height analysis mode (PHA). In the gross mode, it detects x- and gamma-rays from a minimum to a few MeV. In the PHA mode, it detects only those x- and gamma-rays in a narrow

energy range. The PRM-5-3 has three energy regions in the PHA mode, HV1 (centered on 17 keV), HV2 (centered on 59.5 keV) and HV3 (centered on 185.7 keV). In the gross mode, the energy switch determines the minimum energy detected.

During the radiological survey, the PRM-5-3 was set to HV1 gross. Therefore, the maximum range of x- and gamma-rays were detected from approximately 10 keV to 5 MeV.

#### D. High Energy Micro "R" Scintillation Survey Meter

An Eberline Micro "R" Meter Model PRM-7 was used to detect high-energy gamma radiation. This instrument contains an internally mounted NaI(Tl) scintillation crystal 2.5 cm in diameter by 2.5 cm thick and can be used for measure fields of low-level radiation between 10  $\mu$ R/h and 5000  $\mu$ R/h. This instrument is also calibrated with an NBS traceable  $^{226}\text{Ra}$  source and checked daily with an NBS traceable  $^{137}\text{Cs}$ - $^{137\text{m}}\text{Ba}$  source.

### II. SMEAR COUNTING INSTRUMENTATION

The smear counter consists of a gas-flow proportional probe (ANL 10-wire design) which uses an Eberline Mini Scaler Model MS-2. The double-aluminized Mylar probe (window area 400  $\text{cm}^2$ ) uses P-10 (90% argon and 10% methane) as the counting gas. This system consists of two Mini Scalers and two probes. One is used for counting in the alpha mode and the other (shielded) is used for the beta mode. The metal smear holder has been machined to hold ten smears side by side. The smears are placed under the probe and a count is taken.

All smears of contaminated areas and two smears from each set of ten were counted in a Nuclear Measurements Corporation PC-3A or PC-5 Gas-Flow Proportional Counter (PC counter) using a double-aluminized Mylar spun top. The Mylar spun top is placed over non-conducting media such as paper to negate the dielectric effect. This counter also uses a P-10 counting gas. Smears are counted in both the alpha and beta modes of the detector. These instruments are checked using  $^{239}\text{Pu}$  and  $^{90}\text{Sr}$ - $^{90\text{Y}}$  NBS traceable sources.

### III. AIR SAMPLING DEVICE

The air samples were collected with a commercial vacuum cleaner modified at ANL. The air is drawn at a flow rate of 40  $\text{m}^3/\text{h}$ . The particulates in the air are collected on a 200  $\text{cm}^2$  sheet of Hollingsworth-Vose (HV-70 0.23 mm) filter paper. The collection efficiency at these flow rates for 0.3 micron particles is approximately 99.9%.

### IV. GAMMA SPECTRAL INSTRUMENTATION

A Nuclear Data Multichannel Analyzer Model ND-6, utilizing a 2"x2" NaI(Tl) well logging detector, was used for gamma spectral analysis.

APPENDIX 1  
(cont'd.)

## IV. INSTRUMENTATION USED IN SURVEY

	<u>Inventory Number</u>	<u>Probe Area (cm<sup>2</sup>)</u>	<u>Window Thickness (mg/cm<sup>2</sup>)</u>
Eberline PAC-4G-3	183413	51	~ 0.85
Eberline PAC-4G-3	184339	51	~ 0.85
Eberline PAC-4G-3	184340	51	~ 0.85
Eberline Floor Monitor FM-4G using a PAC-4G-3	183414	325	~ 0.85
Eberline PRM-7	188537		
Eberline PRM-7	197330		
Eberline PRM-5-3	184344		
Eberline PRM-5-3	197331		
Eberline E-530 Beta-Gamma End Window	-	-	~ 7
Nuclear Measurements Corp. PC-3A 2π Internal Gas-Flow Counter	119694		
Argonne National Laboratory 10-Wire Flat-Plate Gas-Flow Proportional De- tector with Eberline Mini Scaler MS-2			
Argonne National Laboratory Filter Queen Air Sampler using HV-70 Filter Media			
ND-6 Gamma-Ray Spectrometer	202163		

APPENDIX 1  
(cont'd.)V. AVERAGE INSTRUMENT BACKGROUND READINGS<sup>a</sup>

<u>Instrument</u>	<u>Alpha Mode (cts/min)</u>	<u>Beta and/or Gamma (cts/min)</u>	<u>1 m above floor (<math>\mu</math>R/h)</u>	<u>Contact (mR/h)</u>
Eberline Floor Monitor FM-4G using PAC instru- ments				
183414	0-50	400		
Eberline PAC-4G-3				
183412	0-5	100-200		
184339	0-5	100-150		
183430	0-5	100-150		
Eberline PRM-5-3				
197331		700-1000		
184344		400-500		
Eberline PRM-7				
188537			5-7	
187330			5-7	
Eberline E-530 With Beta-Gamma End Window				
#12				0.02
Nuclear Measurements Corp. PC-3A 2 $\pi$ Internal Gas-Flow Counter	$0.6 \pm 0.1^b$	$46.1 \pm 1.4^b$		
Argonne National Laboratory 10-Wire Flat-Plate Gas-Flow Proportional Detector With Eberline Mini Scaler MS-2	$4.7 \pm 0.5^b$	$560 \pm 5^b$		

<sup>a</sup>Background readings were taken in Room 310 of the Bio-Medical Building.<sup>b</sup>One standard deviation due to counting statistics.

## APPENDIX 2

CONVERSION FACTORS

## I. INSTRUMENTATION

The factors used to convert the readings to units of disintegrations per minute per 100 cm<sup>2</sup> (dis/min-100 cm<sup>2</sup>) and the derivation of those factors are listed below.

A. Conversion Factors

	PAC-4G-3		Floor Monitor (FM-4G)	
	<u>Alpha</u>	<u>Beta</u>	<u>Alpha</u>	<u>Beta</u>
to 100 cm <sup>2</sup>	1.96	1.96	0.31	0.31
cts/min to dis/min for <sup>90</sup> Sr- <sup>90</sup> Y	-	2	-	2
cts/min to dis/min for <sup>239</sup> Pu	2	-	2	-
cts/min to dis/min for normal U	5.9	3.5	5.9	3.5
cts/min to dis/min <sup>226</sup> Ra plus daughters	1.6	4.7	-	-
cts/min to dis/min <sup>14</sup> C	-	2.5	-	-

B. Derivation of Conversion Factors. Floor Monitor

Window Area: ~ 325 cm<sup>2</sup>

Conversion to 100 cm<sup>2</sup> = 0.31 times Floor Monitor readings

. PAC-4G-3

Window Area: ~ 51 cm<sup>2</sup>

Conversion to 100 cm<sup>2</sup> = 1.96 times PAC reading

. 2π Internal Gas-Flow Counter, PC counter

Geometry: Solid Steel Spun Top - 0.50

Geometry: Mylar Spun Top - 0.43

Mylar spun top counting {double-aluminized Mylar window (~ 0.85 mg/cm<sup>2</sup>)} utilizes the well of the PC counter and is a method developed and used by the Argonne National Laboratory Health Physics Section for negating the dielectric effect in counting samples on nonconducting media.

APPENDIX 2  
(Cont'd.)

The PC counter instrument was calibrated using  $^{239}\text{Pu}$  NBS traceable alpha sources. Using a flat-plate, infinitely-thin  $^{226}\text{Ra}$  plus short-lived daughters standard as a source of alpha emissions, the plate was counted in the well of a  $2\pi$  Internal Gas-Flow Counter (PC Counter) with the source leveled to an apparent  $2\pi$  geometry. The alpha counts per minute (cts/min) reading was found to be  $1.8 \times 10^4$  cts/min, or  $1.8 \times 10^4 \div 0.51^* = 3.5 \times 10^4$  disintegrations per minute (dis/min) alpha. Since the source was infinitely-thin, the alpha component was used as the total alpha dis/min of the source.

The same  $^{226}\text{Ra}$  plus daughters source, when counted with the PAC instrument in the alpha mode, was found to be  $2.2 \times 10^4$  cts/min at contact. The conversion factor for cts/min to dis/min for the PAC instrument is  $3.5 \times 10^4 \div 2.2 \times 10^4 = 1.6$  dis/min alpha to cts/min alpha.

The same source was covered with two layers of conducting paper, each  $6.65 \text{ mg/cm}^2$ , to absorb the alpha emissions. With the PAC-4G-3 in the beta mode and in contact with the covered source in the center of the probe, the count was found to be  $7.5 \times 10^3$  cts/min. This indicates a conversion factor of  $3.5 \times 10^4 \div 7.5 \times 10^3 = 4.7$  dis/min alpha to cts/min beta-gamma.

A similar method was used to determine the conversion factors for normal uranium, and for  $^{14}\text{C}$ .

## II. SMEAR COUNT

The conversion factors for cts/min-100  $\text{cm}^2$  to dis/min-100  $\text{cm}^2$  for smear counts are given below:

### A. Conversion Equation (Alpha)

$$\frac{\text{cts/min} - (\text{Bkgd})}{g \times \text{bf} \times \text{sa} \times \text{waf}} = \text{dis/min } \alpha$$

A geometry (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.0 was used when determining alpha activity on a filter media.

The self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

If the energies of the isotope were known, the appropriate window air factor (waf) was used; if the energies of the isotopes were unknown, the (waf) of  $^{239}\text{Pu}$  (0.713) was used.

The (waf) for alpha from  $^{226}\text{Ra}$  plus daughters is 0.55.

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\*The value of 0.51 includes the following factors: geometry (g) = 0.50; backscatter factor (bf) = 1.02; sample absorption factor (sa) = 1.0; window air factor (waf) = 1.0. The product of  $g \times \text{bf} \times \text{sa} \times \text{waf}$  is 0.51.

APPENDIX 2  
(Cont'd.)B. Conversion Equation (Beta)

$$\frac{\text{cts/min} - \{\beta \text{ Bkgd (cts/min)} + \alpha \text{ cts/min}\}}{g \times bf \times sa \times waf} = \text{dis/min } \beta$$

A geometry (g) of 0.43 was standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.1 was used when determining beta activity on a filter media.

The self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

If the energies of the isotopes were known, the appropriate window air factor (waf) was used; if the energies of the isotopes were unknown, the (waf) of  $^{90}\text{Sr}$ - $^{90}\text{Y}$  (0.85) was used.

The (waf) for betas from  $^{226}\text{Ra}$  plus daughters is 0.85.

## APPENDIX 3

RADON-DETERMINATION CALCULATIONS

Calculations for air samples collected with an Argonne National Laboratory-designed air sampler with HV-70 filter media are summarized in this appendix. The appendix also includes the basic assumptions and calculations used to derive the air concentrations.

## I. RADON CONCENTRATIONS BASED ON RaC' RESULTS

The following postulates are assumed in deriving the radon-222 ( $^{222}\text{Rn}$ ) concentrations based on the RaC' alpha count results.

- A. RaA, RaB, RaC, and RaC' are in equilibrium.
- B. RaA is present only in the first count and not the 100-minute decay count.
- C. One-half of the radon progeny is not adhered to airborne particulates (i.e., unattached fraction) and, therefore, is not collected on the filter media.
- D. The geometry factor (g) is 0.43 for both the alpha and beta activity.
- E. The backscatter factor (bf) of 1.0 is used for the alpha activity.
- F. The sample absorption factor (sa) for RaC' is 0.77.
- G. The window air factor (waf) for RaC' is 0.8.
- H. RaB and RaC, being beta emitters, are not counted in the alpha mode.
- I. The half-life of the radon progeny is approximately 36 minutes, based on the combined RaB and RaC half-lives.
- J. Thoron and long-lived alpha emitters are accounted for using the 360 min count and the seven-day count, respectively.
- K. For all practical purposes, RaC' decays at the rate of the composite of RaB and RaC, which is about 36 minutes.

The following postulates are assumed in deriving the thoron ( $^{220}\text{Rn}$ ) concentrations.

- L. ThA, ThB, ThC and ThC' are in equilibrium.
- M. ThA and RaC' have decayed by the 360 min decay count.
- N. The geometry factor (g), backscatter factor (bf), sample absorption factor (sa) and window air factor (waf) are all the same for thoron as for radon.

APPENDIX 3  
(cont'd.)

- O. ThB and 64% of ThC, being beta emitters, are not counted in the alpha mode.
- P. The half-life of the thoron progeny is 10.64 hours (638.4 min) based on the ThB half-life.
- Q. For all practical purposes, 36% of the ThC (alpha branch) and the ThC' decay at the decay rate of ThB which is 638.4 min.
- R. The counter does not differentiate between the ThC alphas and the ThC' alphas.

The following postulate is assumed in deriving the concentration of long-lived radionuclides.

- S. The long-lived activity is constant during the entire counting period. This assumption is valid for isotopes with half-lives longer than a few years.

## II. EQUATIONS USED TO DERIVE AIR CONCENTRATIONS

$$A_o = \frac{A}{e^{-\lambda t}}$$

Where:  $A_o$  = Activity (dis/min) present at the end of the sampling period (usually 40 min)

$A$  = Activity (dis/min) at some time,  $t$ , after end of the sampling period

$t$  = Time interval (min) from end of sampling period to counting interval (usually  $\approx$  100 min)

$$\lambda = \frac{0.693}{t_{1/2}}$$

$t_{1/2}$  = Half-life of isotope (min)

Concentration is determined by the equation:

$$C = \frac{A_o \lambda}{f} \times \frac{1}{1 - e^{-\lambda t_s}}$$

Where:  $C$  = Concentration (dis/min-m<sup>3</sup>)

$A_o$  = Activity on filter media at end of sampling period (dis/min)

APPENDIX 3  
(cont'd.)

$f$  = Sampling rate ( $m^3/\text{min} = m^3/h \times 1 h/60 \text{ min}$ )

$t_s$  = Length of sampling time (min)

$$\lambda = \frac{0.693}{t_{1/2}}$$

$t_{1/2}$  = Half-life of isotope or controlling parent (min)

### III. EXAMPLE CALCULATION

Data obtained in the air sampling of a room have been used below to illustrate the application of the equations for determining activity and concentration.

Data     $f = 40 \text{ m}^3/60 \text{ min}$ ;  $t_s = 40 \text{ min}$   
           at  $t = 100 \text{ min}$ ;  $A = 683.3 \text{ dis/min}$   
           at  $t = 360 \text{ min}$ ;  $A = 154.8 \text{ dis/min}$   
           at  $t = 7 \text{ months}$ ;  $A = 0 \text{ dis/min}$

For thoron:

$$A_o = \frac{154.8}{\exp - \frac{0.693 \times 360}{638.4}} = 228.8 \text{ dis/min}$$

$$C(\text{Tn}) = \frac{228.8 \times \frac{0.693}{638.4}}{40/60} \times \frac{1}{1 - \exp - \frac{0.693 \times 40}{638.4}} = 8.8 \text{ dis/min-m}^3$$

For Radon:

Activity due to thoron at  $t = 100$ .

$$A = \frac{154.8}{\exp - \frac{0.693 \times 260}{638.4}} = 205.3$$

APPENDIX 3  
(cont'd.)

Radon Activity:

$$A = 683.3 - 205.3 = 478 \text{ dis/min}$$

$$A_o = \frac{478}{\exp - \frac{0.693 \times 100}{36}} = 3277 \text{ dis/min}$$

$$C(\text{Rn}) = \frac{3277 \times \frac{0.693}{36}}{40/60} \times \frac{1}{1 - \exp - \frac{0.693 \times 40}{36}} = 176 \text{ dis/min-m}^3$$

Since we assume that on the average half of the progeny is not adhered to airborne particulates, the above concentrations are then multiplied by 2 determine actual concentration:

$C \text{ actual} = C \text{ measured} \times \text{progeny correction factor.}$

$$C(\text{Tn}) = 8.8 \text{ dis/min-m}^3 \times 2 = 17.6 \text{ dis/min-m}^3.$$

$$C(\text{Rn}) = 176 \text{ dis/min-m}^3 \times 2 = 352 \text{ dis/min-m}^3.$$

These are then the resulting concentrations in  $\text{dis/min-m}^3$ . To convert to  $\text{pCi/l}$ , divide these concentrations by  $2.22 \times 10^3$ .

$$C(\text{Tn}) = \frac{17.6 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3/\text{pCi/l}} = 0.0079 \text{ pCi/l}$$

$$C(\text{Rn}) = \frac{352 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3/\text{pCi/l}} = 0.159 \text{ pCi/l}$$

## APPENDIX 4

PERTINENT RADIOLOGICAL REGULATIONS,  
STANDARDS, AND GUIDELINES

Excerpts From

I. DRAFT AMERICAN NATIONAL STANDARD

N13.12

Control of Radioactive Surface Contamination  
on Materials, Equipment, and Facilities to be  
Released for Uncontrolled Use

Where potentially contaminated surfaces are not accessible for measurement (as in some pipes, drains, and ductwork), such property shall not be released pursuant to this standard, but shall be made the subject of case-by-case evaluation.

Property shall not be released for uncontrolled use unless measurements show the total and removable contamination levels to be no greater than the values in Table 1 or Table 2. (The values in Table 2 are easier to apply when the contaminants cannot be individually identified.)

Coatings used to cover the contamination shall not be considered a solution to the contamination problem. That is, the monitoring techniques shall be sufficient to determine, and such determination shall be made, that the total amount of contamination present on and under any coating does not exceed the Table 1 or Table 2 values before release.

APPENDIX 4  
(Cont'd.)

TABLE 1

SURFACE CONTAMINATION LIMITS\*

Group	Description	Nuclides (Note 1)	Limit (Activity) (dis/min-100 cm <sup>2</sup> )*					
			Removable	Total (Fixed plus Removable)				
1	Nuclides for which the non-occupational MPC (Note 2) is $2 \times 10^{-13}$ Ci/m <sup>3</sup> or less or for which the nonoccupational MPC (Note 4) is $2 \times 10^{-7}$ Ci/m <sup>3</sup> or less	227Ac	20	Nondetectable (Note 3)				
		241,242m,243Am						
		249,250,251,252Cf						
		243,244,245,246,247,248Cm						
		125,129I						
		237Np						
		231Pa						
		210Pb						
		238,239,240,242,244Pu						
		226,228Ra						
		228,230Th						
		2			Those nuclides not in Group 1 for which the nonoccupational MPC (Note 2) is $1 \times 10^{-12}$ Ci/m <sup>3</sup> or less for which the nonoccupational MPC (Note 4) is $1 \times 10^{-6}$ Ci/m <sup>3</sup> or less	254Es	200	2000 $\alpha$ Nondetectable $\beta, \gamma$ (Note 5)
						256Fm		
126,131,133I								
210Po								
223Ra								
90Sr								
232Th								
232U								
3	Those nuclides not in Group 1 or Group 2		1000	5000				

APPENDIX 4  
(Cont'd.)

## SURFACE CONTAMINATION LIMITS

\*The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm<sup>2</sup> is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm<sup>2</sup>, if (1) from measurements of a representative number n of sections it is determined that  $1/n \sum_{i=1}^n S_i \geq L$ , where  $S_i$  is the dis/min-100 cm<sup>2</sup> determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm<sup>2</sup> exceeds 3 L.

+Disintegrations per minute per square decimeter.

## NOTES:

- (1) Values presented here are obtained from the Code of Federal Regulations, Title 10, Part 20, April 30, 1975. The most limiting of all given MPC values (for example, soluble versus insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fraction shall be less than 1.
- (2) Maximum permissible concentration in air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as the National Committee on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), or the Nuclear Regulatory Commission (NRC). From the Code of Federal Regulations, Title 10, Part 20, Appendix B, Table 2, Column 1.
- (3) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm<sup>2</sup>.
- (4) Maximum permissible concentration in water applicable to members of the public.
- (5) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey for unconditional release should be performed in areas where the background is  $\leq 100$  counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

APPENDIX 4  
(Cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

Table 2

(All Alpha Emitters, except  $U_{nat}$  and  $Th_{nat}$ , Considered as a Group)\*

Contamination Contingencies	Limit (Activity) (dis/min-100 cm <sup>2</sup> ) <sup>+</sup>	
	Removable	Total (Fixed Plus Removable)
If the contaminant cannot be identified; or if alpha emitters other than $U_{nat}$ (Note 1) and $Th_{nat}$ are present; or if the beta emitters comprise $^{227}Ac$ or $^{228}Ra$ .	20	Nondetectable (Note 2)
If it is known that all alpha emitters are generated from $U_{nat}$ (Note 1) and $Th_{nat}$ ; and if beta emitters are present that, while not identified, do not include $^{227}Ac$ , $^{125}I$ , $^{226}Ra$ , and $^{228}Ra$ .	200	2000 $\alpha$ Nondetectable $\beta, \gamma$ (Note 3)
If it is known that alpha emitters are generated only from $U_{nat}$ (Note 1) and $Th_{nat}$ in equilibrium with its decay products; and if the beta emitters, while not identified, do not include $^{227}Ac$ , $^{125}I$ , $^{129}I$ , $^{90}Sr$ , $^{223}Ra$ , $^{228}Ra$ , $^{126}I$ , $^{131}I$ and $^{133}I$ .	1000	5000

APPENDIX 4  
(Cont'd.)

## ALTERNATE SURFACE CONTAMINATION LIMITS

\*The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm<sup>2</sup> is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm<sup>2</sup>, if (1) from measurements of a representative number n of sections it is determined that  $1/n \sum_{i=1}^n S_i \geq L$ , where  $S_i$  is the dis/min-100 cm<sup>2</sup> determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm<sup>2</sup> exceeds 3 L.

+Disintegrations per minute per square decimeter.

## NOTES:

- (1)  $U_{nat}$  and decay products.
- (2) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm<sup>2</sup>.
- (3) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey of unconditional release should be performed in areas where the background is  $\leq 100$  counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

APPENDIX 4  
(Cont'd.)II. NRC GUIDELINES FOR DECONTAMINATION OF FACILITIES AND  
EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED  
USE OR TERMINATION OF LICENSES FOR BY-PRODUCT  
SOURCE, OR SPECIAL NUCLEAR MATERIAL

November 1976

(These have been retyped for  
purposes of this report)

The instructions in this guide, in conjunction with Table 1, specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table 1 do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.
2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table 1 prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.
3. The radioactivity on the interior surfaces of pipes, drain lines, or duct work shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or duct work. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.
4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer of premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:
  - a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.

APPENDIX 4  
(Cont'd.)

- b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.
5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table 1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:
- a. Identify the premises.
  - b. Show that reasonable effort has been made to eliminate residual contamination.
  - c. Describe the scope of the survey and general procedures followed.
  - d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

APPENDIX 4  
(Cont'd.)

TABLE 3

ACCEPTABLE SURFACE CONTAMINATION LIMITS

NUCLIDES <sup>a</sup>	AVERAGE <sup>b</sup> ccf	MAXIMUM <sup>b</sup> bdf	REMOVABLE <sup>b</sup> bef
U-nat, <sup>235</sup> U, <sup>238</sup> U and associated decay products	5000 dis/min-100 cm <sup>2</sup> α	15,000 dis/min-100 cm <sup>2</sup> α	1000 dis/min-100 cm <sup>2</sup> α
Transuranics, <sup>226</sup> Ra, <sup>228</sup> Ra, <sup>230</sup> Th, <sup>228</sup> Th, <sup>231</sup> Pa, <sup>227</sup> Ac, <sup>125</sup> I, <sup>129</sup> I	100 dis/min-100 cm <sup>2</sup>	300 dis/min-100 cm <sup>2</sup>	20 dis/min-100 cm <sup>2</sup>
Th-nat, <sup>232</sup> Th <sup>90</sup> Sr, <sup>223</sup> Ra, <sup>224</sup> Ra, <sup>232</sup> U, <sup>126</sup> I, <sup>131</sup> I, <sup>133</sup> I	1000 dis/min-100 cm <sup>2</sup>	3,000 dis/min-100 cm <sup>2</sup>	200 dis/min-100 cm <sup>2</sup>
Beta-gamma emitters (nu- clides with decay modes other than alpha emission or spontaneous fission) except <sup>90</sup> Sr and others noted above.	5000 dis/min-100 cm <sup>2</sup> βγ	15,000 dis/min-100 cm <sup>2</sup> βγ	1000 dis/min-100 cm <sup>2</sup> βγ

APPENDIX 4  
(Cont'd.)

TABLE 3

## ACCEPTABLE SURFACE CONTAMINATION LEVELS

<sup>a</sup>Where surface contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for alpha and beta-gamma emitting nuclides should apply independently.

<sup>b</sup>As used in this table, dis/min (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

<sup>c</sup>Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

<sup>d</sup>The maximum contamination level applies to an area of not more than 100 cm<sup>2</sup>.

<sup>e</sup>The amount of removable radioactive material per 100 cm<sup>2</sup> of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

<sup>f</sup>The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

APPENDIX 4  
(Cont'd.)

## III.

SURGEON GENERAL'S GUIDELINES  
as included in 10 CFR Part 712  
Grand Junction Remedial Action Criteria

## 712.1 Purpose

(a) determination by DOE of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colorado, 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 Pub. L. 92-314 (86 Stat. 222) of June 16, 1972.

## 712.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colorado, 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 Energy Research and Development or his duly authorized representative.

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

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

(d) "DOE" means the U.S. Department of Energy or any 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.

APPENDIX 4  
(Cont'd.)

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters 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.

(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-214), 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, Colorado.

(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 milling 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  $1.3 \times 10^5$  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 DOE other than a written interpretation by the General Counsel will be recognized to be binding upon DOE.

## 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. Department of Energy, Washington, D.C. 20545.

APPENDIX 4  
(Cont'd.)

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 recommended 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/h	Greater than 0.05 WL	Remedial action indicated.
From 0.05 to 0.1 mR/h	From 0.01 to 0.05 WL	Remedial action may be suggested.
Less than 0.05 mR/h	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 if 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 DOE 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 DOE 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/h or greater above background.

APPENDIX 4  
(Cont'd.)

(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 exceed 0.02 mR/h 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 0.001 mR/h above background, the indoor radon daughter concentration level is less than 0.01 WL above background, and no possible need for remedial actions exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/h above background but is less than 0.02 mR/h 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/h 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 of 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.

APPENDIX 4  
(Cont'd.)

- (c) Order of application. Insofar as feasible remedial action will be taken in the order in 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/h above background in the case of dwellings and schools and 0.15 mR/h 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. DOE shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

APPENDIX 4  
(cont'd.)

IV. EXCERPTS FROM DOE 5480.1 Chg. 6, Chapter XI

"Requirements for Radiation Protection"

Exposure of Individuals and Population Groups in Uncontrolled Areas.  
Exposures to members of the public shall be as low as reasonably achievable levels within the standards prescribed below.

Radiation Protection Standards  
for Internal and External Exposure  
of Members of the Public

Type of Exposure	Annual Dose Equivalent or Dose Commitment	
	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on Average Dose to a Suitable Sample of the Exposed Population
Whole body, gonads, or bone marrow	0.5 rem (or 500 mrem)	0.17 rem (or 170 mrem)
Other organs	1.5 rem (or 1500 mrem)	0.5 rem (or 500 mrem)

CONCENTRATION IN AIR AND WATER ABOVE NATURAL BACKGROUND

Element (Atomic Number)	Isotope Soluble (S)	Table I Controlled Area		Table II Uncontrolled Area	
		Column 1 Air (pCi/ℓ)	Column 2 Water (pCi/ℓ)	Column 1 Air (pCi/ℓ)	Column 2 Water (pCi/ℓ)
Radon (86)	Rn 220 S	300		10	
	Rn 222 S	100		3	

## APPENDIX 5

## EVALUATION OF RADIATION EXPOSURES

INTRODUCTIONA. Types of Radiation

Radiation is the emission or transmission of energy in the form of waves or particles. Examples are acoustic waves (i.e., sound), electromagnetic waves (such as radio, light, x- and gamma-rays), and particulate radiations (such as alpha particles, beta particles, neutrons, protons, and other elementary particles).

The class of radiation of importance to this report is known as ionizing radiation. Ionizing radiations are those, either electromagnetic or particulate, with sufficient energy to ionize matter, i.e., to remove or displace electrons from atoms and molecules. The most common types of ionizing radiation are x- and gamma-rays, alpha particles, beta particles, and neutrons.

X- and gamma-rays are electromagnetic waves of pure energy, having no charge and no mass or existence at rest. Gamma-rays and x-rays are identical except that x-rays originate in the atom and gamma-rays originate in the nucleus of an atom. X- and gamma-rays are highly penetrating and can pass through relatively thick materials before interacting. Upon interaction, some or all of the energy is transferred to electrons which, in turn, produce additional ionizations while coming to rest.

Alpha particles are positively charged particulates composed of two neutrons and two protons, identical to the nucleus of a helium atom. Due to its comparatively large mass and double charge, an alpha particle interacts readily with matter and penetrates only a very short distance before coming to rest, causing intense ionization along its path.

Beta particles are negatively charged free electrons moving at high speeds. Due to its comparatively small mass and single charge, a beta particle's penetration through matter is intermediate between that of the alpha particle and the gamma-ray, causing fewer ionizations per unit path length than an alpha particle.

B. Sources of Radiation

Ionizing radiations arise from terrestrial radioactive materials (both naturally occurring and man-made), extra-terrestrial (cosmic) sources, and radiation-producing machines. The sources of ionizing radiation important to this report are radioactive materials and cosmic sources.

Most atoms of the elements in our environment remain structurally stable. With time, an atom of potassium, for instance, may change its association with other atoms in chemical reactions and become part of other compounds, but it will always remain a potassium atom. Radioactive atoms, on the other hand, are

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not stable and will spontaneously emit radiation in order to achieve a more stable state. Because of this spontaneous transformation, the ratio of protons and neutrons in the nucleus of an atom is altered toward a more stable condition. Radiation may be emitted from the nucleus as alpha particles, beta particles, neutrons, or gamma-rays, depending uniquely upon each particular radionuclide. Radionuclides decay at characteristic rates dependent upon the degree of stability and characterized by a period of time called the half-life. In one half-life, the number of radioactive atoms and, therefore, the amount of radiation emitted, decrease by one half.

The exposure of man to terrestrial radiation is due to naturally occurring radionuclides and also to "man-made" or technologically enhanced radioactive materials. Several dozen radionuclides occur naturally, some having half-lives of at least the same order of magnitude as the estimated age of the earth. The majority of these naturally occurring radionuclides are isotopes of the heavy elements and belong to three distinct radioactive series headed by uranium-238, uranium-235, and thorium-232. Each of these decays to stable isotopes of lead (Pb) through a sequence of radionuclides of widely varying half-lives. Other naturally occurring radionuclides, which decay directly to a stable nuclide, are potassium-40 and rubidium-87. It should be noted that even though the isotopic abundance of potassium-40 is less than 0.012%, potassium is so widespread that potassium-40 contributes about one-third of the radiation dose received by man from natural background radiation. A major portion of the exposure (dose) of man from external terrestrial radiation is due to the radionuclides in the soil, primarily potassium-40 and the radioactive decay-chain products of thorium-232 and uranium-238. The naturally occurring radionuclides deposited internally in man through uptake by inhalation/ingestion of air, food, and drinking water containing the natural radioactive material also contribute significantly to his total dose. Many other radionuclides are referred to as "man made" in the sense that they can be produced in large quantities by such means as nuclear reactors, accelerators, or nuclear weapons tests.

The term "cosmic radiation" refers both to the primary energetic particles of extra-terrestrial origin that are incident on the earth's atmosphere and to the secondary particles that are generated by the interaction of these primary particles with the atmosphere, and reach ground level. Primary cosmic radiation consists of "galactic" particles externally incident on the solar system, and "solar" particles emitted by the sun. This radiation is composed primarily of energetic protons and alpha particles. The first generation of secondary particles (secondary cosmic radiation), produced by nuclear interactions of the primary particles with the atmosphere, consists predominantly of neutrons, protons, and pions. Pion decay, in turn, results in the production of electrons, photons, and muons. At the lower elevations, the highly penetrating muons and their associated decay and collision electrons are the dominant components of the cosmic-ray particle flux density. These particles, together with photons from the gamma-emitting, naturally occurring radionuclides in the local environment, form the external penetrating component of the background environmental radiation field which provides a significant portion of the whole-body radiation dose to man.

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In addition to the direct cosmic radiation, cosmic sources include cosmic-ray-produced radioactivity, i.e., cosmogenic radionuclides. The major production of cosmogenic radionuclides is through interaction of the cosmic rays with the atmospheric gases through a variety of spallation or neutron-capture reactions. The four cosmogenic radionuclides that contribute a measurable radiation dose to man are carbon-14, sodium-22, beryllium-7, and tritium (hydrogen-3), all produced in the atmosphere.

BACKGROUND RADIATION DOSES

Background radiation doses are comprised of an external component of radiation impinging on man from outside the body and an internal component due to radioactive materials taken into the body by inhalation or ingestion.

Radiation dose may be expressed in units of rads or rems, depending upon whether the reference is to the energy deposited or to the biological effect. A rad is the amount of radiation that deposits a certain amount of energy in each gram of material. It applies to all radiations and to all materials which absorb that radiation.

Since different types of radiation produce ionizations at different rates as they pass through tissue, differences in damage to tissues (and hence the biological effectiveness of different radiations) has been noticed. A rem is defined as the amount of energy absorbed (in rads) from a given type of radiation multiplied by the factor appropriate for the particular type of radiation in order to approximate the biological damage that it causes relative to a rad of x or gamma radiation. The concept behind the unit "rem" permits evaluation of potential effects from radiation exposure without regard to the type of radiation or its source. One rem received from cosmic radiation results in the same biological effects as one rem from medical x-rays or one rem from the radiations emitted by naturally occurring or man-made radioactive materials.

The external penetrating radiation dose to man derives from both terrestrial radioactivity and cosmic radiation. The terrestrial component is due primarily to the gamma dose from potassium-40 and the radioactive decay products of thorium-232 and uranium-238 in soil as well as from the beta-gamma dose from radon daughters in the atmosphere. Radon is a gaseous member of the uranium-238 chain. The population-weighted external dose to an individual's whole body from terrestrial sources in the United States has been estimated as 15 mrem per year for the Atlantic and Gulf Coastal Plain, 57 mrem per year for an indeterminate area along the Rocky Mountains, and 29 mrem per year for the majority of the rest of the United States. The overall population-weighted external dose for the U.S. population as a whole has been estimated to be 26 mrem per year.

The cosmic radiation dose, due to the charged particles and neutrons from secondary cosmic rays, is typically about 30% to 50% of the total from all external environmental radiation. The cosmic-ray dose to the population is estimated to be 26 mrem per year for those living at sea level, and increases with increasing altitude. Considering the altitude distribution of the U.S.

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population, the population-weighted external cosmic-ray dose is 28 mrem per year. The population-weighted total external dose from terrestrial plus cosmic sources is thus 54 mrem per year for the U.S. population as a whole.

The internal radiation doses derive from terrestrial and cosmogenic radionuclides deposited within the body through uptake by inhalation/ingestion of air, food, and drinking water. Once deposited in the body, many radioactive materials can be incorporated into tissues because the chemical properties of the radioisotopes are identical or similar to stable isotopes in the tissues. Potassium-40, for instance, is incorporated into tissues in the same manner as stable potassium atoms because the chemical properties are identical; radioactive radium and strontium can be incorporated into tissues in the same manner as calcium because their chemical properties are similar. Once deposited in tissue, these radionuclides emit radiation that results in the internal dose to individual organs and/or the whole body as long as it is in the body.

The internal dose to the lung is due primarily to the inhalation of polonium-218 and -214 (radon daughters), lead-212 and bismuth-212 (thoron daughters) and polonium-210 (one of the longer-lived radon decay products). The dose to the lung is about 100 mrem per year from inhaled natural radioactivity. The internal dose from subsequent incorporation of inhaled or ingested radioactivity is due to a beta-gamma dose from incorporation of potassium-40, rubidium-87, and cosmogenic nuclides, and an alpha dose from incorporation of primarily polonium-210, radium-226 and -228, and uranium-238 and -234. The dose to man from internally incorporated radionuclides is about 28 mrem per year to the gonads, about 25 mrem per year to the bone marrow, lung, and other soft tissues, and about 117 mrem per year to the bone (osteocytes). The bone dose arises primarily from the alpha-emitting members of the naturally occurring series, with polonium-210 being the largest contributor. The gonadal and soft tissue doses arise primarily from the beta and gamma emissions from potassium-40. The total internal dose from inhaled plus incorporated radioactivity is about 28 mrem per year to the gonads (or whole-body dose), about 125 mrem per year to the lung, about 25 mrem per year to the bone marrow, and about 117 mrem per year to the bone (osteocytes).

The total natural background radiation dose is the sum of the external and internal components. The population-weighted dose for the U.S. population as a whole is about 82 mrem per year to the gonads or whole body, about 179 mrem per year to the lung, about 79 mrem per year to the bone marrow, and about 171 mrem per year to the bone (osteocytes).

Besides the natural background radiation, background radiation doses include contributions from man-made or technologically enhanced sources of radiation. By far, the most significant are x-ray and radiopharmaceutical medical examinations. These contribute a population-averaged dose estimated to be 70 mrem per year for the U.S. population as a whole. Fallout from nuclear weapons testing through 1970 has contributed 50-year dose commitments estimated as 80 mrem external, and 30, 20, and 45 mrem internal to the gonads, lung, and bone marrow, respectively. Contributions from the use of fossil fuels (natural gas and coal) and nuclear reactors; mining, milling, and tailings piles; television sets,

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smoke detectors, and watch dials could be responsible for an additional 5 mrem per year, averaged over the U.S. population as a whole. In addition, the use of radiation or radioactivity for scientific, industrial, or medical purposes may cause workers in the industry and, to a lesser extent, members of the general public, to receive some radiation exposure above natural background.

EVALUATION OF RADIATION DOSE AND POTENTIAL HAZARD

Radiation, regardless of its sources, is considered to be a hazard because of its potential for producing adverse effects on human life. Very large amounts of radiation received over a brief period, i.e., hundreds of rem delivered within a few hours, can produce severe injury or death within days or weeks. Distributed over longer intervals, however, these same doses would not cause early illness or fatality. At doses and rates too low to produce these immediate symptoms, chronic or repeated exposure to radiation can bring about biological damage which does not appear until years or decades later. These low-level effects are stochastic in nature; their probability rather than their severity increases with dose. Primary among these latent or delayed effects are somatic effects, where insults such as cancers occur directly to the individual exposed, and genetic defects, where, through damage to the reproductive cells of the exposed individual, disability and disease ranging from subtle to severe are transmitted to his offspring.

Clinical or observed evidence of a relationship between radiation and human cancers arise from several sources. The most important data come from the victims of Hiroshima and Nagasaki, patients exposed during medical therapy, radium dial painters, and uranium miners. Data exist only for relatively large doses; there have been no direct measurements of increased incidence of cancer for low-level radiation exposures. Evaluation of the available data has led to estimates of the risk of radiation-induced cancer; estimated risks for the lower doses have been derived by linear extrapolation from the higher doses. All radiation exposures then, no matter how small, are assumed to be capable of increasing an individual's risk of contracting cancer.

Data on genetic defects resulting from radiation exposure of humans is not available to the extent necessary to allow an estimate of the risk of radiation-induced effects. Data from animals, along with general knowledge of genetics, have been used to derive an estimate of the risks of genetic effects.

Estimates of health effects from radiation doses are usually based on risk factors as provided in International Commission on Radiological Protection (ICRP), National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), or United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports. Multiplying the estimated dose by the appropriate risk factor provides an estimate of the risk or probability of induction of health effects to an individual or his descendants as a result of that exposure. The evaluation of these risk factors is presently subject to large uncertainties and, therefore, potential continual revision. The risk

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factors recommended by the ICRP for cancer mortality and hereditary ill health to the first and second generations are  $10^{-4}$  per rem of whole body dose and  $4 \times 10^{-5}$  per rem of gonadal dose, respectively. As an example, a whole-body dose of 1 rem would be estimated to add a risk of cancer mortality to the exposed individual of  $10^{-4}$ , i.e., 1 chance in 10,000. However, a precise numerical value cannot be assigned with any certainty to a particular individual's increase in risk attributable to radiation exposure. The reasons for this are numerous and include the following: (1) uncertainties over the influence of the individual's age, state of health, personal habits, family medical history, and previous or concurrent exposure to other cancer-causing agents, (2) the variability in the latent period (time between exposure and physical evidence of disease), and (3) the uncertainty in the risk factor itself.

To be meaningful, an attempt should be made to view such risk estimates in the appropriate context. One useful comparison is with risks encountered in normal life. Another comparison, potentially more useful, is with an estimation of the risks attributable to natural background radiation. Radiation from natural external and internal radioactivity results in the same types of interactions with body tissues as that from "man-made" radioactivity. Hence, the risks from a specified dose are the same regardless of the source. Rather than going through an intermediate step involving risk factors, doses can also be compared directly to natural background radiation doses.

Besides estimation of risks and comparisons to natural background, doses may be compared to standards and regulations. The appropriate standards, the Department of Energy's "Requirements for Radiation Protection," give limits for external and internal exposures for the whole body and specified organs which are expressed as the permissible dose or dose commitment annually in addition to natural background and medical exposures. There are, in general, two sets of limits, one applicable to occupationally exposed persons and the second applicable to individuals and population groups of the general public. The limits for individuals of the public are one-tenth of those permitted for occupationally exposed individuals. The set of limits important to this report are those applicable to individuals and population groups of the public. The limits for individuals of the public are 500 mrem per year to the whole body, gonads, or bone marrow and 1500 mrem per year to other organs. The limits for population groups of the public are 170 mrem to the whole body, gonads, or bone marrow and 500 mrem per year to other organs, averaged over the group. In either case, exposures are to be limited to the lowest levels reasonably achievable within the given limits.

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