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CEX-60.1

CIVIL EFFECTS EXERCISE

EVALUATION OF THE FALLOUT PROTECTION AFFORDED BY BROOKHAVEN NATIONAL LABORATORY MEDICAL RESEARCH CENTER

H. Borella, Z. Burson, and J. Jacovitch

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CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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EVALUATION OF THE FALLOUT PROTECTION AFFORDED BY BROOKHAVEN NATIONAL LABORATORY MEDICAL RESEARCH CENTER

By

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Santa Barbara Laboratory, Santa Barbara, California
February 1961

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ABSTRACT

An experimental study was made to determine the protection against fallout radiation provided by the Medical Research Center at Brookhaven National Laboratory. Shelter areas in the basement which could be used as emergency hospital wards were found to offer satisfactory shielding during a fallout situation.

This study also added data to the nuclear energy civil effects research being conducted by the Civil Effects Test Operations, Division of Biology and Medicine, United States Atomic Energy Commission, on the radiation shielding provided by structures.

A fallout radiation field was simulated by pumping a sealed Co^{60} source through a long length of evenly distributed tubing. Radiation measurements were made inside the Medical Center by dose-integrating ionization chambers.

In general, the protection factors (ratio of open-field exposure dose rate to structure exposure dose rate) varied from 200 to 400 throughout the basement and from 12 to 20 on the first floor. Two isolated areas in the basement indicated much higher protection factors (1400 and 4000). Since this was a large one-story structure with a flat roof, fallout on the roof would probably contribute more than 90 per cent of the total exposure dose rate at most points within the building during a fallout situation. Methods of significantly increasing the protection at most points of interest are limited to increasing the shielding material between the shelter areas and the roof or removing the contamination from the roof.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the participants whose untiring efforts made possible the successful completion of the experiment. Also, the authors gratefully acknowledge the many valuable contributions made by each of the following:

R. L. Corsbie, L. J. Deal, and members of the CETO staff for their over-all support.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Although the degree of protection from fallout radiation afforded by various types of buildings can be estimated statistically, estimates alone do not represent specific information. Recognizing the need for knowledge regarding the protection afforded by conventional structures against the hazards of nuclear attacks or accidents, Civil Effects Test Operations, Division of Biology and Medicine, has conducted a series of measurements to evaluate the protection characteristics of conventional buildings, including residential and office buildings.[1–3] The measurements made during the Brookhaven experiment are part of the continuing effort to meet this need.

1.2 OBJECTIVES

The objectives of the experiment were:

1. To determine the radiation protection throughout the basement area of the Medical Research Center.
2. To determine the radiation protection at selected sites on the first-floor level of the Medical Research Center.
3. To recommend means of improving radiation protection.
4. To determine the effect of a build-up of radioactive contamination in air filters.

1.3 LIMITATIONS

Since patients were to remain in the hospital wings of the building during the measurements and since the animals on the south side of the laboratory section of the building were not to be moved, total exposure doses in these areas were limited to 50 mr to the patients and 1 r to the animals. The total dose given to controlled plants located in a greenhouse 250 ft east of the laboratory building was also limited to 1 r. The total dosage during the measurements remained well below the limits in all cases.

1.4 DESCRIPTION OF THE BUILDING

The Brookhaven National Laboratory (BNL) Medical Research Center is located in the southeast section of the general BNL area at Upton, Suffolk County, in the central section of Long Island. Upton is approximately 70 miles from New York City.

The measurements were made in the basement and on the main floor of block 9, which is the laboratory wing in the eastern part of the Medical Research Center (Figs. 1.1 and 1.2). This building is a one-story reinforced-concrete and brick structure whose basement is partially exposed above ground level. Approximate ground elevations relative to the building are shown in Fig. 1.3. The locations of streets and sidewalks are approximations made from photographs since an accurate site layout was not available. Typical wall and roof sections are illustrated in Figs. 1.4 and 1.5. Figure 1.6 is a plan view of the building and shows the layout of the surrounding structures.

REFERENCES

1. J. A. Auxier et al., *Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources*, Report CEX-58.1, January 1959.
2. J. F. Batter, Jr., et al., *An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building*, Report CEX-59.1, May 1959.
3. J. A. Auxier and T. D. Strickler, *Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources*, Report CEX-59.13, April 1960.

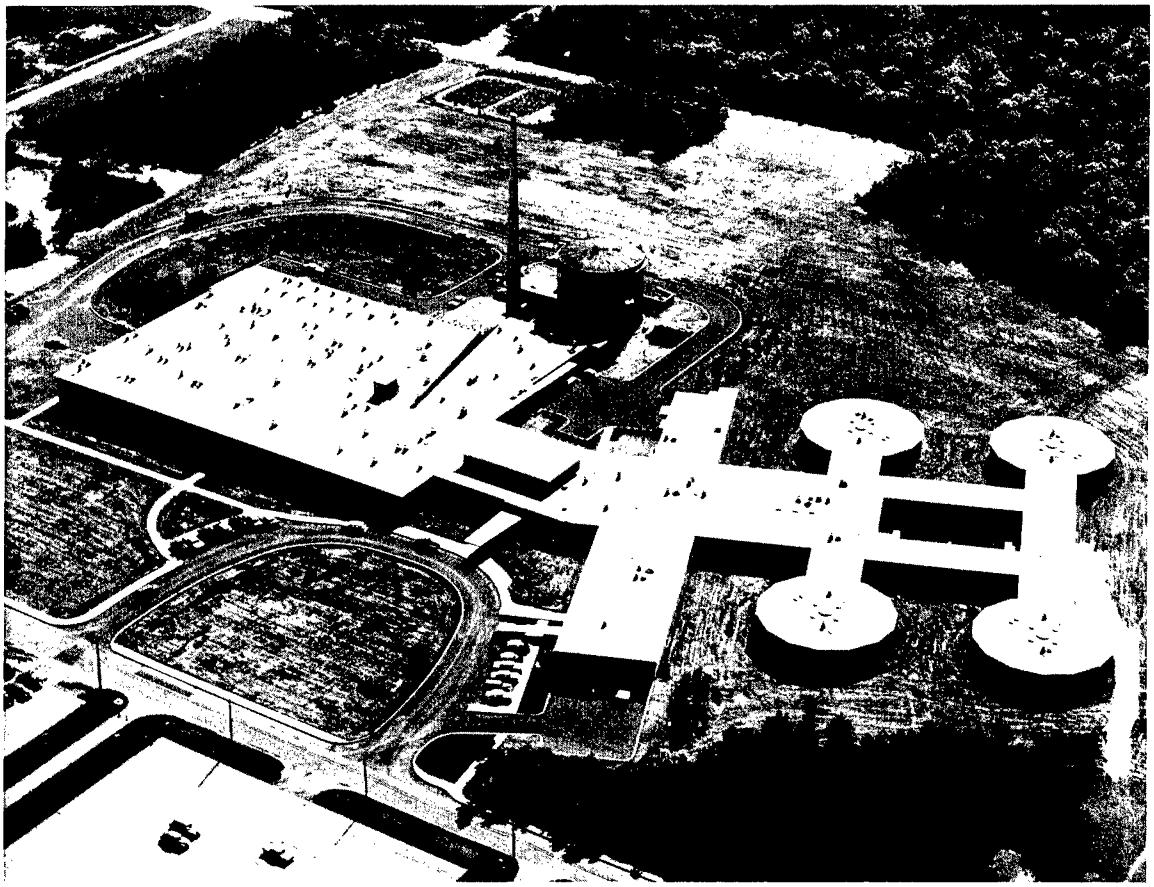


Fig. 1.1—Aerial view of the Medical Research Center (laboratory section on the left).

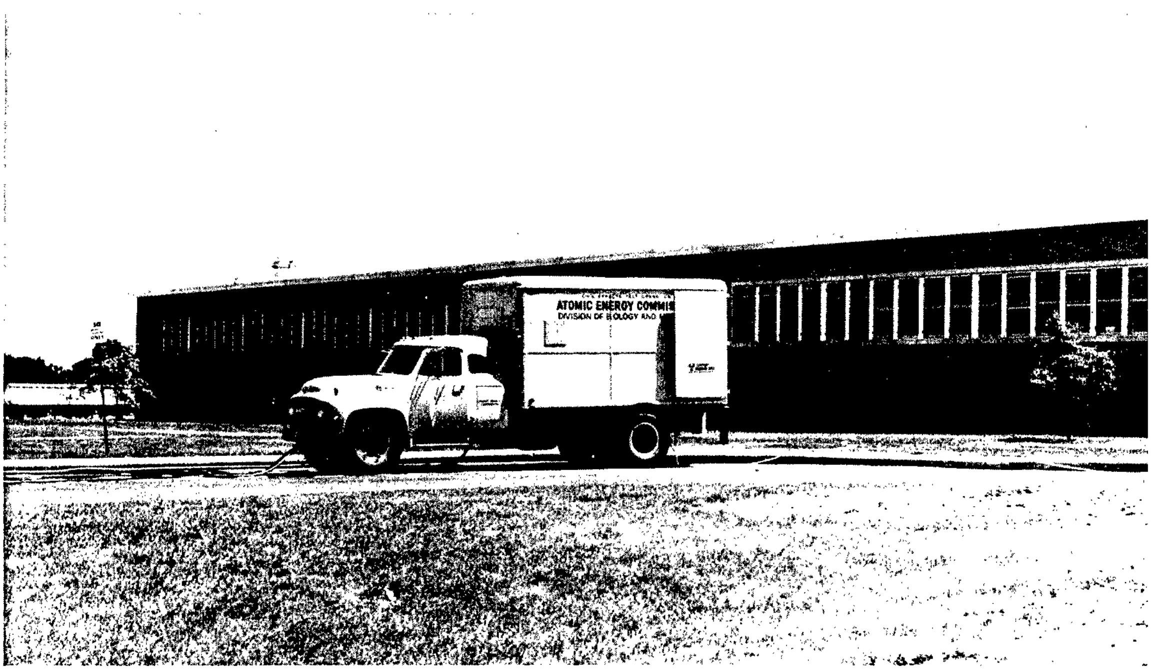
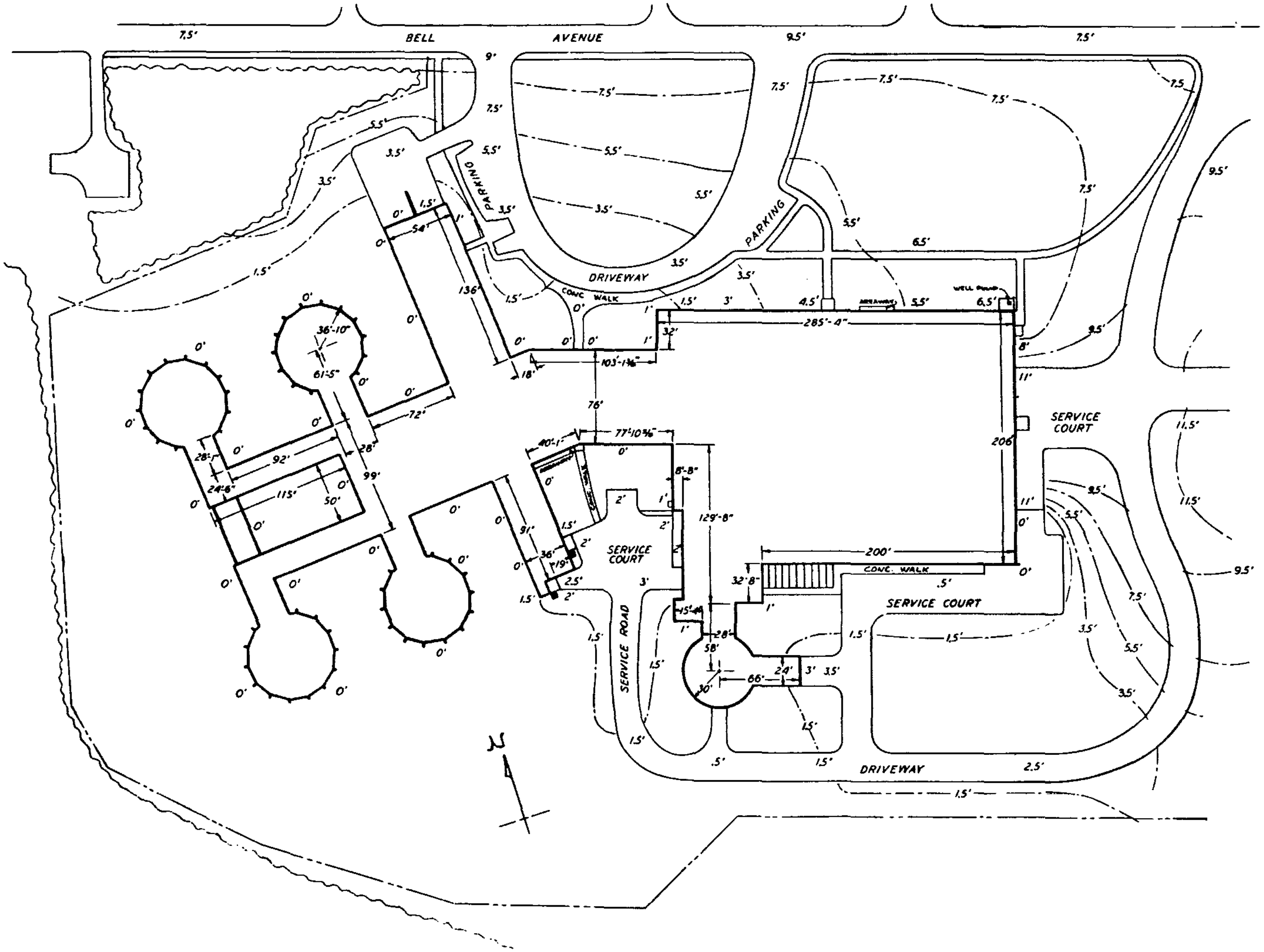


Fig. 1.2—View of laboratory section, Medical Research Center.



1. ELEVATIONS SHOW DISTANCE OF GROUND LEVEL BELOW BASEMENT CEILING
2. BUILDING DIMENSIONS APPLY TO OUTSIDE.

Fig. 1.3—Approximate ground elevations relative to building.

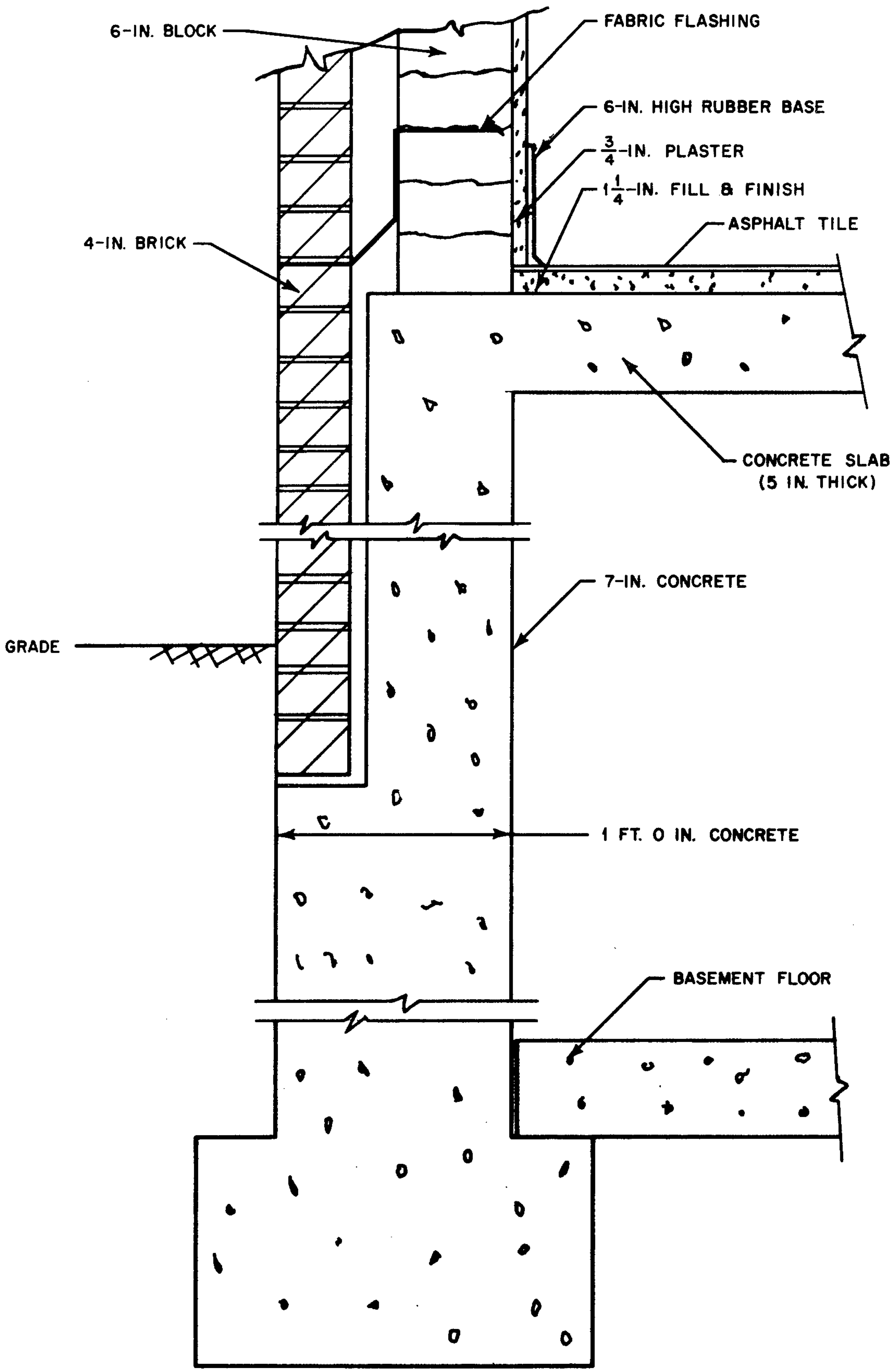


Fig. 1.4—Typical wall section (north wall).

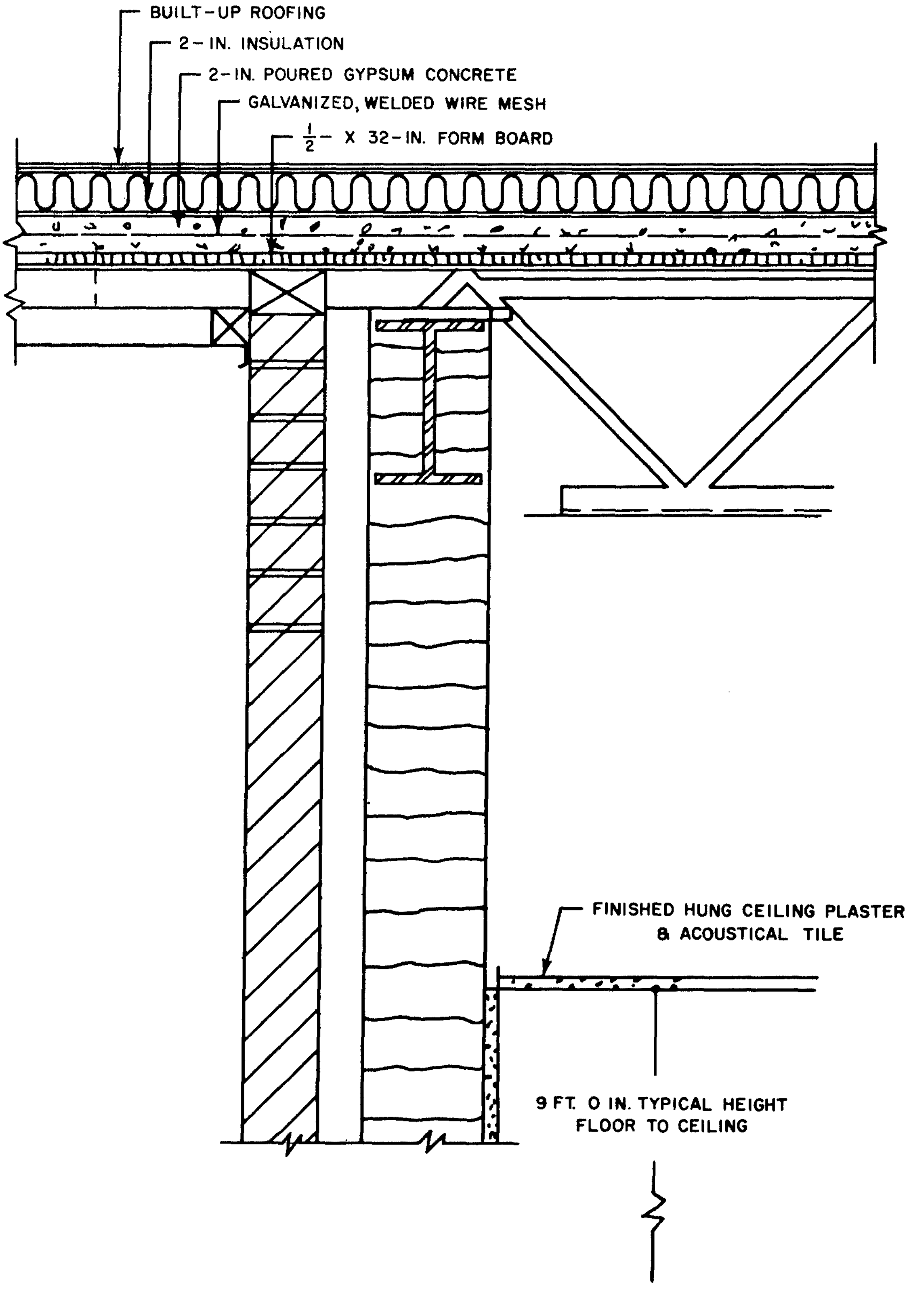


Fig. 1.5—Typical roof section (block 9).

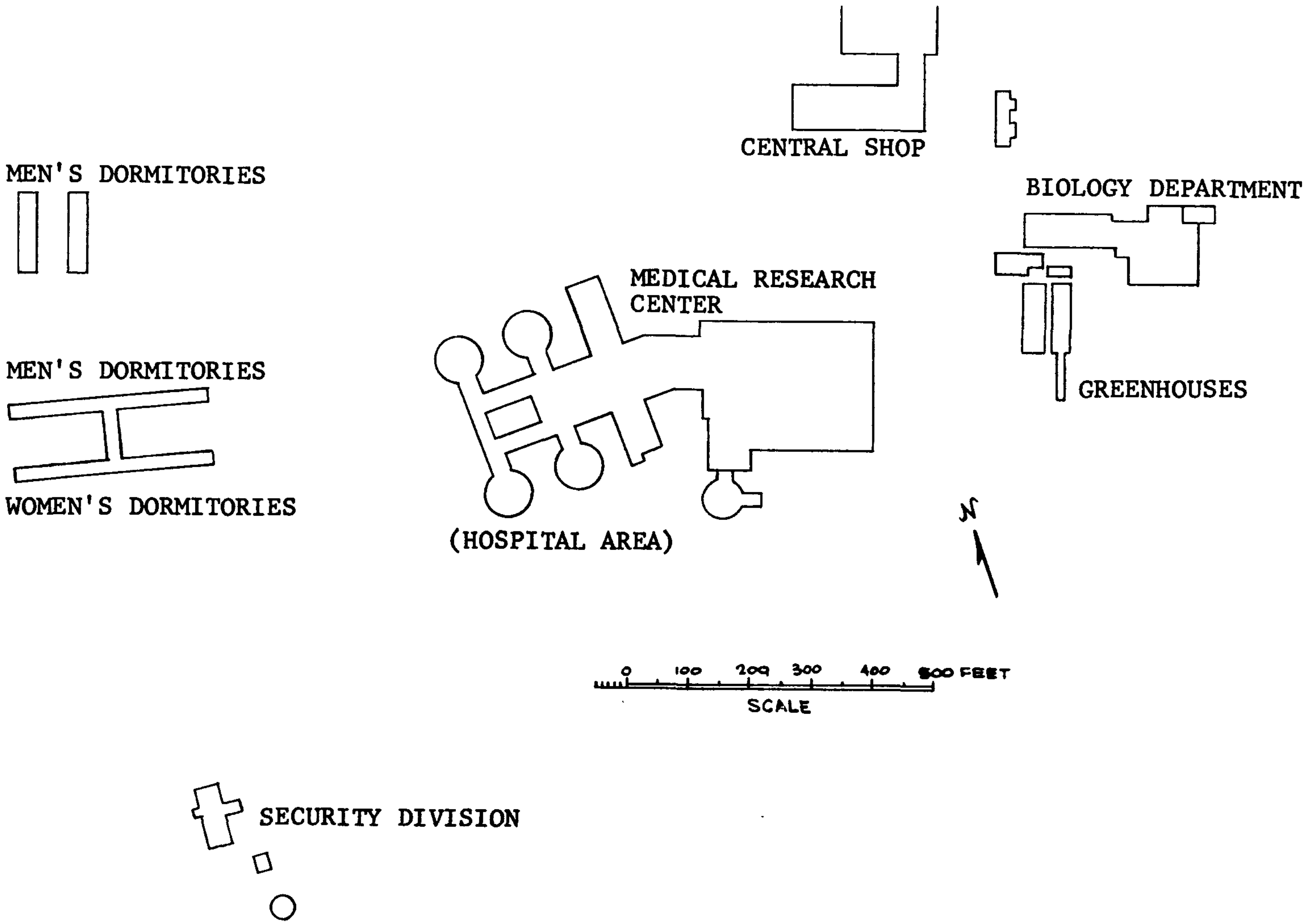


Fig. 1.6—Plan view of building showing layout of surrounding structures.

Chapter 2

DESCRIPTION OF EXPERIMENTAL METHOD

2.1 GENERAL DESCRIPTION

Experimental data were obtained to aid in evaluating the protection provided by the Medical Research Center, specifically by the basement and other possible shelter areas.

Measurements were made using four distinct radioactive-source geometries:

1. Source evenly distributed on the ground outside selected portions of the building
2. Source evenly distributed on selected portions of the Medical Research Center roof
3. Source concentrated in selected air filters and vents
4. Source placed at points on the ground outside selected portions of the building

Detectors were placed within the building at preselected positions to record the dose per exposure.

For measurements with source geometries 1 and 2, a 203-curie Co^{60} source was pumped at a uniform speed through a length of tubing. This tubing was prepositioned over the area of interest; so the amount of tubing per unit area was constant. The source, pumped at a uniform rate, thus simulated an area of uniformly distributed radioactivity. Integrated radiation doses were measured inside the building at desired positions with pocket ionization chambers. Approximately 300 dosimeters were used for each set of measurements.

A point source was used to simulate the accumulation of fallout in air filters and vents (geometries 3 and 4). A 13.3-curie Co^{60} source was placed in selected positions, and the dose (or dose rate) was measured in each area of interest. Measurements were made with pocket ionization chambers and a calibrated scintillation detector.

2.2 MOVING POINT-SOURCE SYSTEM

A method of source circulation similar to the one used for the CETO experiments CEX 58.5 and CEX-59.13 was used for this project.* This system consisted of a hydraulic pumping unit, associated tubing, source-position indicators, a remote-control console, source shield (pig), 203- and 20-curie Co^{60} source containers (slugs), and interconnecting cables. The Co^{60} slug was pumped from the pig, through the tubing, and back into the pig.

The apparatus was contained in three vehicles. The hydraulic system and source shields were mounted on one truck. Tubing reels, power and signal cable reels, and a 5-kw emergency generator were on a caisson trailer (Fig. 2.1). A laboratory truck contained the control console, tools, supplies, and general equipment for the system (Fig. 2.2).

*This system was similar to that used by Technical Operations, Inc., and described in their report TO-B 59-4.

The 203-curie Co^{60} source shield provided a means of storing the slug when it was not being pumped through the tubing. Within the shield were two S-shaped stainless-steel tubes in which the slug traveled. Stops were provided in the center of each tube to halt the motion of the slug when it returned to the shield. A method of locking the slug in place when it was not being used was devised. A picture of this shield is presented in Fig. 2.3.

The 20-curie Co^{60} source shield consisted of a modified shipping container. The two source shields, the air compressor (used to empty the water from the tubing), and the hydraulic system were mounted in an AEC truck (Fig. 2.4).

The hydraulic pumping system consisted of a 120-gal reservoir, a 1-hp 220-volt electric motor, a piston type positive-displacement pump, filters, several hand-operated and electrically operated solenoid valves, and connecting lines. The outside diameter of the source capsule was slightly less than the inside diameter of the tubing. Hence, a flow system rather than a pressure-differential system was utilized. In normal operation the internal pressure was about 100 psi when 3000 ft of tubing was used; the source traveled at 120 ft/min.

An emergency hand pump was provided to retrieve the slug from either direction in the event the main unit failed. The hand device was placed 100 ft away (Fig. 2.5).

The system (Fig. 2.6) was remotely controlled from the console in the laboratory truck, about 500 ft from the pumping system. From this point it was possible to start, stop, or reverse the movement of the slug, with maximum speed obtainable in either direction. Twenty movable magnetic indicators (Fig. 2.7) were used to locate the slug. Clamped to desired points on the tubing, these indicators were connected individually to a series of lights on the console panel.

The Co^{60}, encapsulated in a magnetic stainless-steel container, was conveyed by water through $\frac{1}{2}$-in. Marlex (high-density polyethylene) tubing, rated at 200 psi hoop stress at 130°F for a one-year period. Burst pressure was rated in excess of 1000 psi. The tubing bend radius was limited to a minimum of 2 ft.

2.3 POINT-SOURCE SYSTEM

In addition to the moving point-source system, a stationary, Co^{60} point source was used. The system was a Multitron series 50 (Fig. 2.8), consisting of a source shield mounted on wheels, a hand-powered source drive, and an indicating device. The 13.3-curie Co^{60} source was encapsulated in a container and connected to a 50-ft steel control cable, which traveled inside a flexible guide tube. This control cable passed over a crank-driven wheel in the control unit, which advanced or retracted the source, making it possible for the operator to stand 25 ft away from the source shield and reel the source out to the desired location.

2.4 SOURCES

Radioactive sources used during this experiment were:

1. One 203-curie Co^{60} source
2. One 13.3-curie Co^{60} source
3. One 1.24-curie Co^{60} source
4. One 1.05-mc Co^{60} source (secondary standard)

The 203-curie Co^{60} source was doubly encapsulated in magnetic stainless-steel containers machined to pass through the plastic tubing. Two containers, representing about 100 curies each, were connected by a flexible steel cable $\frac{3}{4}$ in. long (Figs. 2.9 and 2.10). This source was used with the pumping system. A 20-curie Co^{60} source was also available but was not used for this experiment.

Calibration of the 203-curie source was performed at the Nevada Test Site (NTS) prior to the experiment. The polyethylene tubing was placed on two 15-ft ladders. The source was pumped into position and stopped directly between the two ladders at a height of 12 ft. Victoreen r-meters, previously calibrated against National Bureau of Standards calibrated chambers, were used to measure the dose rate at 2, 4, 8, and 16 ft from the source at a height of 12 ft. The calibration curve appears in Fig. 2.11. The source was found to be 207.7 curies at the time of calibration (May 3, 1960); it had decayed to 203 curies at the time of the experiment (July 5 to 10, 1960), assuming 14.53 r/hr/curie at 1 ft.

The 13.3-curie Co^{60} source was a part of the Multitron point-source system previously mentioned. It was calibrated at NTS by the Engineering Radiological Safety Division of the Reynolds Electric Co.

The 1.24-curie Co^{60} source was calibrated by the Medical Center Health Physics Group.

2.5 INSTRUMENTATION

The instrumentation used in this experiment included dose-integrating ionization chambers with associated charger readers and a scintillation-detector system.

Ionization chambers used were:

1. 250 Victoreen model 362 chambers (PIC's)	0- to 200-mr pocket ionization chambers
2. 145 Victoreen model 239 chambers	0- to 10-mr stray-radiation chambers
3. 20 Bendix model 611	0- to 5-r pocket chambers

Victoreen model 287 minometers were used for charging and reading the model 362 and 239 ionization chambers (Fig. 2.12).

The chambers were calibrated prior to the experiment with a Co^{60} standard. Chambers were picked at random and exposed several times to obtain an average dose and standard deviation at several points over the entire range of the chambers. Figure 2.13 is a sample calibration curve.

An energy-response curve was obtained from the Victoreen Instrument Co. for the 0- to 10-mr chambers and is presented in Fig. 2.14.

A scintillation-detector system was used for measurement where the dose rate was extremely low as well as for correlation of measurements taken by the ionization chambers at selected positions. The system (Figs. 2.15 and 2.16) consisted of:

1. The model 812 probe, which contained a hermetically sealed thallium-activated 1-in. by 1-in. NaI crystal optically coupled with DC-200 silicone fluid to a DuMont 6291 photomultiplier. The probe was shielded with 0.030 in. of tantalum to improve the energy response.
2. A model 212 general-purpose linear amplifier.
3. A Baird-Atomic model 134 scaler.
4. A model 630 timer capable of directly reading to the nearest 0.01 min.
5. A model 312 regulated high-voltage supply.
6. A model 412 rate-meter providing both linear and logarithmic displays.

The system was calibrated at BNL using the Co^{60} secondary standard.

2.6 EXPERIMENTAL TECHNIQUE

The experimental technique consisted in measuring the radiation level at points within the building from a simulated contaminated area of known source strength outside. The contaminated field was simulated by moving a point source at constant speed over the area of interest in such a manner that the source spent the same time interval per unit area throughout. By the use of dose-integrating detectors within the building, the total radiation dosage was made to appear as if arising from an area source. This technique has the advantage of averaging local features of the terrain and the building under test in much the same way as would a true fallout field.

The experiment consisted in placing the tubing over eight different areas (Fig. 2.17). Figures 2.18 and 2.19 show the tubing layout for runs 1 and 7. Dosimeters were placed in paper cups hung by string from the ceiling. Figure 2.20 shows a position within a room in the basement, and Fig. 2.21 shows a position in the hall on the first floor.

Ground level in relation to the basement-ceiling level is not constant around block 9 (see Fig. 1.3). The effect of sources on the ground outside a basement wall partially exposed above ground was evaluated by making measurements with the tubing laid over areas north of block 9 (runs 1 and 2). Because most of the basement wall at the east end of the building was exposed above ground level, measurements were made on this side of block 9 (runs 3 and 4).

Since this was a large one-story building with a flat roof, the dose rate from the simulated fallout on the roof was expected to be the principal means of determining the extent of fallout protection. Therefore the tubing was placed over the entire roof of block 9 (in 4 measurements) for runs 5 through 8. Run 5 was performed first to ensure that the animals (directly under run 7) would not receive an overdose of radiation.

The grade level approximated the basement-ceiling level along the south and west side of block 9. This portion of the building was chosen to evaluate the scattered radiation entering the basement areas. A point source was placed at the positions indicated in Fig. 2.22, and the dose rate was measured in the basement with the scintillation detector. The source was placed at position E for comparison of data from run 1. The 13.3-curie point source and the scintillation-detector system (rather than the moving point-source system) were utilized so that the animals would not receive an overdose of radiation.

In addition, a point source was placed near air filters in the basement (Fig. 2.23) and in areaways north of block 9 (Fig. 2.24).

General procedures followed during a specific run were:

1. The polyethylene tubing was distributed over the desired area according to a predetermined plan.

2. A dummy source was pumped through the tubing to make certain the tubing had not been damaged during placement. At this time the dosimeters were charged and placed in preselected locations.

3. When radiological safety clearance was given, the system was energized, and a "hot" run was made. At the conclusion of the test exposure, the source was secured in its container, the dosimeters were read, and their readings were recorded.

Radio contact was maintained at all times with BNL representatives. Appropriate notification of the position of the source was given when necessary.

The majority of the dosimeters were left in place for the combination of runs 1 and 2, 3 and 4, 5 and 6, and 7 and 8, which allowed a considerable saving in time. The test exposures ranged from a minimum of 25 min to about 4 hr, depending upon the dose desired. Figure 2.25 shows the experiment schedule established.

The test exposures were made after normal working hours so that the required areas could be conveniently limited and controlled.

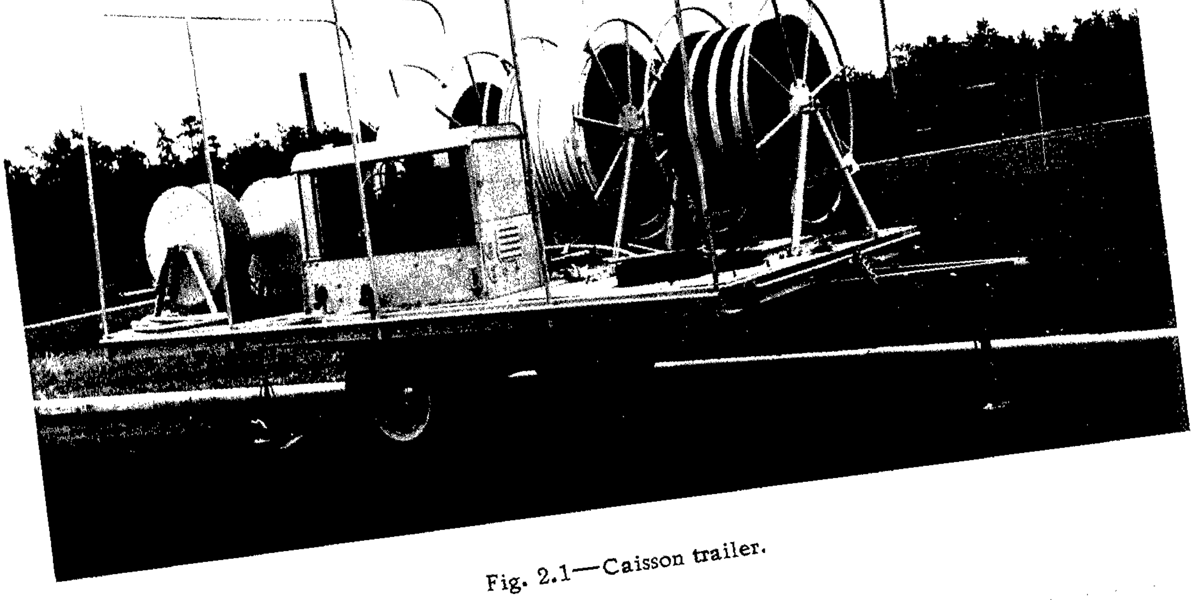


Fig. 2.1—Caisson trailer.

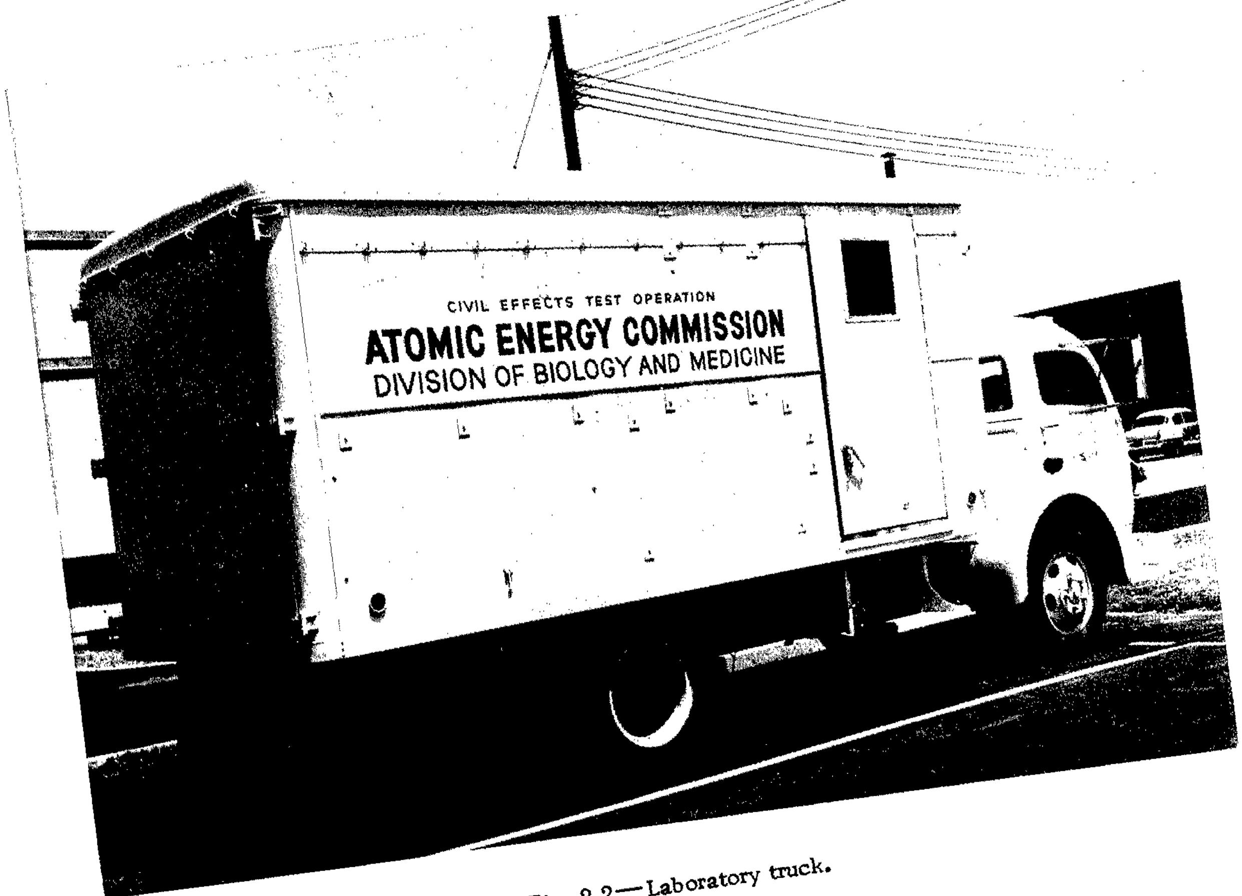


Fig. 2.2—Laboratory truck.

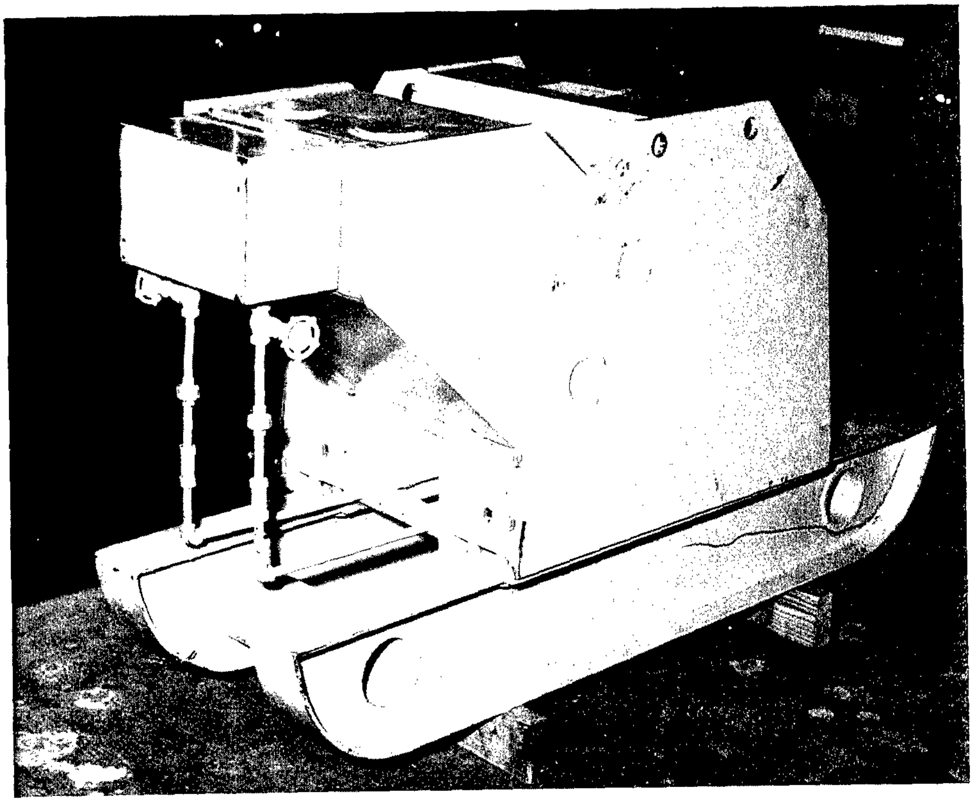


Fig. 2.3—The 200-curie Co^{60} source shield.

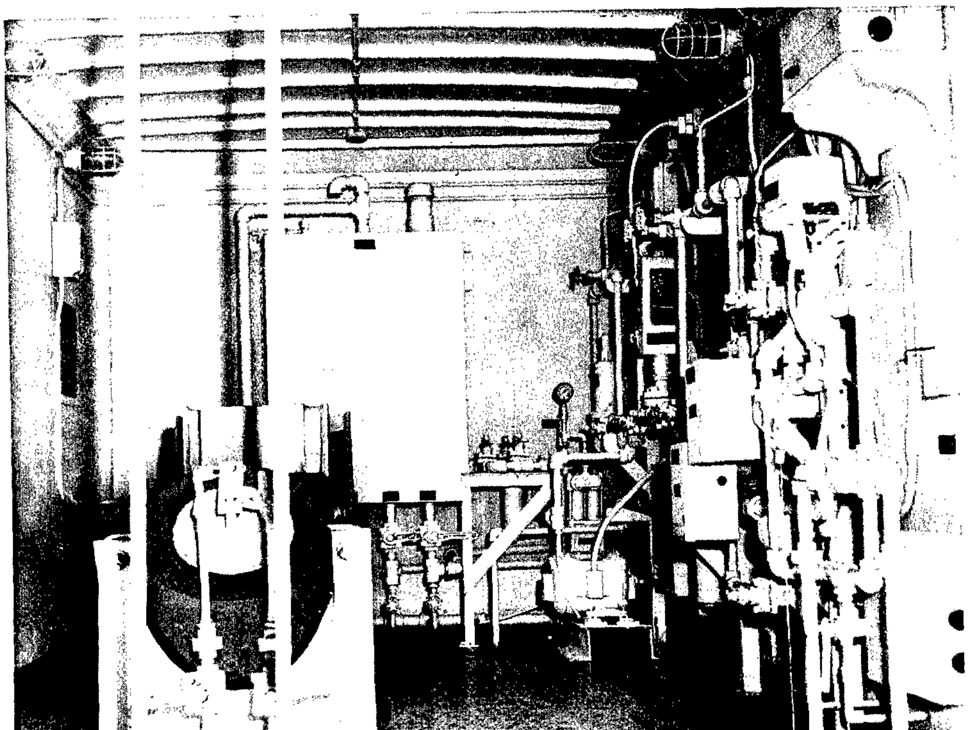


Fig. 2.4—Source truck, showing shields and pumping system.

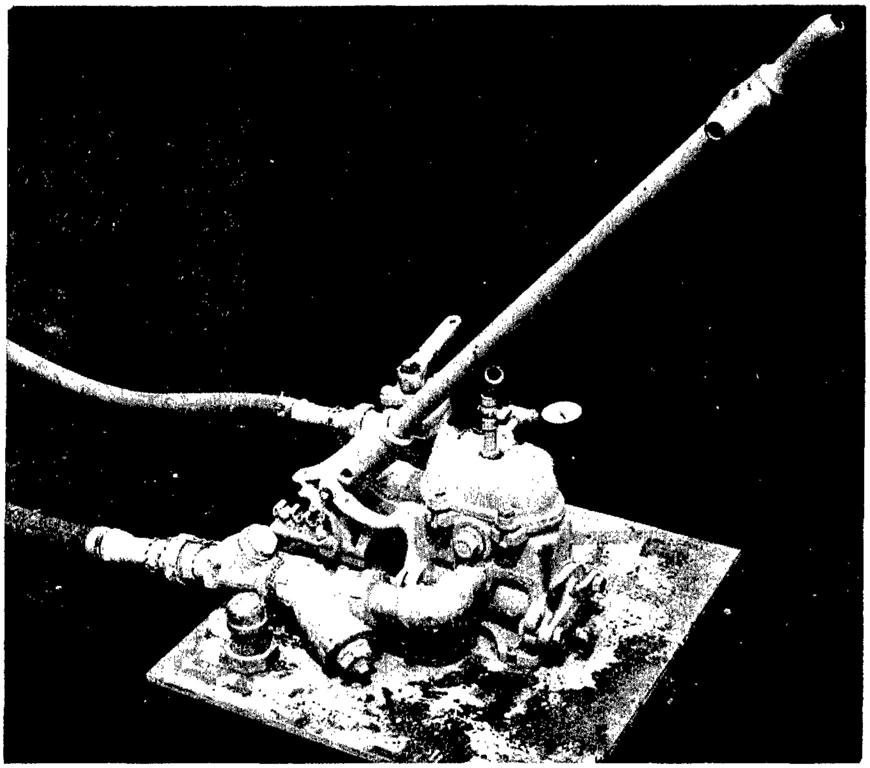


Fig. 2.5—Emergency hand pump.

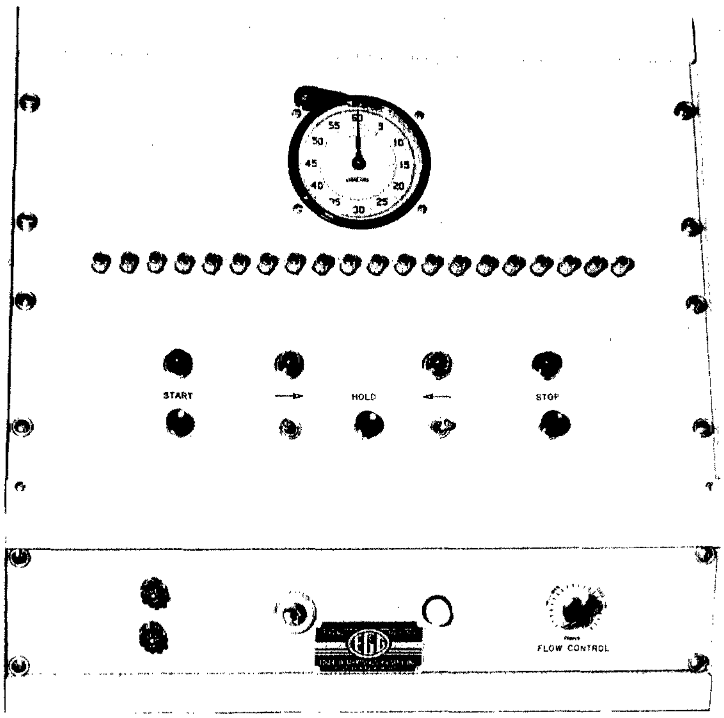


Fig. 2.6—Remote-control console.

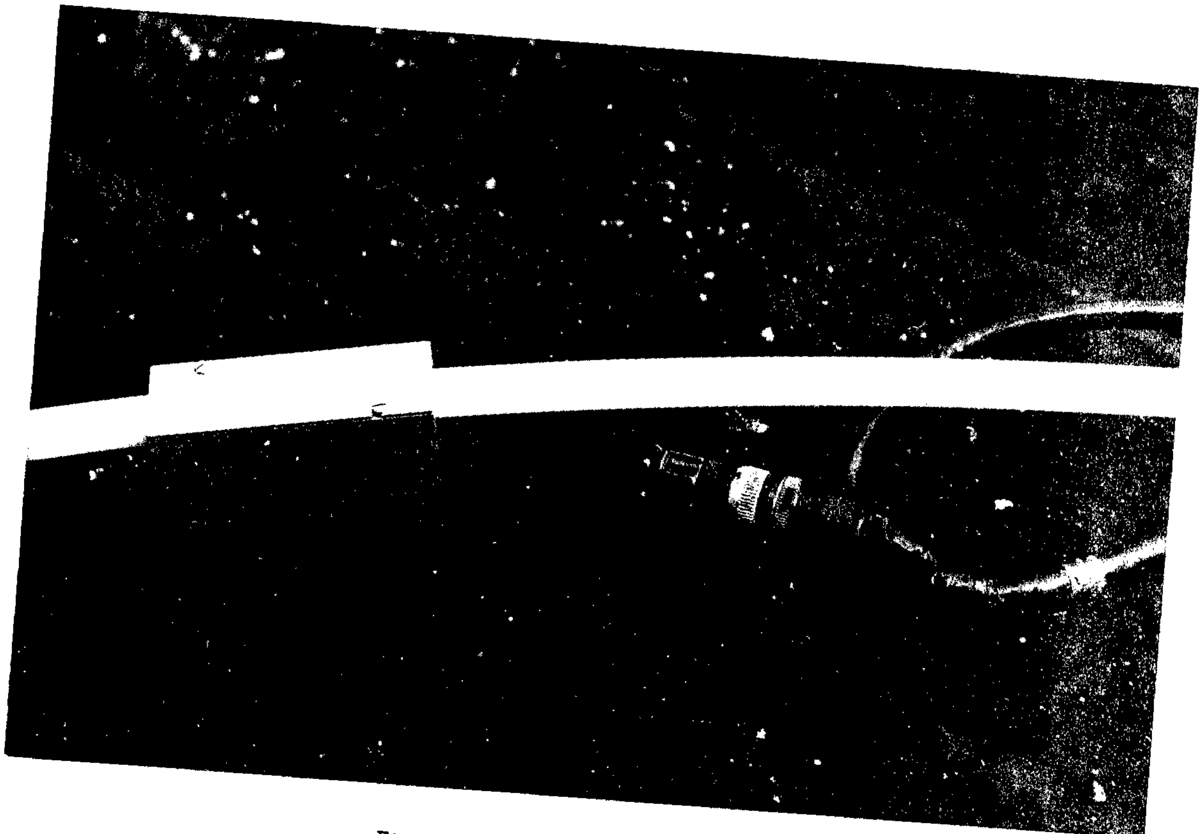


Fig. 2.7—Source-position indicator.

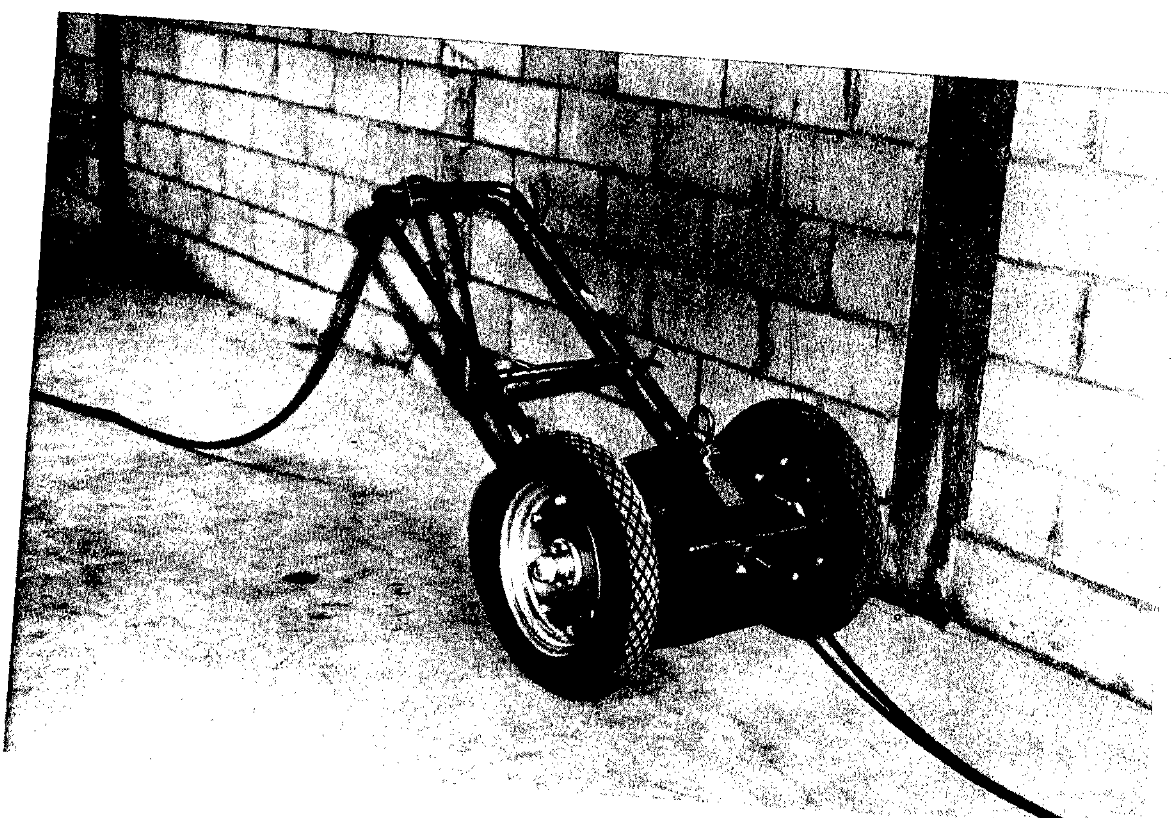


Fig. 2.8—Point-source system (Multitron).

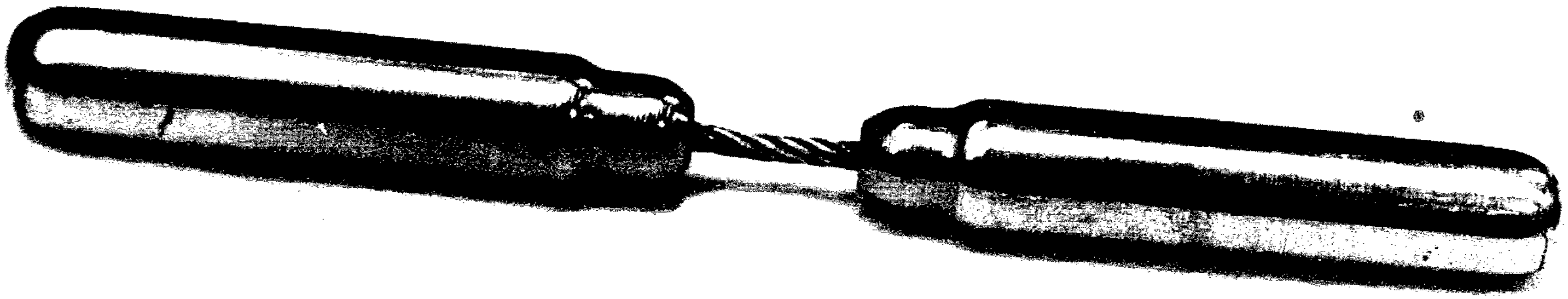


Fig. 2.9—The 200-curie Co^{60} source capsule.

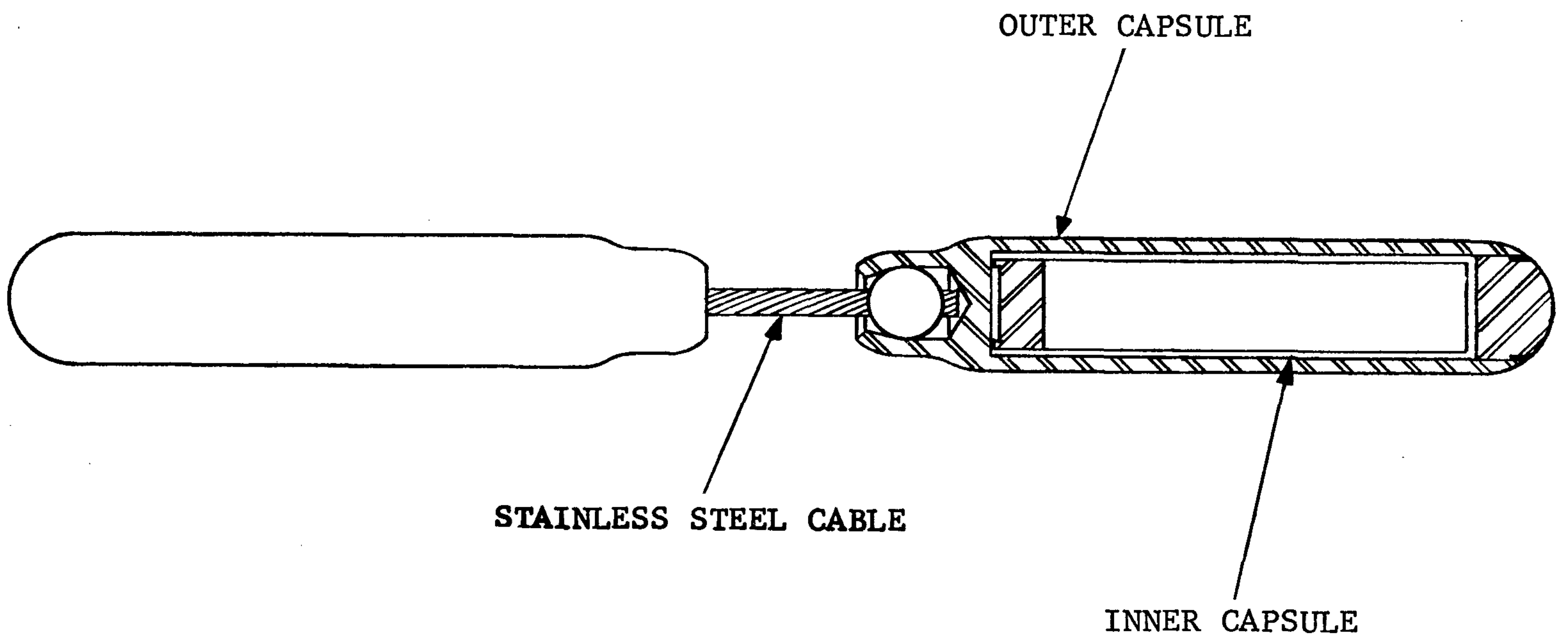


Fig. 2.10—Cutaway view of the 200-curie Co^{60} source capsule.

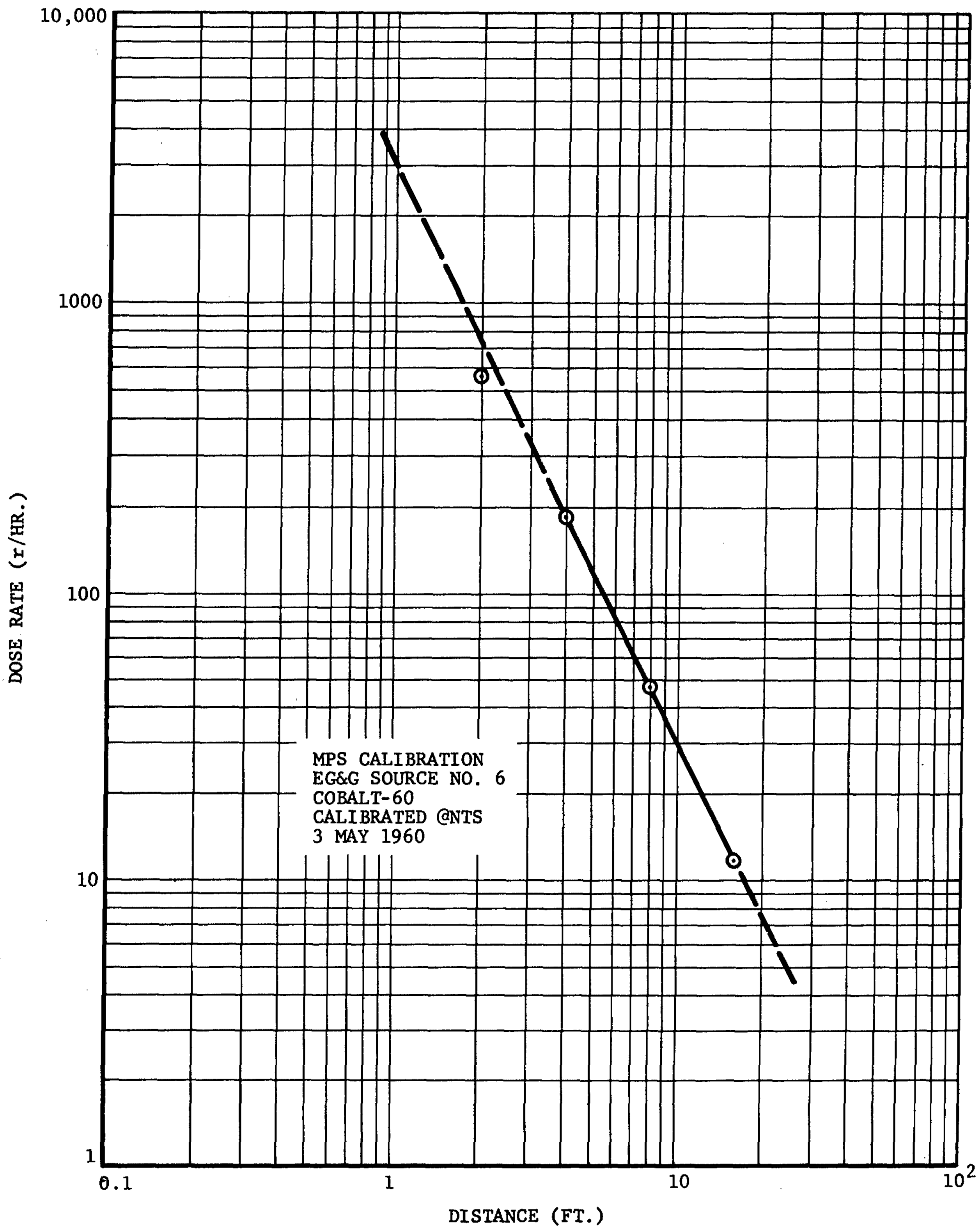


Fig. 2.11—Calibration curve for the 200-curie Co^{60} source.

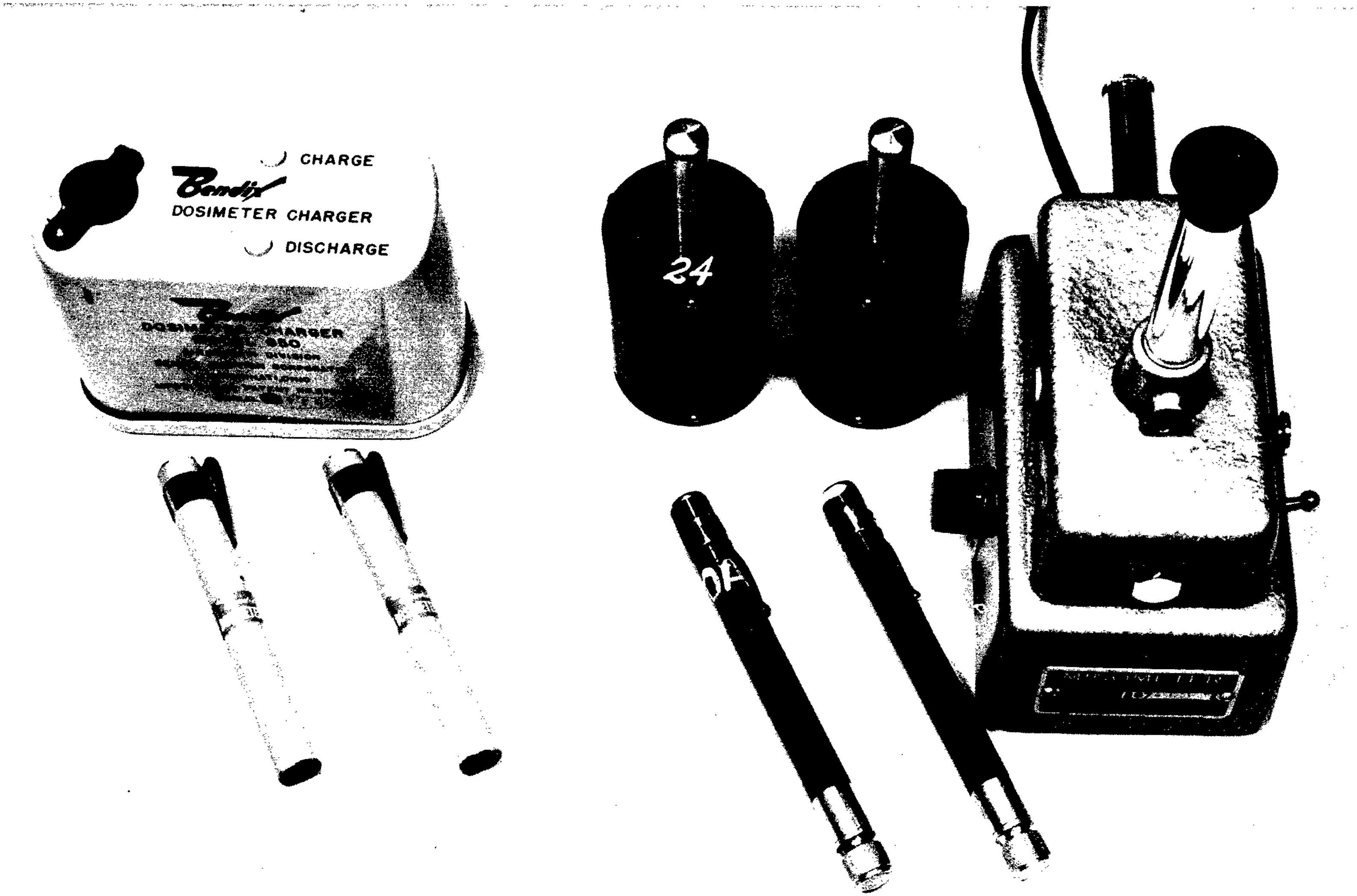


Fig. 2.12—Ionization chambers and charger readers.

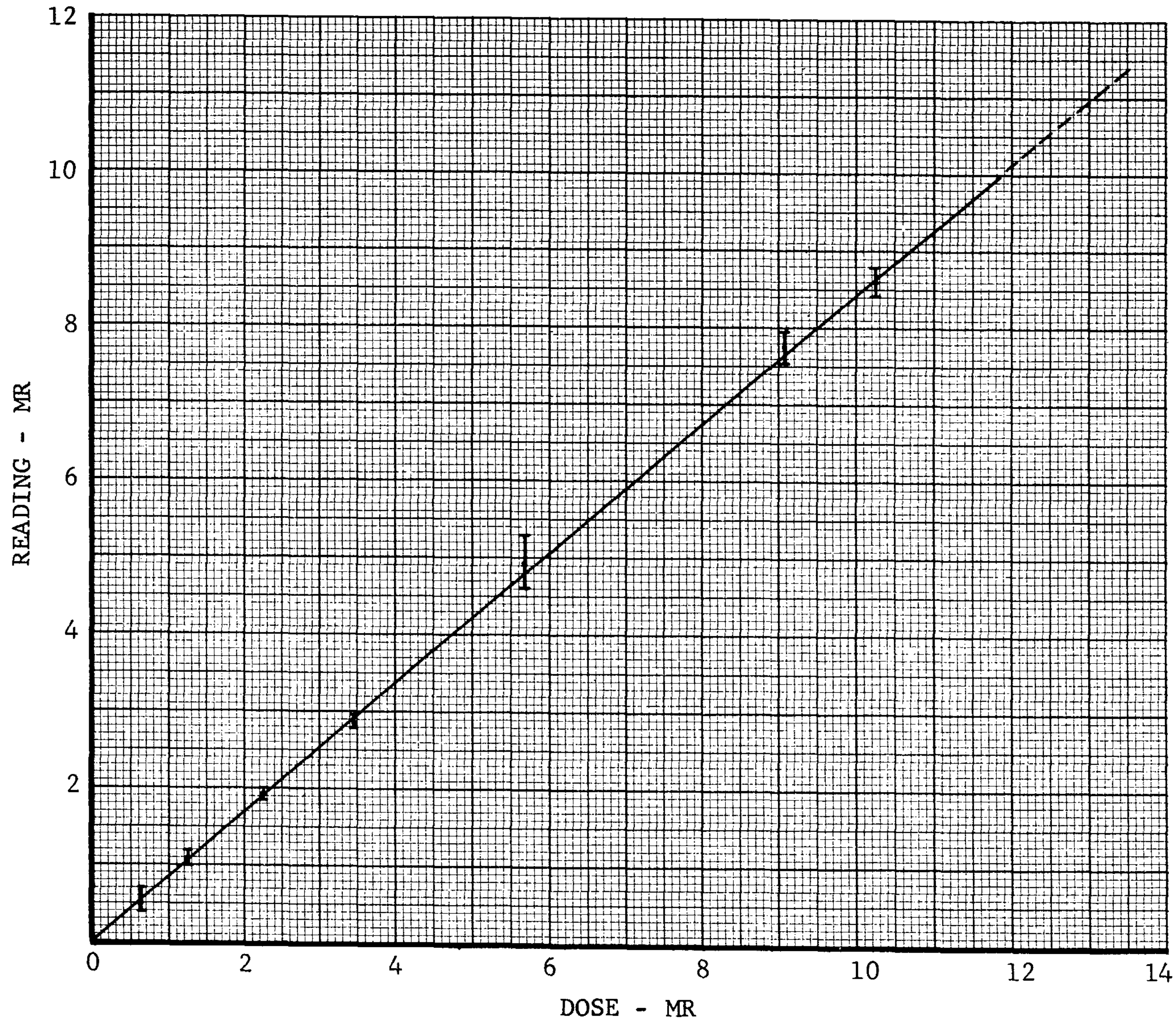


Fig. 2.13—Calibration curve for Victoreen model 239 ionization chambers.

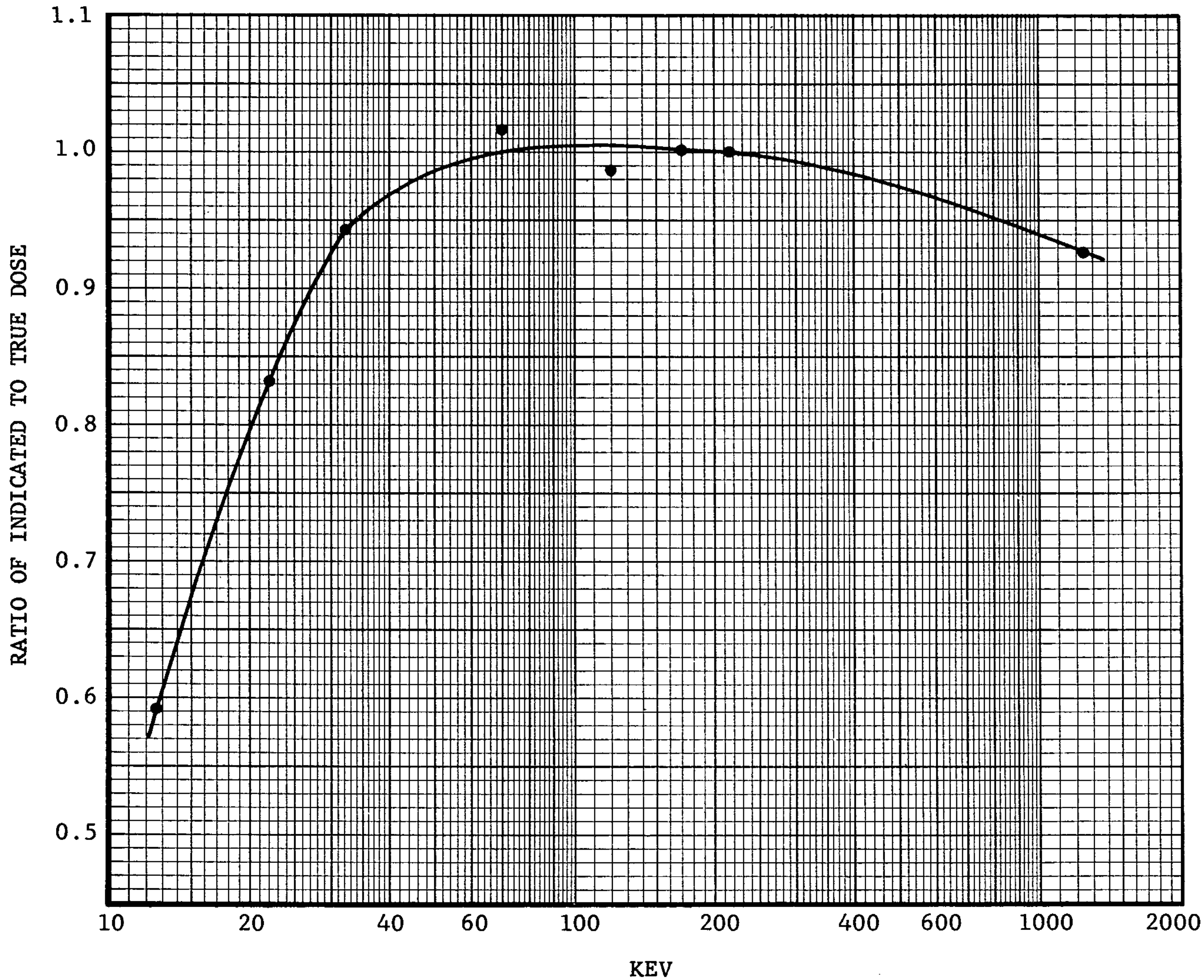


Fig. 2.14—Spectral response of model 239 stray-radiation chamber.

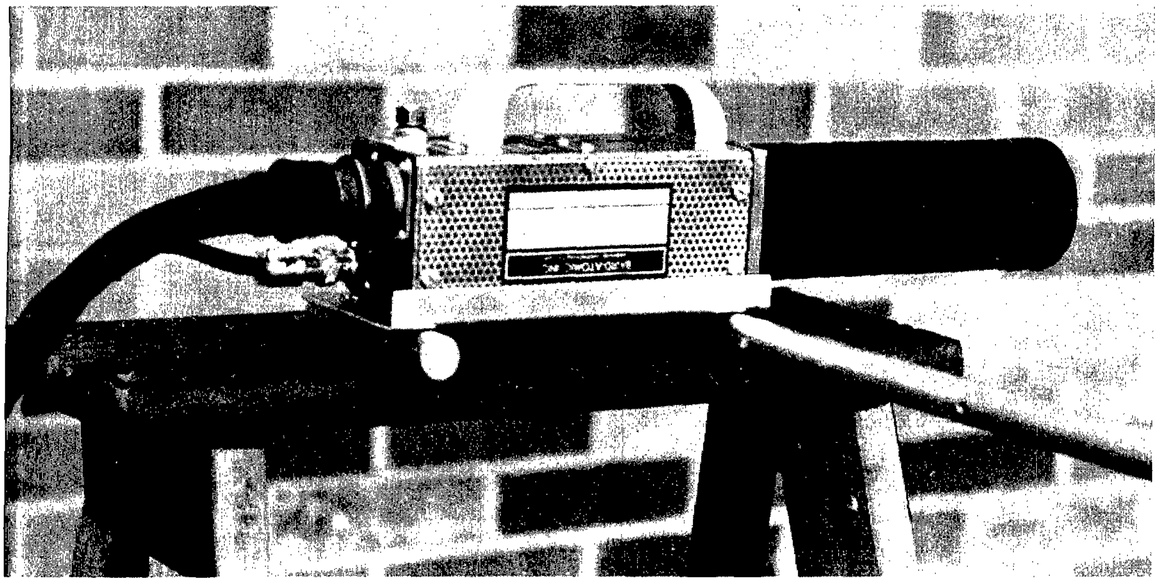


Fig. 2.15—Scintillation-crystal assembly.

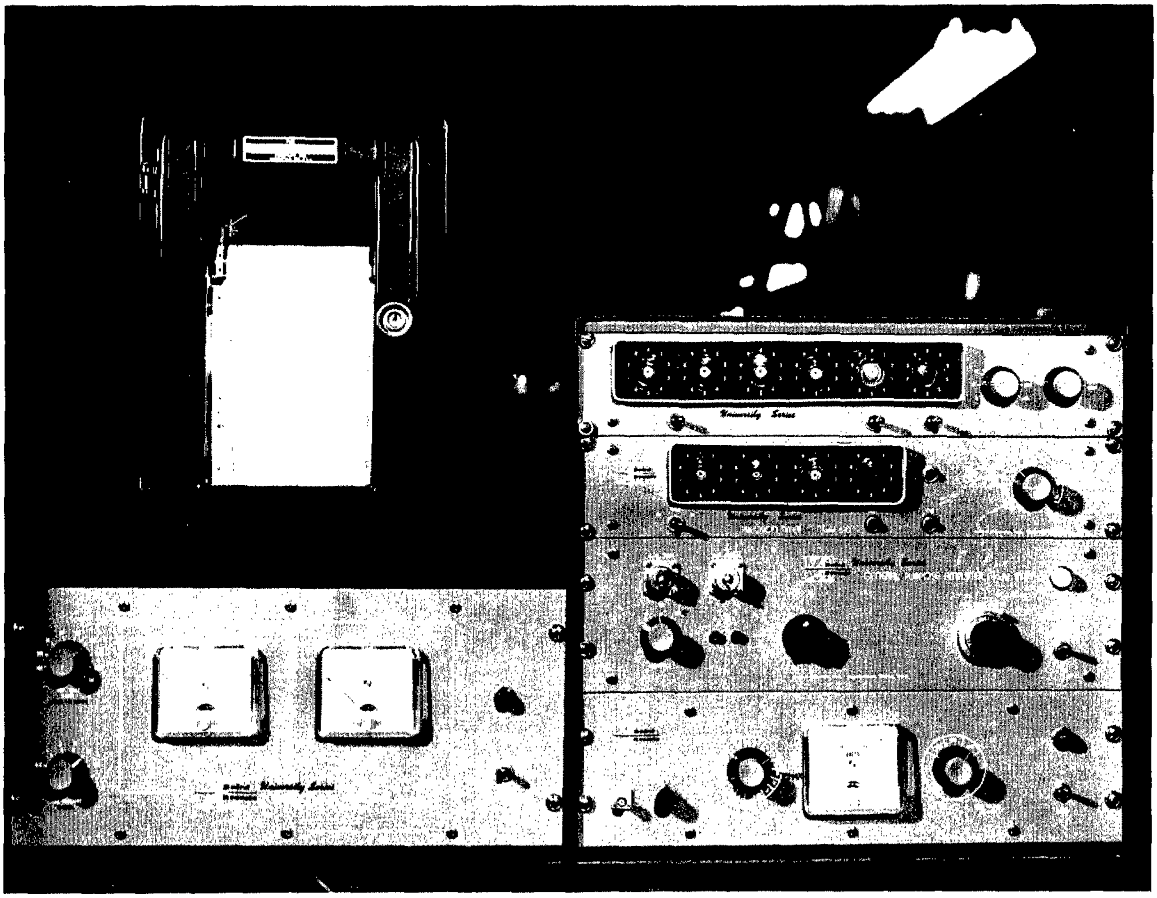


Fig. 2.16—Scintillation counting and recording equipment.

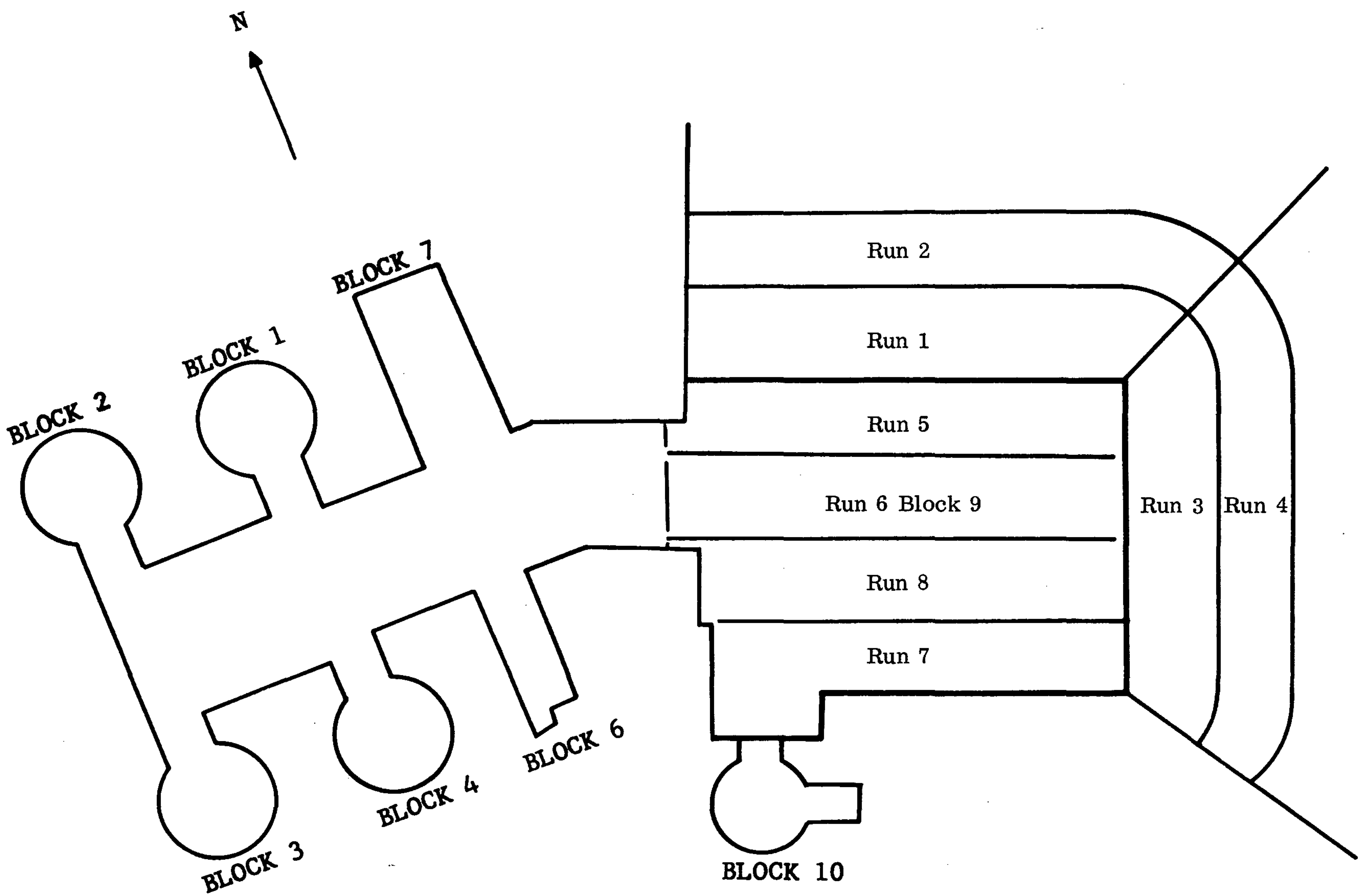


Fig. 2.17—Specific runs.

Fig. 2.18—Tubing layout for run 1.

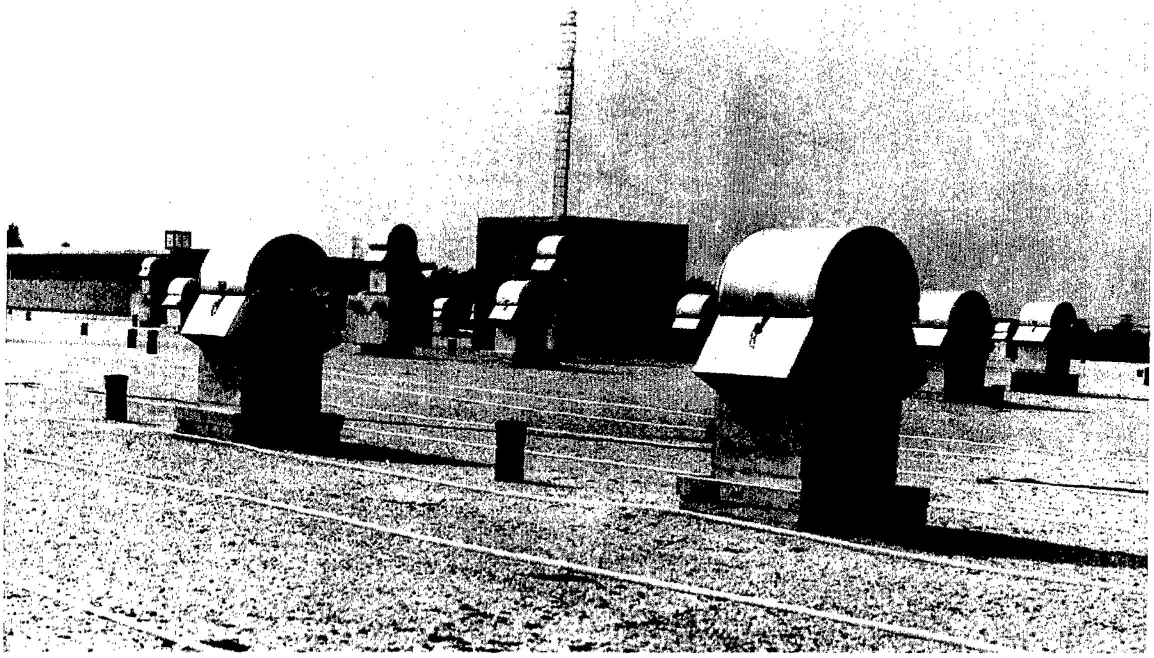


Fig. 2.19—Tubing layout for run 7.

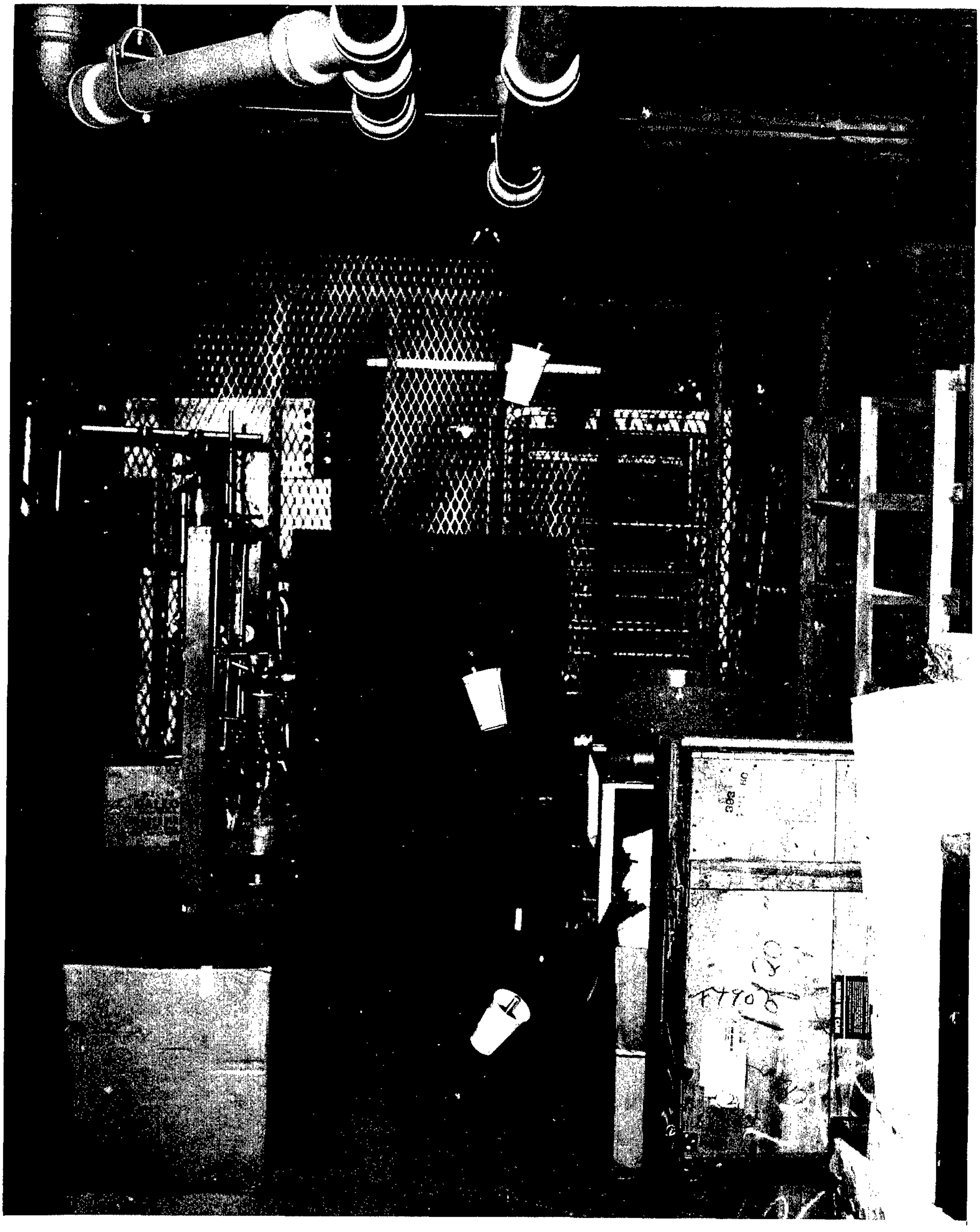


Fig. 2.20—Dosimeter position in a room in the basement.

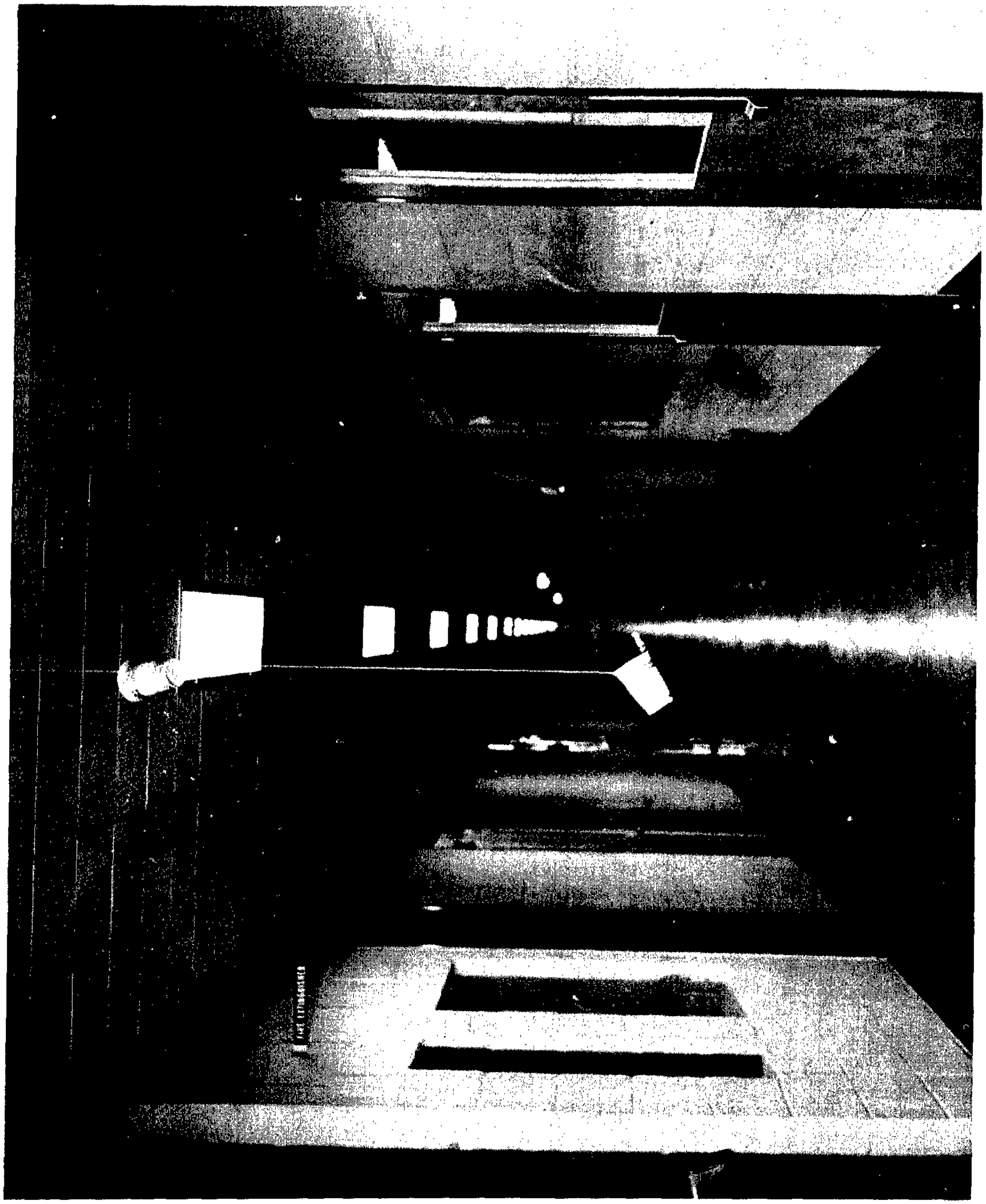


Fig. 2.21—Dosimeter position in the hallway on the first floor.

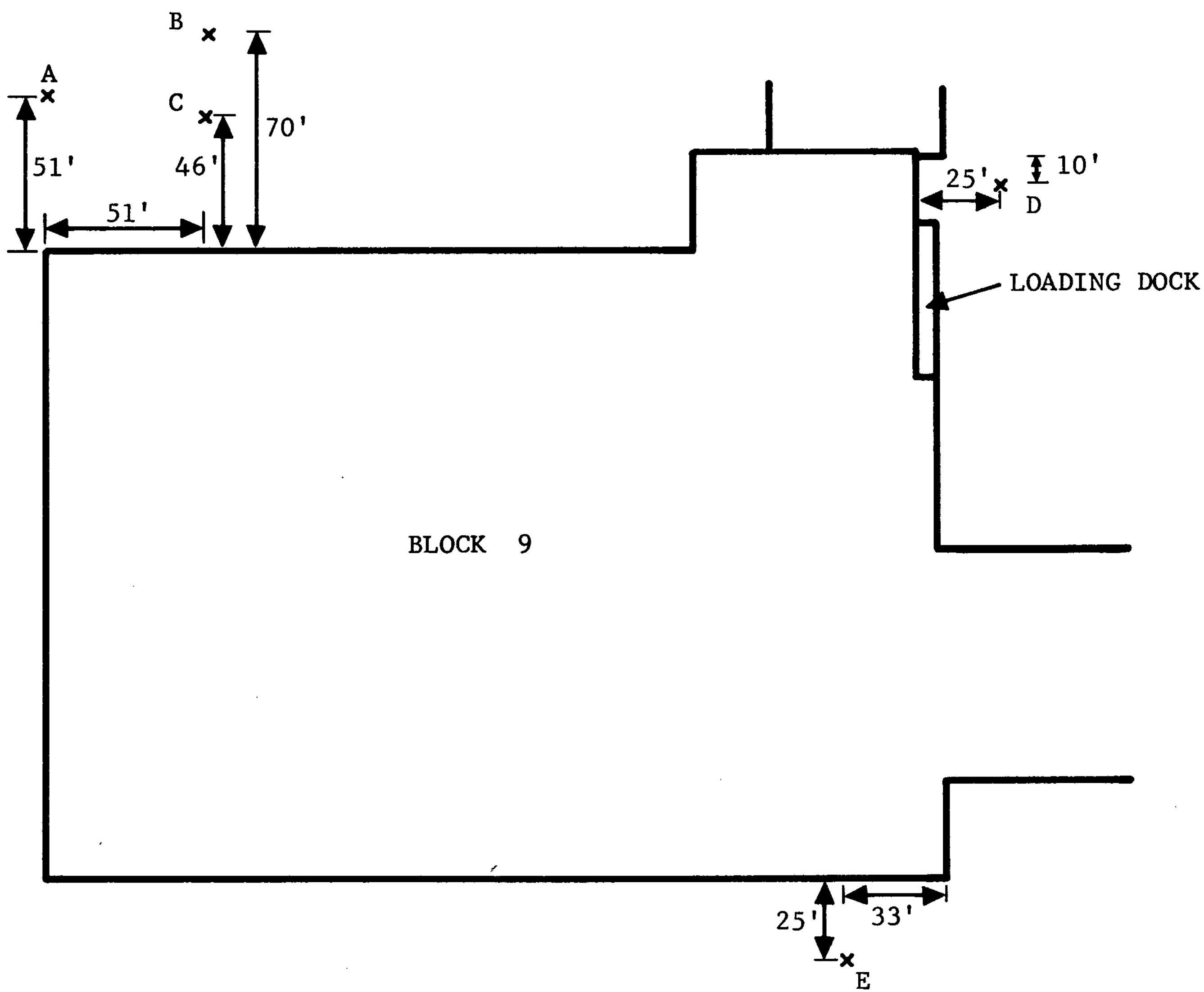


Fig. 2.22—Point-source experiments on the ground.

Fig. 2.23—Point-source position near air filters.

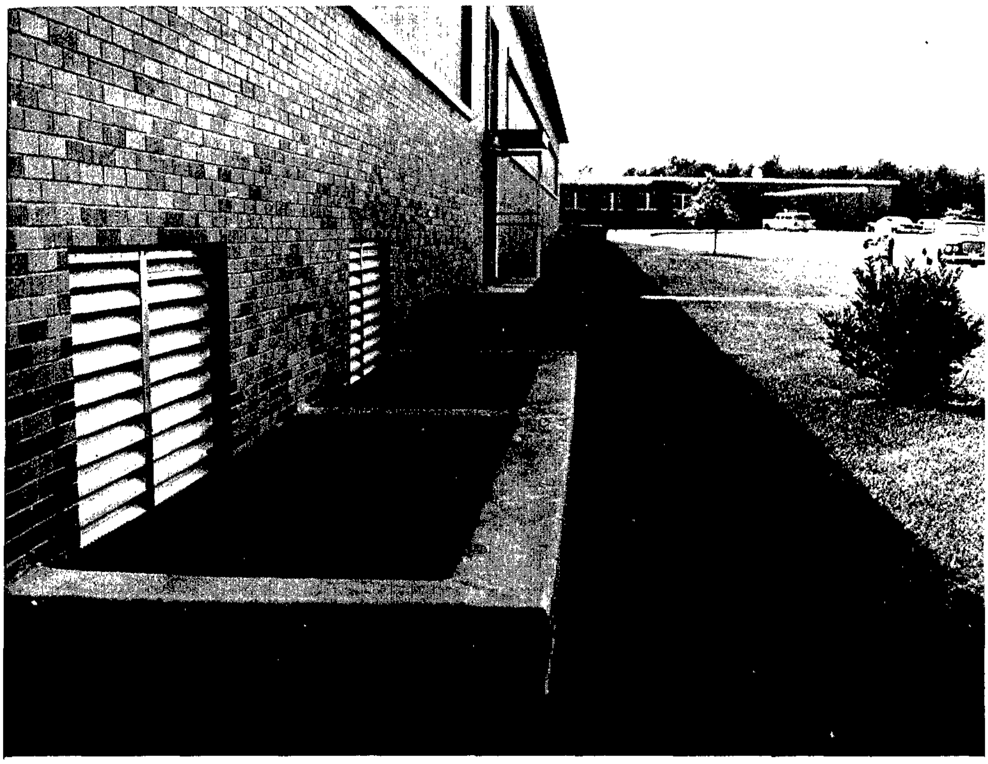


Fig. 2.24—Areaways north of block 9.

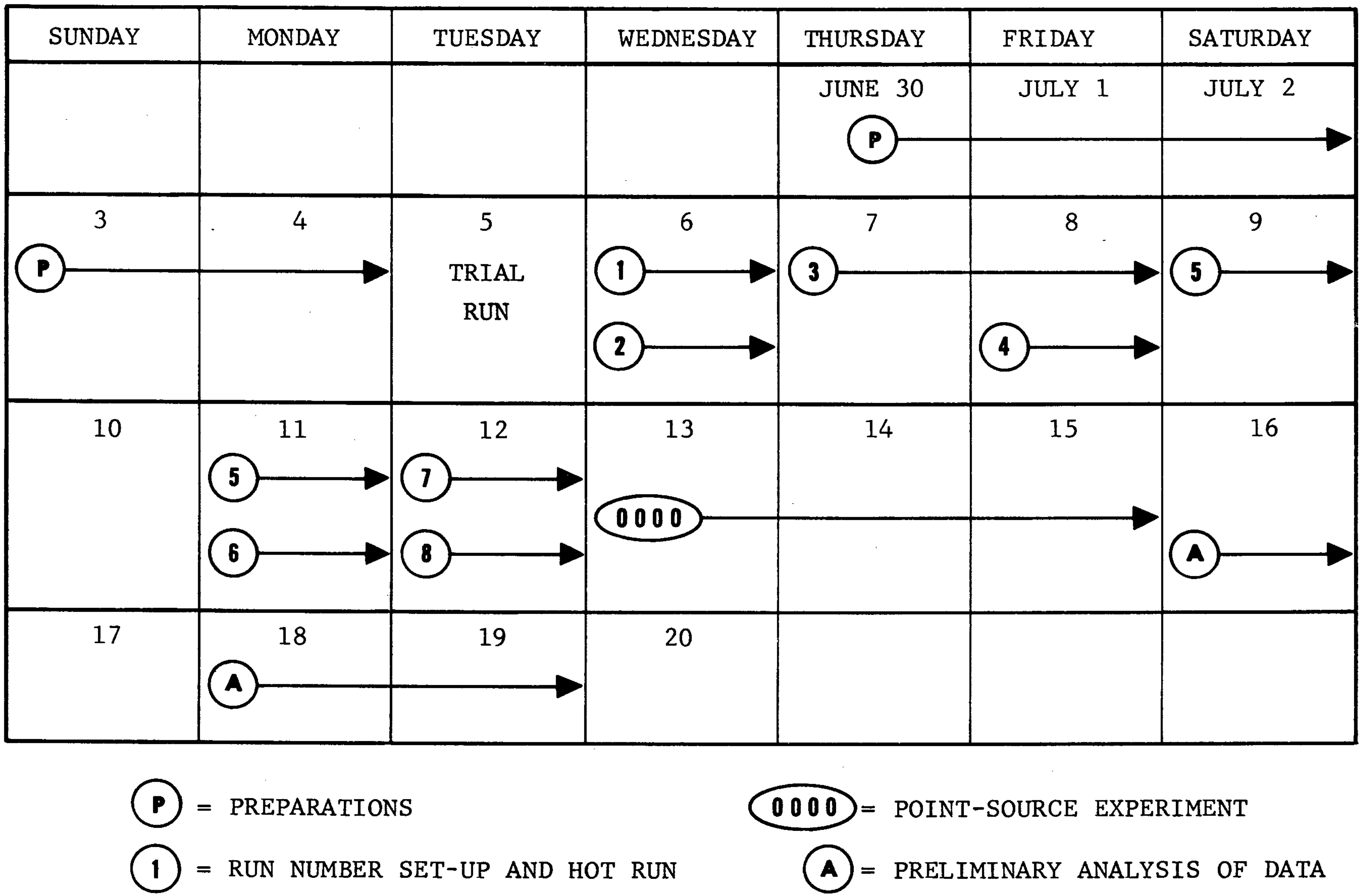


Fig. 2.25—Experiment schedule.

Chapter 3

PRESENTATION OF DATA

3.1 AREA-SOURCE DATA

Area sources of radioactivity were simulated at eight different locations on the roof and on the ground outside block 9, as indicated in Fig. 2.17. Table 3.1 includes all the information pertinent to each test run. The data obtained from the test runs were corrected for dosimeter leakage and/or background* temperature, pressure, and calibration, and then were normalized to milliroentgens per hour per millicurie per square foot.

Floor plans of the basement and first floor are presented in Figs. 3.1 and 3.2, together with dosimeter-position numbers. All the data from the area-source experiments are presented in Tables 3.2 through 3.9. The data are presented in milliroentgens per hour per millicurie per square foot at different heights above the floor at various positions throughout the building. Where the dosimeter readings were extremely low, and therefore questionable, an indication is shown in the tables.

3.2 POINT-SOURCE DATA

3.2.1 Source on Stairway Roof

A point source of 1.24 curies of Co^{60} was placed in the center of the roof over the stairway, and dosimeters were located at various positions on the first floor and basement. The normalized data appear in Table 3.10.

3.2.2 Source in Areaways

A point source of 13.3 curies of Co^{60} was placed in both of the areaways north of block 9 (see Figs. 2.24 and 3.1). The areas consisted of 45.5 sq ft each. The Multitron source system was used for this experiment, and the exposure time was 1 hr. The normalized data appear in Table 3.11.

3.2.3 Source Near Filter System

The filters for the air-circulation system are located in Mechanical Room No. 1 (see Fig. 3.1). A point source was placed near one of the filters (Fig. 2.23), and the dose was measured (by the ionization chambers) at various positions in the basement. The Multitron source system was used, and the exposure time was 1 hr. The source was placed 3 ft 10 in. above the floor and 17 ft 8 in. from the center of the doorway in Mechanical Room No. 1. All readings

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*The low-range (10 mr full scale) chambers read approximately 0.3 mr after a 24-hr background and/or leakage test.

were taken at the 4-ft level. The data appear in Table 3.12 normalized to milliroentgens per hour per curie.

3.2.4 Source at Various Locations on the Ground

The 13.3-curie Co^{60} point source was placed at various positions on the ground along the south and west side of block 9, as shown in Fig. 2.22. The dose rate at several positions in the basement was measured by the scintillation-detector system.

The radiation level in the basement from the source placed in positions A and B was only slightly more than background, even next to the south wall. Therefore, these readings are not presented.

The scintillator data taken with the source at positions C, D, and E, corrected and normalized to milliroentgens per hour per curie, are presented in Table 3.13.

A small portion of the basement wall between the loading dock and reactor building along the west side of block 9 was exposed. Since the basement area near the reactor building was a possible shelter area, the source was placed in position D to aid in evaluating this area.

3.3 MISCELLANEOUS DATA

Miscellaneous data were taken during runs 3 and 4. The data and locations appear in Table 3.14. Film badges were furnished and read by the Medical Center Health Physics Group.

Table 3.1—AREA-SOURCE EXPERIMENTS

Test run	Exposure time, hr	Temp. (av.), °C	Press. (av.), in.	Area, sq ft	Source strength, curies	Location*
1	3.48	27	29.68	18,670	203	North side of block 9, 0 to 60 ft
2	3.30	27	29.68	16,980	203	North side of block 9, 60 to 108 ft
3	2.86	28	29.88	14,274	203	East side of block 9, 0 to 60 ft
4	3.12	28	29.88	15,642	203	East side of block 9, 60 to 108 ft
5	0.422	28	29.78	14,890	203	About one-fourth of block 9 roof
6	0.428	28	29.78	14,890	203	About one-fourth of block 9 roof
7	0.408	28	29.58	15,323	203	About one-fourth of block 9 roof
8	0.442	28	29.58	16,841	203	About one-fourth of block 9 roof

*See Fig. 2.17.

Table 3.2—DATA FOR RUNS 1 AND 2 ON FIRST FLOOR

	Dose rate*				Dose rate*		
Position	At 2 ft	At 4 ft	At 6 ft	Position	At 2 ft	At 4 ft	At 6 ft
301		2.3		352		4.4¶	22
302		2.6		354		5.2¶	20
305		2.2		356		2.3¶	16
306		2.0		357		0.55‡	
307		2.0		358		0.23†	
308		2.2		359		0.23†	
309		0.15†		367		0.26‡	
310		0.18†		368	0.23‡	0.29‡	0.34‡
311		0.15†		369	0.34‡	0.42‡	0.55‡
312		0.21†		370	0.32‡	0.47‡	0.55‡
313		0.15†		371		0.73	
314		0.21†		372	0.55‡	1.0	1.0
323		0.15†		373	0.21†	0.21†	0.21†
324		0.18†		374		0.21†	
325		0.75‡		382	0.23†	0.23†	0.21†
326		0.81‡		383	0.23†	0.23†	0.23†
327		0.23†		384		0.23†	
328		0.15†		385		0.29†	
331		0.18†		386		0.42‡	
332		0.15†		387		0.44‡	
334		0.75‡		388		0.86	
335		2.5		389	0.42‡	0.57‡	0.65‡
336		0.23†		390		0.02	
337		0.18†		392		0.02	
340		0.18†		393		0.01§	
341		0.23†		394		0.01§	
342		0.73‡		395		0.23‡	
343		0.83‡		404		0.21†	
345		0.21†		405		0.21†	
346		0.21†		406		0.42‡	
350		0.23†		407		0.21†	
351		0.44‡		408		0.23†	

	Dose rate*	
Position	For run 1 (4 ft)	For run 2 (4 ft)
301	1.6	0.99
302	1.9	1.1
305	1.3	0.84
306	1.2	0.94
307	1.1	0.86
308	1.2	0.99
335	1.6	1.1

*Dose rate normalized to milliroentgens per hour per millicurie per square foot.

† The 0- to 200-mr chambers used read less than 10 mr.

‡ The 0- to 200-mr chambers used read between 10 and 30 mr.

§ The 0- to 10-mr chambers used read less than 0.5 mr.

¶ The 0- to 5-r chambers used read less than 300 mr.

Table 3.3—DATA FOR RUNS 3 AND 4 ON FIRST FLOOR

	Dose rate*				Dose rate*		
Position	At 2 ft	At 4 ft	At 6 ft	Position	At 2 ft	At 4 ft	At 6 ft
305		0.12†		334		0.10†	
306		0.15†		356	0.47‡	0.54‡	0.75‡
307		0.84		358		5.2	
309		0.30‡		359		2.9	
310		0.10†		360		1.8	
311		0.10†		361		2.6	
318		0.10†		363		0.20‡	
319		0.12†		364		0.12†	
320		0.25‡		365		0.25‡	
321		2.2		366		0.15†	
322		0.27‡		367		0.10†	
323		0.25‡		368	0.22†	0.25‡	
324		0.22‡		369	0.20†	0.20†	0.17†
325		0.54‡		370	0.12†	0.22‡	0.30‡
326		0.05†		371		0.12†	
327		0.15†		372	0.10†	0.10†	0.13†
328		0.07†		373	0.07†	0.07†	0.05†
329		0.12†		374		0.15†	
330		0.07†		375		0.10†	
331		0.07†		376		0.05†	
332		0.07†		377		0.05†	

	Dose rate*	
Position	For run 3 (4 ft)	For run 4 (4 ft)
308		0.96
309	0.12†	0.12†
321	1.2	1.3
322	0.22†	0.20†
323	0.17†	0.12†
324	0.15†	0.15†
325	0.27‡	0.20†

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.

† The 0- to 200-mr chambers used read less than 10 mr.

‡ The 0- to 200-mr chambers used read between 10 and 30 mr.

Table 3.4—DATA FOR RUNS 5 AND 6 ON FIRST FLOOR

Position	Dose rate* at 4 ft	Position	Dose rate* at 4 ft	Position	Dose rate* at 4 ft
301	30	339	1.9†	378	2.1†
302	29	340	5.5†	379	4.7†
305	33	341	22	380	1.9†
306	27	342	24	381	3.3†
307	30	343	25	382	34
308	30	345	28	383	30
309	27	346	6.5	384	35
310	28	347	2.4†	385	33
311	22	350	29	386	33
312	22	351	23	387	31
313	35	352	34	388	31
314	29	353	32	389	28
315	1.9†	354	30	390	4.1†
316	1.9†	356	28	391	3.8†
317	2.1†	357	33	392	4.7†
318	2.1†	358	Off scale	393	4.8†
319	2.1†	359	Off scale	394	4.0†
320	1.9†	360	2.9†	395	9.7
321	1.9†	361	1.9†	396	3.8†
322	2.2†	362	1.9†	397	1.9†
323	5.8†	363	2.1†	398	2.2†
324	31	364	2.2†	401	2.1†
325	28	365	2.4†	402	1.7†
326	27	366	2.6†	403	1.9†
327	28	367	29	404	35
328	5.7†	368	31	405	33
329	1.9†	369	33	408	Off scale
330	2.2†	370	28	409	12
331	5.4	371	35	410	2.1†
332	28	372	29	411	1.9†
334	29	373	34	412	1.7†
335	22	374	34	413	1.9†
336	28	375	3.8†	414	1.7†
337	6.7	376	1.9†	417	4.5†
338	2.1†	377	1.7†	418	27

Position	Dose rate* At 2 ft	At 6 ft	At 8 ft
354	27	37	39
356	23	34	37
368	25	37	44
369	29	40	Off scale
370	23	35	38
372	23	31	42
373	27	40	44
382	28	40	Off scale
383	25	36	Off scale

Position	Dose rate* At 6 ft‡	At 8 ft§	At 8 ft‡
354		38	
356		41	
368	34	41	44
369	44	41	44
370	33	43	38
372	28	39	36
373		43	
382		40	
383		34	
389		38	

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.
† The 0- to 200-mr chambers used read between 10 and 30 mr.
‡ Film badges.
§ The 0- to 5-r chambers used all read below 300 mr.

Table 3.5 — DATA FOR RUNS 7 AND 8 ON FIRST FLOOR

Position	Dose rate* at 4 ft	Position	Dose rate* at 4 ft	Position	Dose rate* at 4 ft	Position	Dose rate* at 4 ft
301	0†	331	22	361	33	389	0.18†
302	0.18†	332	0.18†	362	31	390	0†
305	0†	334	0†	363	23	391	0†
306	0.18†	335	0.18†	364	31	392	0†
307	0†	336	0.18†	365	27	393	0†
308	0.18†	337	22	366	28	394	0†
309	1.5†	338	23	367	0†	395	0.18†
310	1.3†	339	28	368	0†	396	31
311	0.95†	340	22	369	0†	397	34
312	1.8‡	341	0†	370	0†	398	31
313	0.95†	342	0.18†	371	0†	399	28
314	0†	343	0†	372	0†	400	27
315	24	345	0†	373	0†	401	36
316	26	346	23	374	0.18†	402	25
317	24	347	29	375	19	403	27
318	33	348	27	376	20	404	0.18†
319	29	349	27	377	24	405	0†
320	29	350	0.18†	378	38	406	0†
321	22	351	0.37†	379	32	407	0†
322	23	352	0†	380	36	408	0.18†
323	20	353	0.37†	381	26	409	17
324	0.37†	354	0†	382	0†	410	28
325	0.18†	355	0†	383	0†	411	27
326	0†	356	0†	384	0†	412	31
327	0.37†	357	0†	385	0†	413	31
328	21	358	0†	386	0†	414	31
329	20	359	0†	387	0†	415	25
330	25	360	27	388	0.18†	416	25

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.
† The 0- to 200-mr chambers used read less than 10 mr.
‡ The 0- to 200-mr chambers used read between 10 and 30 mr.

Table 3.6 — DATA FOR RUNS 1 AND 2 IN BASEMENT

Position	Dose rate* At 2 ft	Dose rate* At 4 ft	Dose rate* At 6 ft	Position	Dose rate* At 2 ft	Dose rate* At 4 ft	Dose rate* At 6 ft	Position	Dose rate* At 2 ft	Dose rate* At 4 ft	Dose rate* At 6 ft
1	0.065	0.090	0.19	38		0.11		113	0.023	0.021	0.023
2		0.34†		41		0.11		120		0.003§	
3		0.24		42		0.090		122		0.003§	
4		0.49†		45		0.026		124	0.005§	0.008§	0.005§
5		0.23†		47		0.041		125	0.003§	0.003§	0.005§
6		0.75†		49		0.070		126	0.010§	0.008§	0.018§
8		0.83†		51	0.13	0.12	0.14	128		0.013§	
9		0.91		52		0.13		131		0§	
10		1.0		54		0.090		132		0.003§	
11		0.94†		56	0.065	0.044		135		0.003§	
12		1.2		67	0.021	0.021	0.021	154		0.003§	
13		1.3		70	0.075	0.070		156		0.003§	
14		0.23		74	0.034	0.031	0.039	157	0§	0§	0.005§
15		0.29		77		0.003§		158	0§	0§	0.003§
16		0.090		80		0.013		159	0.005§	0.005§	0.010§
17	0.19	0.19	0.21	81		0.015		161		0.003§	
19		0.041		83	0.039	0.034	0.070	163		0.003§	
20		0.26‡		85		0.026		168		0§	
21		0.29		86		0.031		179	0§	0§	0§
22		0.26†		87		0.031		180		0§	
23		0.49†		89		0.010		181		0.003§	
24	0.47†	0.78†	0.70†	91		0.005§		182	0§	0.003§	0§
25		0.85†		93		0.003§		186	0§	0.003§	0.003§
26		0.96		94		0.008§		196	0§	0§	0§
27		0.039		95	0.005§	0.010§	0.005§	202	0.003§	0§	0§
29	0.090	0.090	0.080	96		0.005§		222		0.12	
30		0.10		98		0.026		224		0.19	
32		0.13		100	0.021	0.028	0.034	231		0§	
33		0.21‡		103		0.013		244		0.008§	
34	0.25	0.26		105		0.008§		138		0.003§	
35		0.41†		106		0.015		102		0.018	
36		Off scale		107		0.005§		101		0.028	
37		0.18‡									

Position	Dose rate* For run 1	Dose rate* For run 2
7	0.57†	0.18‡
97	0.018	0.005§
99	0.023	0.003§
123	0.003§	0.003§
144	0§	0§
221	0.096	0.015
223	0.15	0.023
229	0§	0.003§
233	0§	0§

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.
† The 0- to 200-mr chambers used read between 10 and 30 mr.
‡ The 0- to 200-mr chambers used read less than 10 mr.
§ The 0- to 10-mr chambers used read less than 0.5 mr.

Table 3.7 — DATA FOR RUNS 3 AND 4 IN BASEMENT

Position	Dose rate* At 2 ft	Dose rate* At 4 ft	Dose rate* At 6 ft	Position	Dose rate* At 2 ft	Dose rate* At 4 ft	Dose rate* At 6 ft	Position	Dose rate* At 2 ft	Dose rate* At 4 ft	Dose rate* At 6 ft
1		0.002†		90		0.012		147		0.002†	
3		0.002†		92		0.035		149		0.22‡	
5		0.002†		94		0.070		151		0†	
7		0.002†		95		0.10		153		0†	
9	0†	0†	0.005†	96		0.13		155		0†	
11		0.007†		97		0.17		156		0.002†	
14		0.12‡		98		0.22		157	0†	0.005†	0.007†
15		0.17‡		99		Off scale		158		0†	
21		0.005†		100	0.47§	0.47§		159	0.007	0.007	0.020
23		0.002†		101		0.64		161		0.012	
25		0.007†		102		1.1		162		0.27§	
28		0.005†		103		0.44		163		0.10	
30		0†		107		0.042		164		0.30	
32		0.002†		111		0†		165		0.002†	
34	0.005†	0.005†	0.007†	112		0.005†		167		0.002†	
35		0.010		113	0.002†	0.005†	0.010†	169	0.002†	0.005†	0.002†
36		0.020		114		0.005†		170	0.005†	0.002†	0†
38		0.027		115	0.002†	0.005†	0.007†	172	0.007	0.017	0.012
39		0.17‡		119		Off scale		174		0.060	
40		0.050‡		120		0.002†		175		0.17‡	
44		0†		122		0†		176		0.27‡	
46		0.005†		123		0.002†		177		0.002†	
48		0†		124	0.002†	0.007†	0.002†	179		0†	
50	0†	0.002†	0.005†	125	0.002†	0.002†	0.002†	181		0.007†	
51	0.012	0.005†		126		0.007†		183		0†	
52		0.010	0.012	128		0.020		185		0.027	
54		0.020		129		0.032		186		0.025‡	
55		0.10‡		130		0.012		187		0.070	
56		0.080		131		0.085		188		0.075†	
64		0.005†		132		0.27		190		0.002†	
67		0.007†		133		0.81§		191		0.002†	
71		0.007†		134		0.61§		192		0.002†	
72		0.015		136		Off scale		193		0†	
74		0.027		137		0.47§		196		0.002†	
76		0.17‡		138		1.3		198		0†	
77		0†		139		4.5		199		0.002†	
79		0†		140		0.20‡		202		0.002†	
81		0.012		142		0†		206		0.002†	
83	0.007†	0.022	0.025	143		0†		208		0.007†	
84		0.030		144		0.002†		230		0.002†	
86		0.032		145		0.002†		232		0.005†	
87		0.22‡		146	0.002†	0.005†	0.010†	244		0.002†	

Position	Dose rate* For run 3	Dose rate* For run 4	Position	Dose rate* For run 3	Dose rate* For run 4
41	0.47§	0.025‡	89	0.37	0.12‡
42	1.3	0.20‡	104	2.4	0.91
43	1.5	1.0	105	7.0	1.9
57	0.069	0.042	106	Off scale	
58	0.39	0†	117	1.6	0.37§
60	3.1	0.55§	118	3.8	0.74§
62	Off scale		150	0.52§	0.30§
63	4.3	1.6	231	0†	0†
88	0.54	0.20‡	233	0†	0†

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.
† The 0- to 10-mr chambers used read less than 0.5 mr.
‡ The 0- to 200-mr chambers used read less than 10 mr.
§ The 0- to 200-mr chambers used read between 10 and 30 mr.

Table 3.8—DATA FOR RUNS 5 AND 6 IN BASEMENT

	Dose rate*				Dose rate*				Dose rate*		
Position	At 2 ft	At 4 ft	At 6 ft	Position	At 2 ft	At 4 ft	At 6 ft	Position	At 2 ft	At 4 ft	At 6 ft
1	0.60	0.64	0.76	45		1.5		98		0.76	
2		1.0		46		1.5		107		0†	
3		1.1		47		1.2		108		0.80	
4		0.92		48		0.94		109		0.33	
5		0.92		49		0.19		110		0.22	
6		1.1		50		0.29		111		0.52	
7		0.62		52	1.4	1.5	0.80	112		0.48	
8		0.66		53		1.6		113		0.21	
9		1.1	1.3	54		1.4		115		0.28	
10		1.2		55		1.1		118		0.22	
11		1.3		56		1.2		120		0.017†	
13		1.2		57		1.2		121		0.035†	
15		0.35		60		Off scale		122		0.050†	
16		0.97		64		0.73		123		0.035†	
17		1.9		65		1.6		124		0.73	
18		1.9		66		Off scale		125		0.017†	
20		1.4		67	1.1	1.1	1.1	127		0.070	
21		1.5		68		0.26		128		0.17	
22		0.19		69		0.28		129		0.19	
23		0.76		70	1.2	1.3		132		0†	
24	1.5	1.5	1.7	71		1.7		135		0.050†	
25		1.8		72		1.4		140		0†	
26		1.8		73		1.6		148		0†	
27		0.66		74		1.5		155		0†	
28		1.3		75		1.3		172		0†	
29		1.5		76		1.2		176		0†	
30		1.1		77		0.83		179		0†	
31		0.90		78		1.1		188		0†	
32		0.086		79		1.4		189		0†	
33		0.19		80		0.94		191		0†	
34	0.92	0.99		81		Off scale		193		0†	
35		1.1		82		0.33		203		0†	
36		1.3		83	0.94	0.99	1.1	206		0†	
37		1.4		84		0.90		219		0.92	
38		1.4		85		1.1		220		1.1	
39		1.6		86		1.1		221		0.22	
40		1.4		87		1.1		223		1.5	
42		1.1		88		0.80		226		1.4	
43		1.4		89		0.78		150		0†	
44		0.80									

	Dose rate for run 5			Dose rate for run 6	
Position	At 4 ft	At 6 ft	Position	At 4 ft	At 6 ft
51	0.52	0.81	51	0.66	1.3
222	0.50		222	0.31	
224	1.2		224	0.50	

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.
† Chambers read less than 0.5 mr.

Table 3.9—DATA FOR RUNS 7 AND 8 IN BASEMENT

	Dose rate*				Dose rate*				Dose rate*		
Position	At 2 ft	At 4 ft	At 6 ft	Position	At 2 ft	At 4 ft	At 6 ft	Position	At 2 ft	At 4 ft	At 6 ft
7		0†		124	1.4	1.4	1.4	169		1.4	
9		0†		125	1.1	1.2	1.2	170		1.2	
34		0†		126		1.3		171		1.3	
45		0†		127		1.0		172		1.1	
57		0†		128		0.35		173		1.1	
63		0.055†		129		0.31		174		1.0	
64		0.11		132		1.1		175		1.0	
66		0†		133		1.3		176		1.3	
67		0†		134		1.4		177		1.1	
69		0†		136		Off scale		178		1.1	
71		0†		137		0.70		179		0.94	
73		0†		139		1.6		180		0.37	
75		0.018†		140		1.1		181		1.1	
77		0†		141		1.1		182		0.87	
78		0†		142		1.6		183		0.78	
79		0.018†		143		1.6		184		0.52	
80		0†		144		1.3		185		0.55	
81		0†		145		1.6		186		0.50	
82		0.055†		146	1.3	1.4	1.5	187		0.50	
83		0.037†		147		1.4		188		0.46	
84		0.018†		148		1.1		189		0.35	
85		0.018†		149		1.1		190		0.092	
86		0†		150		0.78		191		0.092	
87		0†		151		1.3		192		0.074	
88		0.055†		152		1.4		193		0.13	
89		0.13		153		1.0		194		0.20	
107		0.35		154		1.3		195		0.24	
108		0.15		155		1.6		196	0.13	0.11	0.11
109		0.24		156		1.1		197		0.81	
110		0.29		157		0.98		198		0.52	
111		0.46		158		1.0		199		0.67	
112		0.70		159		1.3		200		0.67	
113	0.46	0.46	0.39	160		1.1		201		0.67	
114		0.46		161		0.77		202		0.80	
115		0.57		162		0.77		203		0.50	
117		Off scale		163		1.3		206		0.55	
119		Off scale		164		0.77		207		0.46	
120		1.1		165		1.1		208		0.50	
121		1.7		166		1.4		209			0.50
122		1.7		167		1.7		244			0.50
123		1.3		168		1.5		245		0†	

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.
† Chambers used read less than 0.5 mr.

Table 3.10—DATA FROM POINT SOURCE ON TOP OF STAIRWAY ROOF*

Position	Normalized data (4 ft), mr/hr/mc/sq ft
80	0†
95	0†
111	0.046†
244	1.5
417	3.2
418	27

* Source, 1.24 curies; area, 120 sq ft.
† The 0- to 10-mr chamber used read less than 0.5 mr.

Table 3.11—POINT SOURCE IN AREAWAYS NORTH OF BLOCK 9

Position	Dose rate* at 4 ft	Position	Dose rate* at 4 ft
7	0.0014†	38	0.0037
8	0.0027	50	0.0044
9	0.0099	51	0.0065
10	0.10‡	52	0.011
11	0.12	53	0.012
12	0.015	54	0.0034
22	0.0034	55	0.0017
23	0.0065	69	0.0034
24	0.025	70	0.0054
25	0.092‡	71	0.0065
26	0.16	72	0.0061
32	0.0020	73	0.0048
33	0.0034	83	0.0031
34	0.0102	84	0.0027
35	0.037‡	85	0.0034
36	0.037‡	112	0.0014†
37	0.017§	113	0.0010†

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.
† The 0- to 10-mr chambers used read less than 0.5 mr.
‡ The 0- to 200-mr chambers used read between 10 and 30 mr.
§ The 0- to 200-mr chambers used read less than 10 mr.

Table 3.12—DATA FOR POINT SOURCE NEAR FILTER SYSTEM

Position	Dose rate*	Position	Dose rate*
54	0.03†	140	9.0¶
55	0.02†	146	0.02†
56	0.03†	147	0.03†
57	0.03†	149	11¶
72	0.015†	150	17¶
73	0.015†	158	0.01†
74	0.04	159	0.03†
75	0.03†	160	0.03†
76	0.06	161	0.08
84	0†	162	1.8§
85	0.01†	163	1.6§
86	0.015†	164	4.9
87	0.07	170	0.02†
88	0.2‡	171	0.03†
89	0.3‡	172	0.34
105	1.9§	173	0.47
106	14	174	0.21
107	0.14	175	0.4‡
113	0†	176	3.4
114	0.015†	184	0.16
125	0.01†	185	0.23
126	0.01†	186	0.11
132	3.8¶	187	0.62
133	25	188	0.27
134	28	206	0.03†
137	15¶	207	0.02†
138	24	208	0.17
139	7.5¶		

* Dose rate normalized to milliroentgens per hour per curie.
† The 0- to 110-mr chambers used read less than 0.5 mr.
‡ The 0- to 200-mr chambers used read less than 10 mr.
§ The 0- to 200-mr chambers used read between 10 and 30 mr.
¶ The 0- to 5-r chambers used read less than 300 mr.

Table 3.13—DATA WITH POINT SOURCE ON GROUND

(Readings taken at 4-ft level unless noted)

Position (See Fig. 2.21)	Dose rate, mr/hr/curie $\times 10^{-3}$
Source in Position C	
184	0.23
172	0.076
207 (ceiling)	1.9
Source in Position D	
190	0.48
191	1.7
192	24
193	44
194	0.26
196	11
197	0.37
198	0.76
199	1.6
200	0.40
201	0.46
Source in Position E	
3	140
18	96
27	23
28	28
29	25
46	9.8
66	3.0

Table 3.14—MISCELLANEOUS DATA TAKEN DURING RUNS 3 AND 4

(All points 3 ft above ground)

Position	Dose (0- to 5-r PIC), mr	Dose (film badge), mr
Directly above tubing near center of run 3		10,350*
Between tubing near center of run 3		10,150*
Between tubing near center of both runs		11,900
Between tubing near center of both runs		11,800
1 ft 9 in. from effective edge of run 4, at center line of area, away from building	4,950	5,620
10 ft, as above	2,770	3,170
20 ft, as above	1,750	2,050
30 ft, as above	1,180	1,400
50 ft, as above	850	940
70 ft, as above	550	590

* Run 3 only.

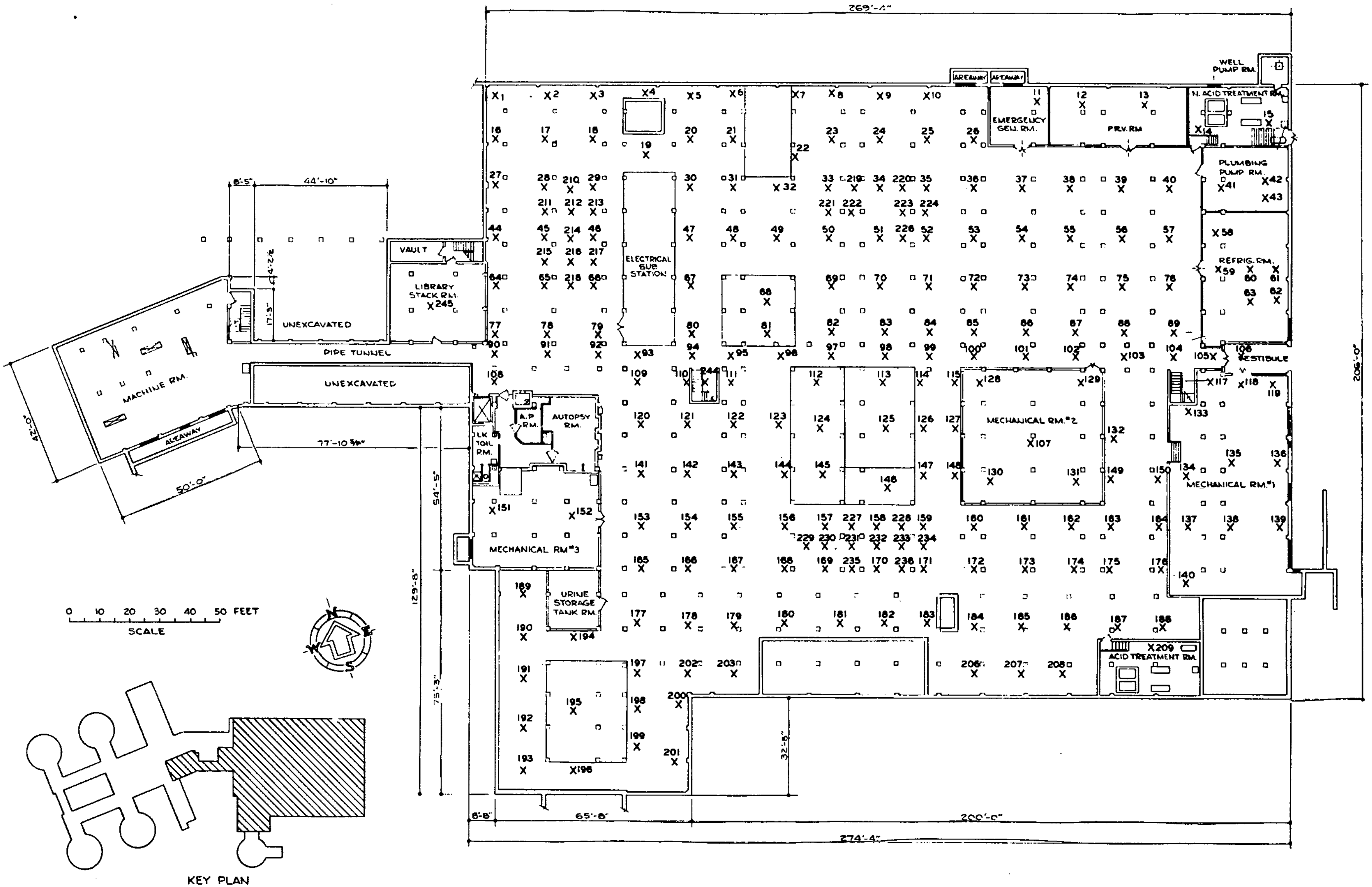

Fig. 3.1 —Layout of basement with detector positions indicated.

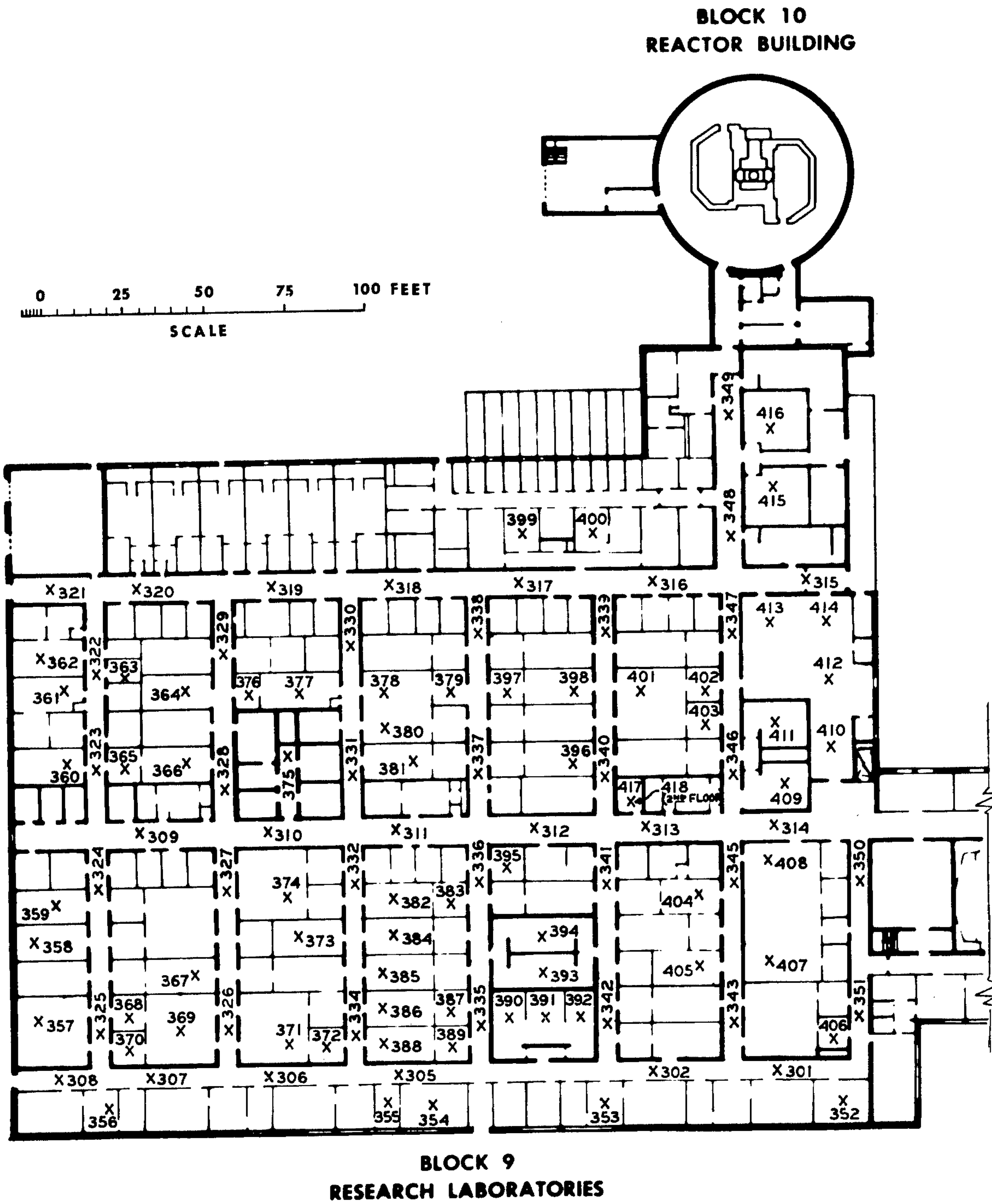

Fig. 3.2—Layout of first floor with detector positions.

Chapter 4

ANALYSIS AND CONCLUSIONS

4.1 GENERAL

The numerical value indicating the protection afforded by a given structure is known as the "protection factor." It is defined as the ratio of the exposure dose rate 3 ft above a smooth infinite plane uniformly contaminated with a radioactive material to the dose rate inside the structure at the point in question when the structure (roof) and ground are covered by the same source distribution. Accordingly,

$$\text{P.F.} = D_\infty / D \tag{4.1}$$

where D_∞ is the total infinite-plane dose rate and D is the dose rate at the point in question.

The value of the total infinite-plane dose rate has been evaluated in the literature[1–4] and is estimated[4] to be 500 mr/hr using Co^{60} as the radioactive material distributed to a source density of 1 mc/sq ft.

The use of Co^{60} in simulating fallout radiation for shielding factors has been discussed by Eisenhauer.[2] The protection factors for radiation from fission products and Co^{60} gamma radiation should compare to within 10 per cent.[4]

It is impractical to approximate an infinite-plane field of radiation in measuring experimentally a structure's protection factor. Therefore, a radiation field was simulated over areas on the ground and on the roof of the Medical Center such that the protection factors would be determined largely by experimental data. The contribution from those areas not simulated was analytically estimated from experimental data. These values were added to the measured values, and the protection factors were determined.

It was convenient when ascertaining the value of D in Eq. 4.1 to consider its total value to be made up of several parts:

$$D = R + G_n + G_e + G_s + G_w \tag{4.2}$$

where R is the dose rate from simulated contamination on the roof and the other terms represent dose rates from contamination on the ground to the north, east, south, and west of the building, respectively. The total value of R was experimentally measured. The values of the other terms are estimated in the following sections.

4.2 ESTIMATION OF THE NORTH AND EAST CONTRIBUTIONS

It is noted in Table 3.1 and Fig. 2.17 that measurements were made on the north and east side of block 9 out to 108 ft from the building. The dose-rate contribution from the area beyond 108 ft was estimated and added to the measured value to make up the north (G_n) and east (G_e) contributions in Eq. 4.2.

The values of the two terms were considered separately and each was considered to be made up of two parts

$$G_n = G_{n1} + G_{n2} \tag{4.3}$$

and

$$G_e = G_{e1} + G_{e2} \tag{4.4}$$

where G_{n1} and G_{e1} are the measured values and G_{n2} and G_{e2} are the estimated far-field values.

In estimating the value of G_{n2}, the following assumption was made

$$D_{n1}/D_{n2} = G_{n1}/G_{n2} \tag{4.5}$$

where D_{n1} is the unshielded dose rate 3 ft above the ground from a contaminated area equal to the measurement area north of the building with the same geometry. The term D_{n2} is then the unshielded dose rate from beyond the measurement area. The value of G_{n2} is found by multiplying the ratio D_{n2}/D_{n1} by the measured value, G_{n1}.

$$G_{n2} = G_{n1}\ (D_{n2}/D_{n1}) \tag{4.6}$$

The values of D_{n2}/D_{n1} were estimated by the use of calculations from concentric circular source areas rather than from rectangular source areas (calculations of the dose rate from rectangular source areas are difficult and time consuming). It has been shown[1,2,5] that no serious error is introduced if rectangular source distributions are theoretically converted to circular source distributions for calculation purposes. The equations used were

$$D_1 = 2\pi QC \int_{r_1}^{r_2} \frac{e^{-\mu(\rho^2+h^2)^{1/2}}}{\rho^2 + h^2}\, \rho\, d\rho \tag{4.7}$$

and

$$D_2 = 2\pi QC \int_{r_2}^{\infty} \frac{e^{-\mu(\rho^2+h^2)^{1/2}}}{\rho^2 + h^2}\, \rho\, d\rho \tag{4.8}$$

where Q = source strength per unit area
C = dose rate at unit distance from a point source of unit strength
μ = absorption coefficient[6] in air, 2.061×10^{-3} ft^{-1}
h = 3 ft
r_1 = equivalent radial distance from point in question to nearest edge of measurement area
r_2 = equivalent radial distance from point in question to farthest edge of measurement area

The values of r_1 and r_2 were found by adaptation of the method presented in Ref. 5, and the ratio D_2/D_1 was equated to D_{n2}/D_{n1}.

Equations 4.5 and 4.6 do not include the scatter component. However, no serious error is incurred since the far-field contribution is at most points less than 5 per cent of the total basement dose.

The far-field contribution from the east side of the building was found in the same manner. This method was used for all points in the basement. The far-field contribution to most points on the first floor was considered negligible since the measured roof contribution was exceedingly high compared to the measured ground contribution.

4.3 ESTIMATION OF THE SOUTH AND WEST CONTRIBUTIONS

As mentioned in Chap. 1, operational limitations prohibited measurements of area sources on the south and west sides of the building. Also, the ground level was above the basement ceiling level at most points, resulting in a minor contribution from the south and west compared to that of the roof.

However, point-source experiments were performed on these sides to aid in estimating the south and west contributions to the total dose rate. Measurements were also made with the point source on the north side of the building to provide data for comparison with area-source data. The south and west contributions were estimated by simple ratios of point-source data and area-source data and geometrical similarity of detector positions. (The existence of the loading dock and room walls in the basement in relation to detector positions was also considered.) For example, it was assumed that

$$P_n/P_s = G_n/G_s \tag{4.9}$$

where P_n is the dose rate at a particular detector position from the point source on the north side, P_s is the dose rate at a similar geometric position from the point source placed on the south side of the building (includes inverse-square corrections), and G_n and G_s are as previously defined.

No serious error is incurred by the use of the above method since the south and west contributions at most points* were less than 5 per cent of the total basement dose.

4.4 NORMALIZATION

In the determination of protection factors, it was necessary to normalize all the data to a constant source density. The data were normalized to milliroentgens per hour per millicurie per square foot by dividing the true doses, D_t (corrected dosimeter readings), in milliroentgens by the source strength, S, in millicuries and multiplying by the average of the area-to-time ratio, $(A/T)_{av.}$, for the two separate exposures in which the dosimeters were left in place:

$$\text{Normalized data} = \left(\frac{D_t}{S}\right)\left(\frac{A}{T}\right)_{av.} \tag{4.10}$$

As mentioned previously, the dosimeters were left in place for two separate area-source measurements. Thus the value of D_t is the corrected dose, as read by a dosimeter, for the combination of runs 1 and 2, 3 and 4, 5 and 6, or 7 and 8. The data can be normalized in this manner if the area-to-time ratios for the two runs are equal. These ratios differed less than 2 per cent from their average.

4.5 PROTECTION FACTORS

The dose-rate contribution from those areas not simulated was analytically estimated using experimental data. These values were than added to the normalized measured values, and the protection factors were calculated by Eq. 4.1. They appear in Tables 4.1 and 4.2 and are presented at each detector position in Figs. 3.1 and 3.2. The basement protection factors were also plotted on the basement floor plan. These appear in Fig. 4.1.

The roof contribution was the major factor in determining the protection at almost any point in the building. For instance, at any point in the basement, except next to the walls and near the east entrance, the simulated contamination on the roof contributed more than 90 per

*The west contribution was between 5 and 30 per cent of the total dose at positions 189 through 196.

cent to the total dose rate. In all rooms on the first floor, except those next to the walls, the roof contributed more than 95 per cent.

The doses in the basement from the roof runs were affected by equipment, walls, and fixtures on the first floor, as well as by pipes, air ducts, equipment, and reinforcing columns in the immediate environment. As a result, the protection factor at an individual point was sometimes considerably different than one adjacent to it. For this reason, an approximate protection-factor contour map was drawn (Fig. 4.2).

In general, the protection factors varied from 200 to 400 throughout the basement, except in certain areas. The protection factor in the east entrance was about 30. The effect of the detectors "looking" at the radioactive area on the ground outside the doorway is noted on the contour map. A small area in the north portion of the basement indicated a protection factor as high as 1400. This area is directly below the low-level counting rooms on the first floor, which have an extra thickness of concrete above them. The protection factor in these rooms was about 100 as compared to below 20 in others.

Another small area in the southwest corner of the basement indicates a high protection factor (approximately 4000). This area has a 12-in. concrete ceiling.

The protection factors generally ranged from 12 to 20 on the first floor, except in the low-level counting rooms and directly in front of a window. These factors should generally apply to all rooms and hallways on the first floor.

Measurements were made at the 2-, 4-, and 6-ft levels at many positions both in the basement and first floor. Little difference (less than 10 per cent) in the radiation level was noted at different heights in the basement. On the first floor the dose rate was generally 15 to 25 per cent higher at the 6-ft level than at the 4-ft level, and 10 to 15 per cent lower at the 2-ft level than at the 4-ft level, except directly in front of the windows.

4.6 BUILD-UP OF RADIOACTIVITY IN THE FILTER SYSTEM

A point source was placed near the filters in Mechanical Room No. 1 in the basement to simulate accumulation of fallout in the filter system. The measurements were normalized to milliroentgens per hour per curie. Dose-rate contours were estimated from the data and drawn on a basement floor plan. This contour map appears in Fig. 4.3. The radiation level from build-up of radioactivity in the filter system will probably be negligible compared to the roof contribution for most points in the basement (except those in the filter system room itself). The assumption is that the air-circulation system would be off while fallout is coming down.

4.7 DISCUSSION AND GENERAL CONCLUSIONS

Fully accurate predetermination of a protection factor cannot be achieved because of the many unpredictable effects associated with a fallout situation. These include areas of non-uniform contamination, accumulation on walls of buildings, etc. The values resulting from this experiment are based on simulation of a uniform fallout field and represent approximations of the actual protection factor.

Methods of significantly increasing the protection are limited to increasing the interposing shielding material and/or removing the contamination itself. The protection in the basement near the east entrance (detector positions 99 through 105) could be increased by erecting a curtain wall (concrete blocks, sand bags, etc.) near the entrance. This would significantly decrease the dose rate from direct radiation coming from the ground outside the entrance.

Complete health physics procedures were followed during the experiment according to the radiological safety plan in Appendix A. Maximum exposure to project personnel, as read by pocket ionization chambers, was 60 mr. Maximum exposure to the plants in the greenhouse was less than 500 mr; to the animal colony, less than 150 mr; and to nurses and patients, less than 30 mr, as read by film badges issued and processed by the Medical Center Health Physics Group.

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4. T. D. Strickler and J. A. Auxier, *Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources,* Report CEX-59.13, April 1960.
5. C. L. Schlemm, A. E. Anthony, Jr., and Z. G. Burson, *Scattered Gamma Radiation Measurements from a Co^{60} Contaminated Field,* Report AFSWC-TN-59-6, January 1959.
6. W. S. Snyder and J. L. Powell, *Absorption of γ Rays,* USAEC Report ORNL-421, March 1950.

Table 4.1 — PROTECTION FACTORS AT POSITIONS IN THE BASEMENT OF THE MEDICAL RESEARCH CENTER

Position	P.F.	Position	P.F.	Position	P.F.	Position	P.F.	Position	P.F.
1	640	46	310	96	280	148	430	190	4200
2	340	47	390	97	250	149	300	191	4200
3	350	48	470	98	270	150	290	192	4000
4	310	49	1400	99	190	151	370	193	2400
5	400	50	980	100	170	152	350	194	2400
6	240	51	340	101	150	153	500	195	1900
7	300	52	270	102	110	154	390	196	3200
8	280	53	250	104	67	155	310	197	600
9	210	54	300	105	29	156	470	198	910
10	180	55	330	107	980	157	500	199	710
11	180	56	340	108	520	158	490	200	710
13	160	57	320	109	860	159	380	201	710
15	520	60	70	110	960	160	420	202	600
16	440	63	46	111	500	161	610	203	940
17	220	64	570	112	410	162	430	206	860
18	210	65	310	113	660	163	320	207	1000
20	260	67	430	114	630	164	290	208	910
21	250	68	1400	115	550	165	450	219	390
22	760	69	1200	120	430	166	360	220	430
23	300	70	340	121	290	167	290	221	1000
24	170	71	270	122	280	168	340	222	500
25	150	72	290	123	380	169	350	223	290
26	140	73	270	124	230	170	400	224	260
27	680	74	300	125	420	171	370	226	330
28	330	75	310	126	370	172	430	244	240
29	300	76	290	127	440	173	400		
30	400	77	600	128	790	174	420		
31	440	78	440	129	790	175	340		
32	1400	79	340	132	280	176	270		
33	780	80	500	133	160	177	450		
34	320	82	930	134	190	178	450		
35	240	83	410	137	300	179	530		
36	210	84	450	138	140	180	1300		
37	260	85	390	139	65	181	450		
38	290	86	400	140	330	182	560		
39	250	87	280	141	440	183	620		
40	310	88	190	142	300	184	810		
41	210	89	250	143	300	185	770		
42	140	92	340	144	370	186	830		
43	98	93	330	145	310	187	740		
44	580	94	310	146	350	188	780		
45	320	95	290	147	350	189	1300		

Table 4.2 — PROTECTION FACTORS AT POSITIONS ON THE FIRST FLOOR OF THE MEDICAL RESEARCH CENTER

Position	P.F.	Position	P.F.	Position	P.F.
301	15	342	19	384	14
302	15	343	19	385	15
305	14	345	17	386	15
306	17	346	17	387	16
307	15	347	15	388	15
309	17	348	17	389	17
310	16	349	16	390	120
311	21	350	17	391	120
312	20	351	21	392	110
313	14	352	12	393	100
314	17	353	13	394	120
315	15	354	14	395	49
316	17	355	14	396	14
317	18	356	16	397	14
318	14	360	15	398	15
319	15	361	13	399	16
320	16	363	19	400	17
321	18	364	15	401	13
322	19	365	17	402	18
323	19	366	16	403	17
324	16	367	17	404	14
325	17	368	15	405	15
326	17	369	14	406	14
327	17	370	17	407	12
328	18	371	14	408	12
329	22	372	17	409	16
330	18	373	15	410	15
331	17	374	14	411	17
332	17	375	21	412	14
334	16	376	22	413	14
335	19	377	19	414	14
336	18	378	12	415	17
337	17	379	13	416	17
338	19	380	13	417	72
339	17	381	17	418	12
340	18	382	15		
341	22	383	17		

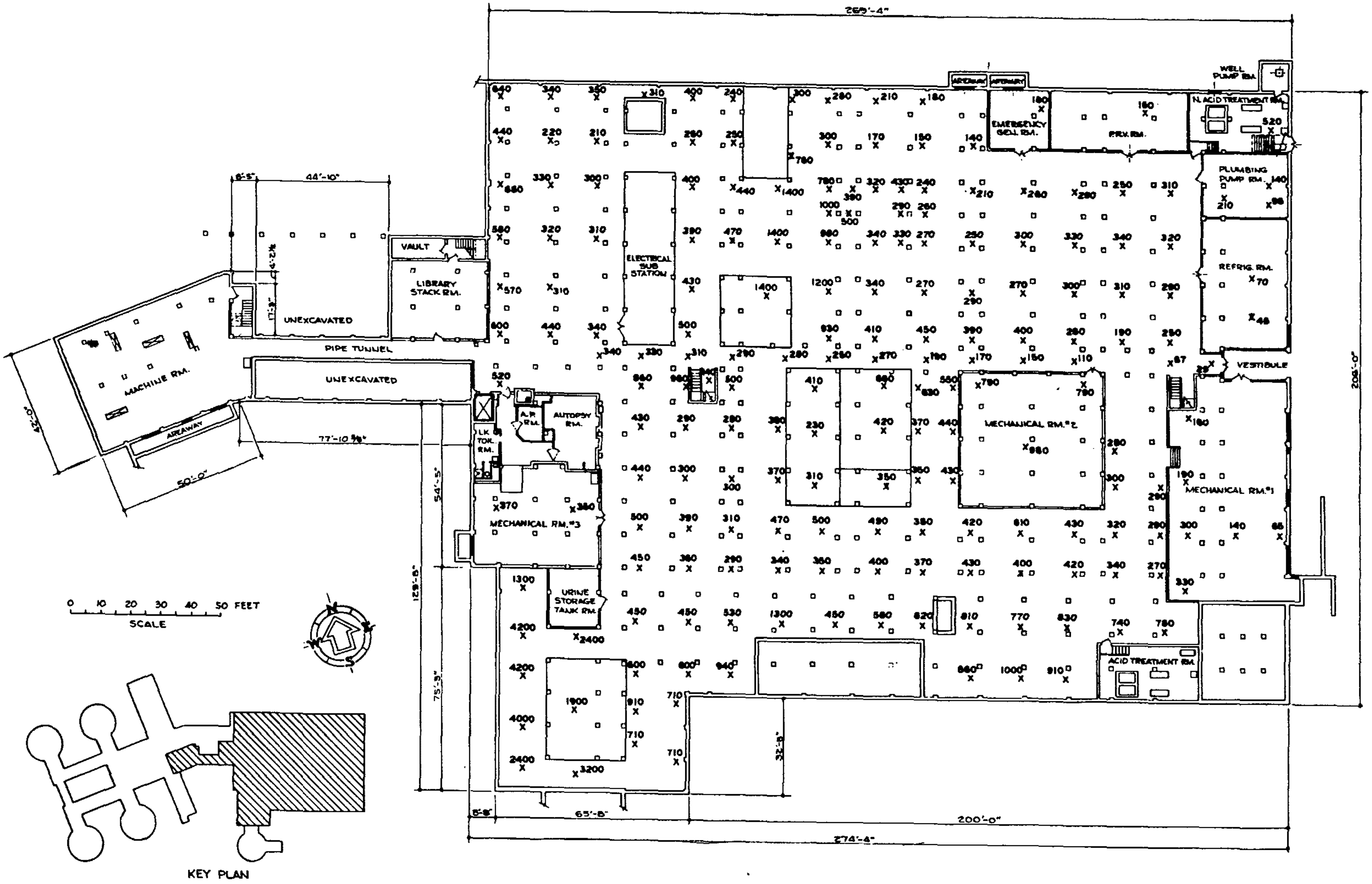

Fig. 4.1—Protection factors plotted on basement floor plan.

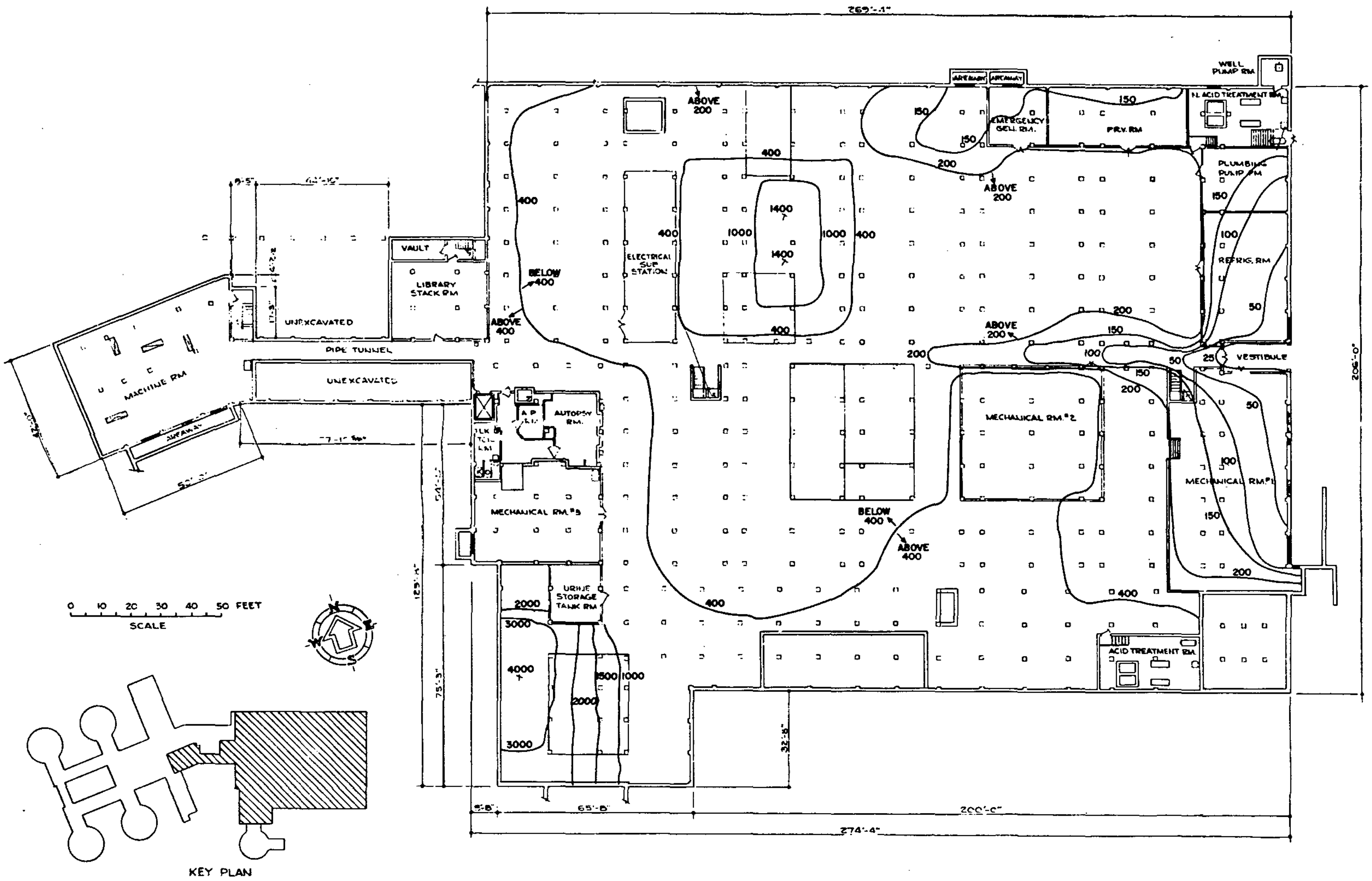

Fig. 4.2—Approximate protection-factor contour map.

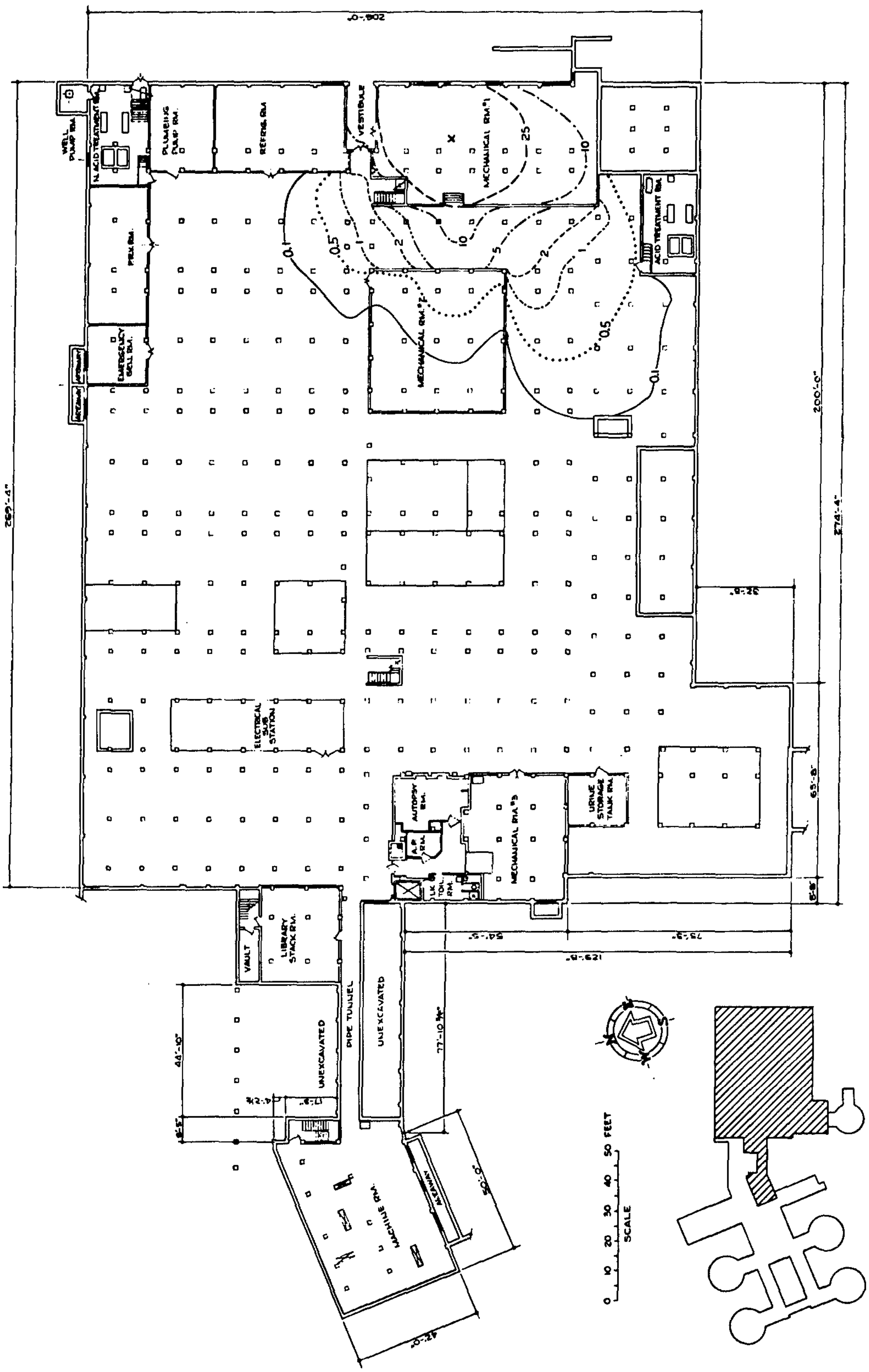

Fig. 4.3—Estimated dose-rate (normalized to milliroentgens per hour per curie) contours from a point source placed near the filter system.

Appendix A

BROOKHAVEN PARTICIPATION*

The primary reason for the Medical Department's participation in the experiment was to ascertain the suitability of specific basement areas in the Medical Research Center for shelter and temporary hospital use in the event of a hazardous fallout situation. For planning purposes information was needed on both the quantity of protection and the relative protection from point to point throughout the basement.

During the study an attempt was made to measure the gamma spectrum at three locations. Units consisting of NaI (thallium-activated) crystals and associated multichannel analyzers were used.

So as not to interfere with other work being carried out with the analyzers, the locations of two units and their associated shielding were not altered.

One 8- by 4-in. crystal was located in the whole-body counting room. This room, 6 by 7 by 9 ft, is constructed of 6-in. steel and lined with lead, cadmium, and copper. At this location most of the data obtained were at about background level. However, during the first run, covering the front of the building, data were obtained showing a slight peak at 1.33 Mev. Most of the scatter radiation measured was in the low-energy range, with a peak at about 200 kev. (Data were not obtained below 100 kev in this unit.)

A second 5- by 4-in. crystal was in the low-level counting room on the ground floor. This crystal was shielded on all sides (except the top) by a layer of lead bricks. Removal of the lead bricks increased the background to a level that prevented use of the unit. Even with the lead shielding, data could be obtained only for a fraction of the run because the counting rate was too high to allow a continuous count over the total run length. The lead shielding detracted greatly from the validity of the data, but the energy spectrum obtained indicates that much of the energy is scatter radiation at lower energy than the 1.17- and 1.33-Mev energy associated with Co^{60}.

A third unit, consisting of an unshielded $1\frac{1}{2}$- by $1\frac{1}{4}$-in. NaI (thallium-activated) crystal, together with its phototube and high-voltage supply, was connected to a 256-channel Nuclear Data Analyzer. The unit was placed at about the center of the basement area near the region of interest as a fallout shelter. The analyzer was left in the same position during all runs.

Figure A.1 shows the position of the three units with reference to a first-floor plan. The data in Figs. A.2 to A.4 were obtained with the small crystal in the basement area.

Figure A.2 shows the spectrum obtained with a Co^{60} standard placed directly on the crystal. The two cobalt peaks, 1.17 and 1.33 Mev, are evident.

Figure A.3 shows the spectrum obtained during the run covering the north area of the roof (run 5). The graph indicates that most of the energy measured by the crystal was below 300 kev, with a much smaller peak at 1.17 and 1.33 Mev.

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*Appendix A was prepared by Dr. R. Conard, Dr. S. Fine, and C. Meinhold.

Figure A.4 shows the spectrum obtained during the run covering the south end of the roof (run 7). During this run the energy was again measured by the crystal as being to a large extent below 300 kev.

A second experiment was carried out using a Co^{60} point source of 1.6 curies placed on the roof at various locations. The scintillation detector and associated spectrum-analyzer equipment were located at the same point in the basement as in the fallout protection studies. The results are shown in Fig. A.5. Spectrum A is that obtained with the source on the roof and, as nearly as could be ascertained, directly over the crystal. Spectrums B, C, D, and E represent those obtained by moving the source approximately 15 ft laterally for each measurement.

The following conclusions can be drawn from Fig. A.5:

1. Most of the energy seen at the crystal was less than the 1.17- and 1.33-Mev energy obtained from the Co^{60} source.
2. With increased distance and increased shielding, the effective energy observed at the crystal was decreased.
3. There was no evident alteration in the spectrum at the lower energies with increased distance or increased shielding (using a specific crystal). For example, the ratio of the count of A to B or A to C appears to be constant.
4. No definite conclusions can be drawn concerning the actual energy spectrum since the crystal is energy dependent and accounts for a great deal of scatter radiation.
5. There are no measurements of the low-energy components since the crystal unit is unsuitable for measurements in the low-energy range (0 to 100 kev).

Similar studies have been carried out by other groups to measure the degradation of gamma rays in water in comparison with theoretical values.[1] The radiation dosage and energy distribution produced at several depths in a hole in the ground by a Co^{60} source suspended at various locations have also been measured.[2] In these experiments degradation of the Co^{60} energy spectrum was obtained at the detector.

A.1 SUMMARY OF ENERGY MEASUREMENTS

During the various Co^{60} runs made to evaluate the basement of the medical building as a fallout shelter, the energy spectrum was obtained at three locations. Data obtained from the analyzers indicated that considerable degradation of the energy spectrum occurred when contrasted with the original cobalt spectrum. Studies using a point source at various locations on the roof substantiated this result.

A.2 CONCLUSIONS AND RECOMMENDATIONS

1. Energy spectra obtained at various locations in further shielding studies might offer some information of value in:
   (a) determining the energy spectrum obtained at that point with the present shielding
   (b) ascertaining the effect of further shielding on the energy spectrum obtained and on the attenuation of the radiation
   (c) correlating the actual data obtained with theoretical calculations.
2. If this study is pursued further, the characteristics of the crystal and associated equipment with regard to their energy dependence should be known and corrected for. Possibly several crystals covering different energy ranges could be used. Their information might then be fed into different multichannel analyzers or in parallel into one analyzer.
3. Through the use of a two-dimensional analyzer or a specifically coded analyzer, which would separate through coding the pulses from a number of crystals, data can be collected from several crystals placed at different locations or covering different energy ranges throughout the duration of a run simulating a fallout field.

A.3 RADIOLOGICAL SAFETY PLAN

All the experimental measurements were made during off-hours and on weekends for minimum interruption in the normal work schedule of the Medical Research Center. There were no unusual incidents, and the measurements were made within the criteria established for radiation-safety operations. Radiation safety of all personnel not directly associated with the experimental measurements was the responsibility of the Medical Department.

The basic radiological safety program was one of strict personnel control. Before the start of each run, BNL security police were stationed in position to cover all exterior entrances to block 9 and block 10. A team of three health physics people then checked the building to see that it had been evacuated. This check was designed so that no one could inadvertently slip by and be left in the area. Similar procedures were necessary for some runs in the biology building.

After all necessary evacuations were complete, the Health Physics Control Center was established in the lobby for all runs except those just to the north of block 9. For these runs the Control Center was moved back toward the industrial-medicine section.

The security guards then manned barricades on the road approaches to the area. A guard was stationed at the southeast corner of a snow fence that sealed off a large area to the south and east of the building. The position and number of barricades were determined by the location of the source area.

All persons entering the area were logged in at the Control Center, and knowledge of their precise whereabouts was required before each run.

Radio communication was established between all guard locations, the police headquarters, the EG&G control truck, and the Control Center. In addition, land-line communication was established between the Control Center and the EG&G truck. During the runs, constant checks were made of the radiation levels at each of the guard locations and at other points beyond the control area. Personnel were allowed in the area during a source run only if accompanied by a health physics surveyor.

A radiation survey was performed at the conclusion of each run to verify that the source was in its shield. There were no significant personnel exposures over the entire course of the project.

REFERENCES

1. M. M. Weiss and W. Bernstein, *Degradation of Gamma Rays in Water, Phys. Rev., 92*(5): 1264-1265 (December 1953).
2. W. Bernstein, D. Clareus, and M. M. Weiss, *Studies on the Propagation of Gamma Rays in Air*, USAEC Report BNL-1707, 1953.

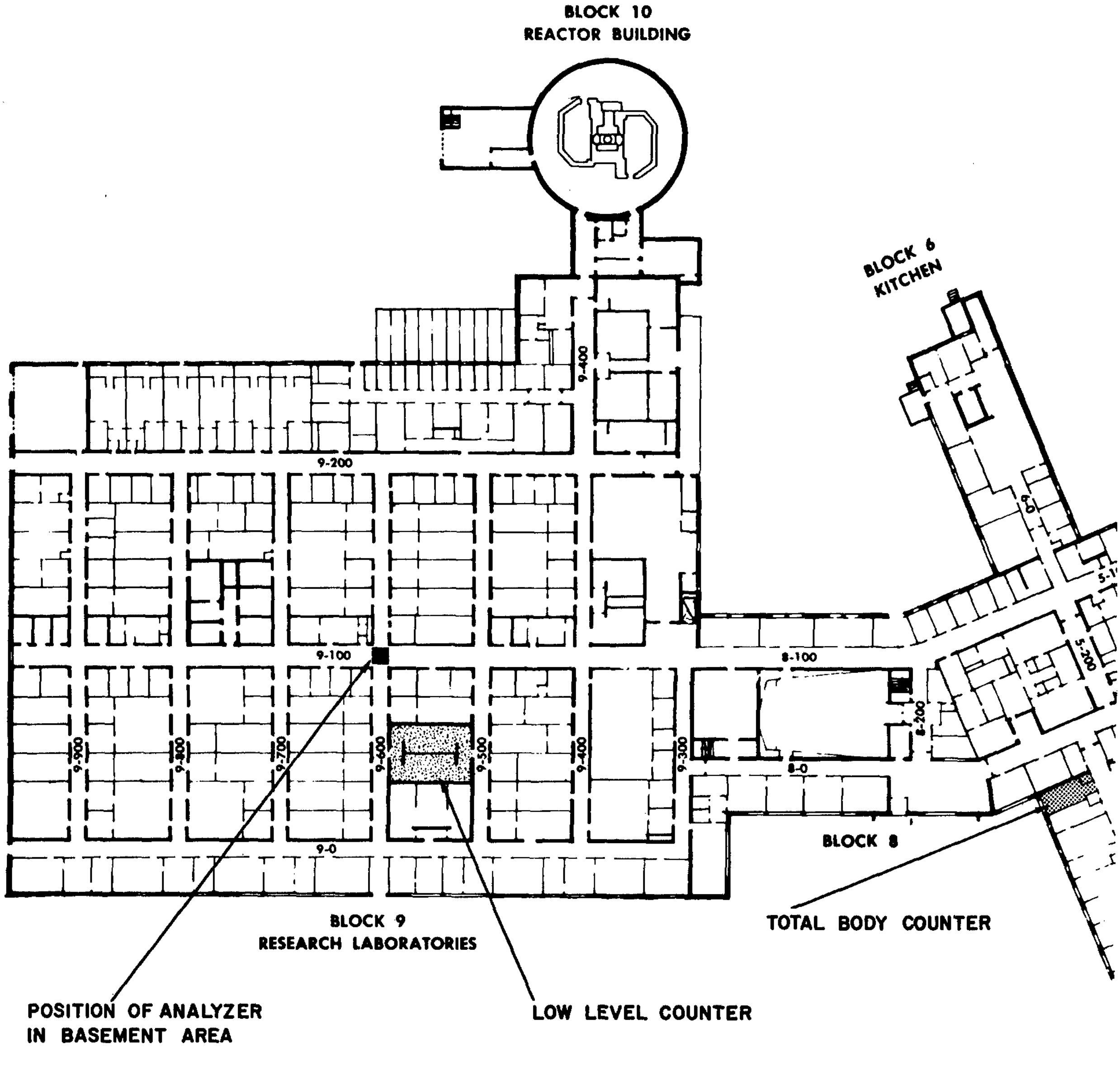

Fig. A.1—Detector positions in building (first-floor plan).

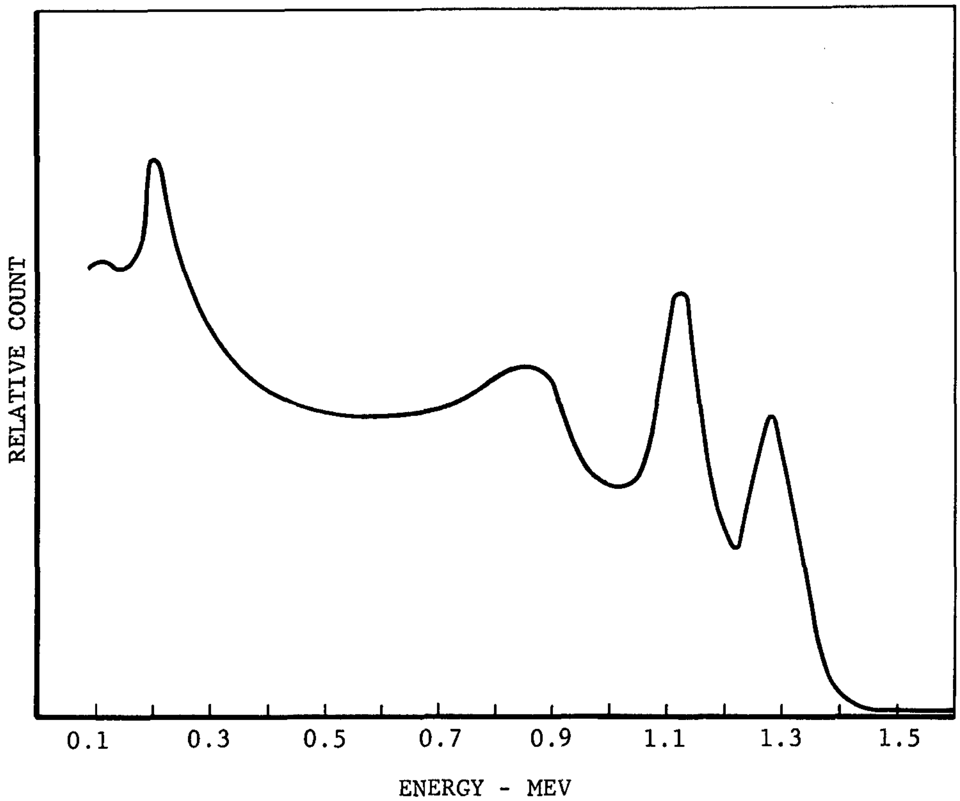

Fig. A.2—Co^{60} standard spectrum.

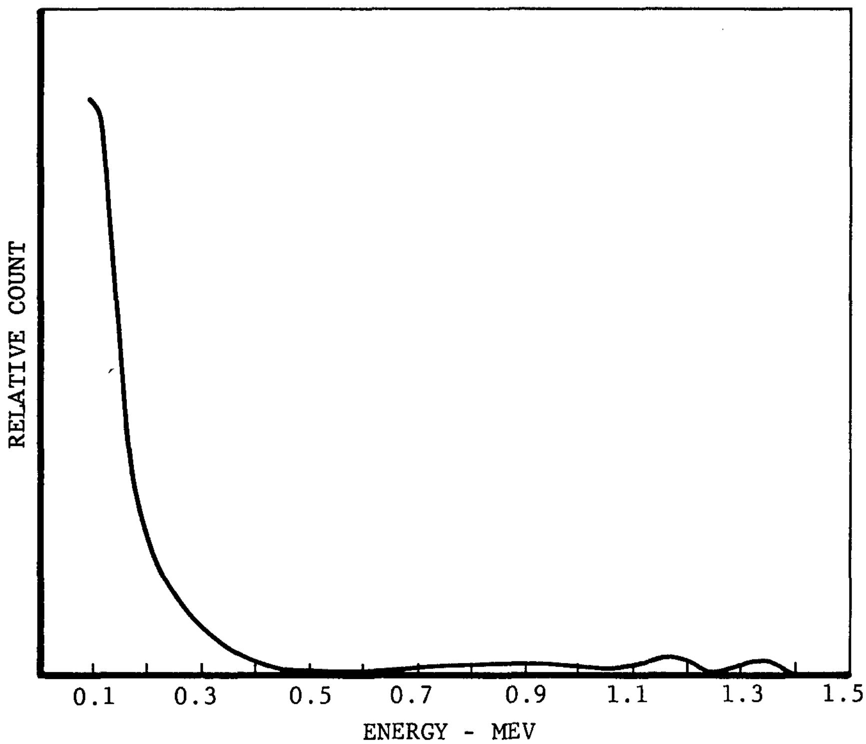

Fig. A.3—Gamma spectrum from run 5, north area of roof.

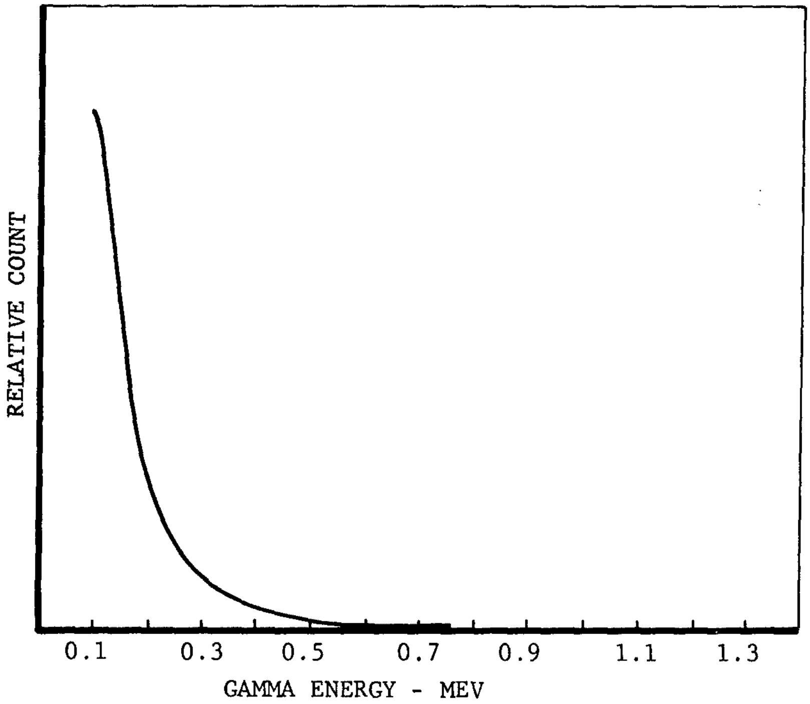

Fig. A.4—Gamma spectrum from run 7, south area of roof.

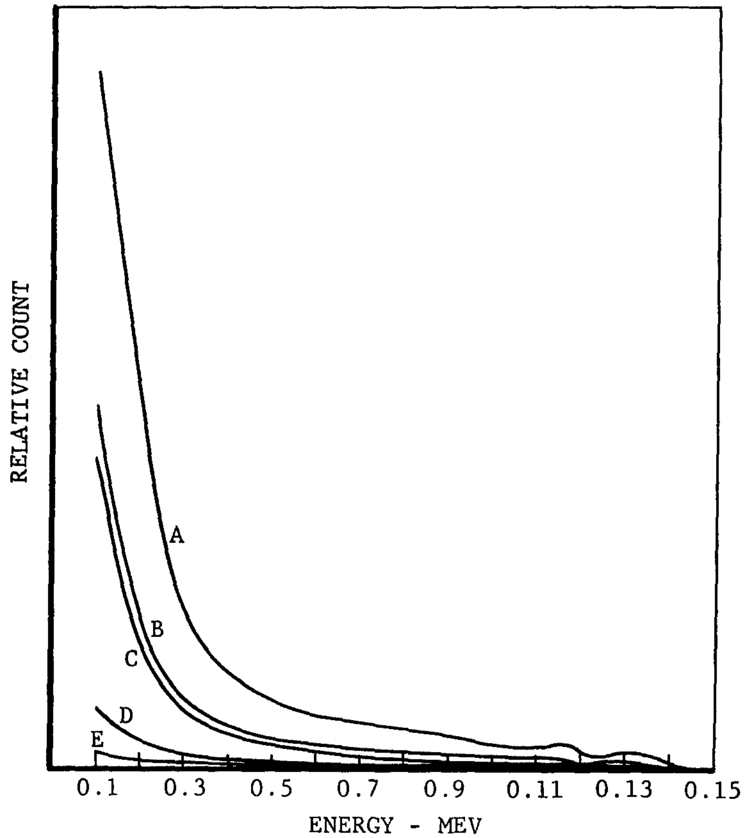

Fig. A.5—Gamma spectra obtained in basement from point source on roof.

Appendix B

SAMPLES OF DATA, ANALYSIS, AND EVALUATION

This appendix contains samples of data and the process through which protection factors were calculated. Reference is made to Chap. 4 in the main body of the report for definitions and explanations of all terms used.

Table B.1 contains the measured and estimated values (normalized) of the contribution from different portions of the building to a particular detector position. The sum of these contributions was used to calculate the protection factor at that position.

Table B.2 shows a sample of data and the process for correction and normalization.

Table B.3 contains a sample of the estimation of the far-field contribution from the north side of the building. The values of G_{n1} were measured. The values of D_{n2}/D_{n1} were calculated from Eqs. 4.6 and 4.7, where $r_1 = 10$ and $r_2 = 145$ for positions 9 and 10 and $r_1 = 14$ and $r_2 = 146$ for position 11. The values of G_{n2} were then found by multiplication of the first two columns. The north contribution G_n is the sum of G_{n1} and G_{n2}.

Table B.4 contains a sample of calculations for the west contributions. The loading dock extends to within approximately 20 ft of the reactor building. Therefore, there is a small area of the basement wall partially exposed above ground next to position 193. The dose rate at position 3 on the north side (geometric similarity to position 193) from the point source on the north side was 140×10^{-3} mr/hr/curie. The dose rate at position 193 from the source on the west side was 44×10^{-3} mr/hr/curie. The area-source contribution to position 3 from runs 1 and 2 was 0.24 mr/hr/mc/sq ft. From a simple ratio the west contribution to position 193 was estimated to be 0.075 mr/hr/mc/sq ft:

$$\frac{140 \times 10^{-3} \text{ mr/hr/curie}}{44 \times 10^{-3} \text{ mr/hr/curie}} = \frac{0.24 \text{ mr/hr/mc/sq ft}}{0.075 \text{ mr/hr/mc/sq ft}}$$

The measured values from runs 1 and 2 were used, rather than the total estimated north contribution, since block 6 was relatively close to the southwest corner of block 9.

The west contribution to positions 194 and 195 was estimated in the same manner, considering the position of the loading dock and geometric location and estimated dose rates at similar positions. This method gives only a rough approximation of the west contribution. No serious error is introduced, however, since the roof contribution was the major factor in determining the magnitude of the protection. Even if the west contributions had been disregarded, the answers would be within a factor of 2.

Table B.5 contains a sample of calculations for the south contributions. The dose rate at position 3 from the source on the north side was 140×10^{-3} mr/hr/curie. Considering inverse-square attenuation only, if the source on the south side had been placed 25 ft from position 207, the dose rate at this position would have been 10.5×10^{-3} mr/hr/curie. The total north contribution to position 3 was 0.34 mr/hr/mc/sq ft. The south contribution was then estimated to be 0.025 mr/hr/mc/sq ft by a simple ratio of point-source and area-source values. The south contribution to position 208 would be approximately the same as to position 207.

Table B.1—DOSE RATE* FROM DIFFERENT PORTIONS OF BUILDING AT A PARTICULAR DETECTOR POSITION

	G_n		G_e		R						
Position	G_{n1} (runs 1 and 2)	G_{n2} (north far-field)	G_{e1} (runs 3 and 4)	G_{e2} (east far-field)	Runs 5 and 6	Runs 7 and 8	North areaways	G_s (south)	G_w (west)	Sum	P.F.
9	0.91	0.34	0	0	1.09	0	0.01	0	0	2.35	210
10	1.01	0.38	0	0	1.23	0	0.10	0	0	2.72	180
11	0.94	0.41	0.01	0.01	1.31	0	0.12	0	0	2.80	180
144	0	0	0	0	0.03	1.31	0	0	0	1.34	370
145	0	0	0	0	0.03	1.61	0	0	0	1.64	300
146	0	0	0.005	0.005	0.03	1.39	0	0	0	1.43	350
193	0	0	0	0	0	0.13	0	0	0.075	0.205	2400
194	0	0	0	0	0	0.20	0	0	0.003	0.203	2400
195	0	0	0	0	0	0.24	0	0	0.027	0.267	1900
207	0	0	0.005	0.010	0	0.46	0	0.025	0	0.50	1000
208	0	0	0.007	0.015	0	0.50	0	0.025	0	0.55	910

* Dose rate normalized to milliroentgens per hour per millicurie per square foot.

Table B.2—CORRECTION AND NORMALIZATION OF DATA

Position	Reading from runs 7 and 8, mr	Corrected for background, mr	Corrected for temp. and press., mr	Corrected for calib., mr	Normalized, mr/hr/mc/sq ft
144	6.5	6.3	6.5	7.1	1.31
145	7.9	7.7	7.9	8.7	1.60
146	6.8	6.6	6.8	7.5	1.38

Table B.3—ESTIMATION OF THE FAR-FIELD CONTRIBUTION

Position	G_{n1}, mr/hr/mc/sq ft	D_{n2}/D_{n1}, mr/hr/mc/sq ft	G_{n2}, mr/hr/mc/sq ft	G_n, mr/hr/mc/sq ft
9	0.91	0.377	0.34	1.25
10	1.01	0.377	0.38	1.39
11	0.94	0.436	0.41	1.35

Table B.4—ESTIMATION OF THE WEST CONTRIBUTION

Position	P_n, mr/hr/curie	P_w, mr/hr/curie	G_n, mr/hr/mc/sq ft	G_w, mr/hr/mc/sq ft
193	140×10^{-3}	44×10^{-3}	0.24	0.075
194	23×10^{-3}	0.26×10^{-3}	0.26	0.003
195	28×10^{-3}	11×10^{-3}	0.070	0.027

Table B.5—ESTIMATION OF THE SOUTH CONTRIBUTION

Position	P_n, mr/hr/curie	P_s, mr/hr/curie	G_n, mr/hr/mc/sq ft	G_s, mr/hr/mc/sq ft
207	140×10^{-3}	10.5×10^{-3}	0.34	0.025
208	140×10^{-3}	10.5×10^{-3}	0.34	0.025

Appendix C

DESCRIPTION OF DETECTOR POSITIONS

Figures 2.19 and C.1 are typical scenes showing pipes, air ducts, and equipment in the basement of the Medical Research Center. The detectors in the basement and on the first floor were located in the most open areas possible so that scattered radiation from nearby equipment would be at a minimum. Some positions were of necessity near pipes, air ducts, etc., which may have affected the measured dose. A brief description of each of the positions is presented in Table C.1.

Table C.1 — DETECTOR POSITIONS

Position	Description	Position	Description
1	4 ft from north wall, approximately 2 ft from west wall	52	$2\frac{1}{2}$ ft to air compressor
2	Clear	53	Clear
3	Clear	54	Clear
4	Between wall and small room, one pipe	55	Clear
5	1 ft from large pipe	56	6 in. below center of air duct
6	1 ft from large pipe	57	3 ft below galvanized-steel duct, 12 ft from room wall
7	1 ft from wire fence	58	6 ft to large motor, pipes, in refrig. room
8	Clear	59	Clear, in refrig. room
9	Clear	60	2 ft to large pipe, in refrig. room
10	Clear	61	3 ft from wall, in refrig. room
11	In emergency generator room, clear; 4 ft from wall, 8 ft from generator	62	3 ft to wall, approximately 4 ft to insulation wall, in refrig. room
12	Clear in PRV room	63	Under a maze of pipes and ducts, in refrig. room
13	In PRV room, approximately 4 ft from large tank	64	6 in. below edge of duct
14	Near stairs, concrete walls on 3 sides, 2 to 4 ft away, in acid room	65	6 in. below edge of duct
15	Approximately 2 ft from small tank in acid room	66	6 in. below edge of duct
16	Clear	67	Clear
17	Clear	68	Inside wire fence, fairly clear
18	Clear	69	Clear
19	Halfway between wall and wire	70	Clear
20	Clear	71	Clear
21	Clear	72	Clear
22	1 ft from wire fence	73	Clear
23	Clear	74	Clear
24	Clear	75	1 ft below center of duct
25	Clear	76	Clear, approximately 12 ft from large room wall
26	Clear, approximately 6 ft from wall	77	6 in. below edge of duct
27	Clear	78	6 in. below edge of duct
28	Clear	79	3 ft below edge of duct
29	Clear	80	3 ft below edge of duct
30	$1\frac{1}{2}$ ft from cold-air duct	81	Inside wire fence, fairly clear
31	1 ft from cold-air duct	82	1 ft below edge of duct
32	6 in. below air duct	83	3 ft below center of duct
33	6 in. below air duct	84	3 ft below center of duct
34	6 in. below side of duct	85	2 ft below center of duct, 2 small tanks nearby
35	6 in. below side of duct	86	2 ft below center of duct
36	6 in. below side of duct	87	6 in. below center of duct
37	6 in. below side of duct	88	Between concrete post and air duct, about 4 ft out of line
38	6 in. below side of duct	89	Near duct and lots of equipment, about 3 ft out of line
39	Clear, about 3 ft to duct	90–106	Clear
40	$1\frac{1}{2}$ ft below galvanized-steel duct, 12 ft from room wall	107	Center of Mech. Room No. 2, near motors, pipes, and ducts
41	Clear, pump room	108	About 2 ft from post
42	Clear, pump room	109	Clear
43	Clear, pump room	110	2 ft from wall
44	Clear	111	Fairly clear
45	Clear	112	Fairly clear, inside wire fence
46	Clear	113	Fairly clear, inside wire fence
47	Clear	114	Clear
48	1 ft to top of transformer	115	Clear, approximately 4 ft from wall
49	Clear, 4 ft below air duct		
50	Clear		
51	Clear		

Table C.1—DETECTOR POSITIONS (Continued)

Position	Description	Position	Description
116		180	2 ft from post
117	Clear, in Mech. Room	181	2 ft from wooden crates
118	Near 8-in. pipe	182	2 ft from wooden crates
120	Clear	183	3 ft from wall of small room
121	Clear	184	Clear
122	Clear	185	Clear
123	$1\frac{1}{2}$ ft to wooden cabinet	186	Clear
124	Fairly clear, inside wire fence	187	3 ft from post
125	Fairly clear, inside wire fence	188	2 ft below edge of duct
126	1 ft to small tank	189	Below maze of ducts and pipes
127	Approximately 4 ft from wall	190–194	Clear
128	Clear, inside room	195	Clear, in wire fence
129	Clear, inside room	196	Clear
130	Clear, inside room	197	Clear
131	Below several pipes, inside room	198	Clear
132	6 ft below edge of duct	199	Near duct
133	Approximately 3 ft from wall, near large air duct, inside room	200	Clear, approximately 4 ft from wall
		201	Clear, approximately 4 ft from wall
134	Clear	202	Clear
135	Clear	203	Near several boards
136	Clear	204	Clear, inside room
137	Fairly clear	205	Clear
138	Clear	206	Clear, approximately 12 ft from wall
139	Clear	207	Clear, approximately 12 ft from wall
140	Near air duct	208	2 ft from post
141	Clear	209	Approximately 3 ft from wall in room
142	Clear	210–243	Clear, 8 ft apart as indicated on Fig. 3.1
143	Clear	244	6 ft high near stairway
144	Clear, 3 ft from wooden cabinets	245	Library stock room
145	Clear, inside wire fence	301–351	Long hallways approximately 11 ft from nearest corridor. Short hallways approximately 14 ft from nearest corridor, approximately 9 ft from nearest corridor for exits
146	Clear, inside wire fence		
147	Clear		
148	About 4 ft from wall		
149	About 4 ft from wall		
150	About 4 ft from wall, below pipes	352	Center, conference room
151	Clear, inside room	353	Center of one side, approximately 3 ft from wall
152	Clear, inside room		
153	Clear	354	About 2 ft from center
154	6 in. below edge of duct	355	Small room, approximately $1\frac{1}{2}$ ft from closest wall
155–163	Clear		
164	Approximately 4 ft from wall, under pipes	356	Center of one side, approximately 3 ft from wall
165	Under maze of ducts and pipes	357	Corner, approximately 6 ft from walls
166	6 in. below edge of air duct	358	6 ft from one side, center
167	2 ft below edge of air duct	359	Center
168	2 ft below edge of air duct	360	Approximately 6 ft from door, center of one side
169	2 ft below edge of air duct		
170	$1\frac{1}{2}$ ft below edge of air duct	361	Off center about 7 ft toward door
171	$1\frac{1}{2}$ ft below edge of air duct	362	6 ft from wall, center of one side
172	Near air duct	363	About 3 ft from two walls in small room
173	$2\frac{1}{2}$ ft from air duct (upper right)	364	Center
174	$2\frac{1}{2}$ ft from air duct (upper right)	365	Center
175	3 ft from post, 2 ft from air duct	366	About 6 ft from door, one side
176	3 ft from post, 4 ft from wall	367	About 6 ft from door, one side
177	Clear	368	Center
178	6 in. below edge of duct	369	Corner, open, 6 ft from walls
179	Clear	370	Center

Table C.1—DETECTOR POSITIONS (Continued)

Position	Description	Position	Description
371	Corner, about 6 ft from walls	397	Center
372	Center	398	Center, one side approximately 6 ft from door
373	One side, about 6 ft from wall	399	Center, one side approximately 6 ft from door
374	Corner about 6 ft from walls	400	Center
375	Approximately 6 ft from wall, center	401	Corner, approximately 6 ft to 8 ft from walls
376	Center	402	Center
377	Center	403	Center
378	Corner, approximately 6 ft from walls	404	Center
379	Center	405	Center
380	Corner, approximately 6 ft from walls	406	Center
381	One side, approximately 6 ft from wall	407	Corner, approximately 6 ft to 8 ft from wall
382	Center	408	Corner, approximately 6 ft to 8 ft from wall
383	Center	409	Center
384	Center	410	Center
385	One side, approximately 6 ft from door	411	Center
386	One side, approximately 6 ft from door	412	Center
387	Center	413	Corner, approximately 8 ft from wall
388	One side, approximately 6 ft from door	414	Corner, approximately 8 ft from wall
389	Center	415	Center of one side, approximately 6 ft from wall
390	Almost in center	416	Center of one side, approximately 6 ft from wall
391	Almost in center	417	Center of stairway
392	Almost in center	418	Center of stairway, top
393	Center of one side, approximately 6 ft from wall		
394	Center of one side, approximately 6 ft from wall		
395	Center		
396	Center, one side approximately 6 ft from door		

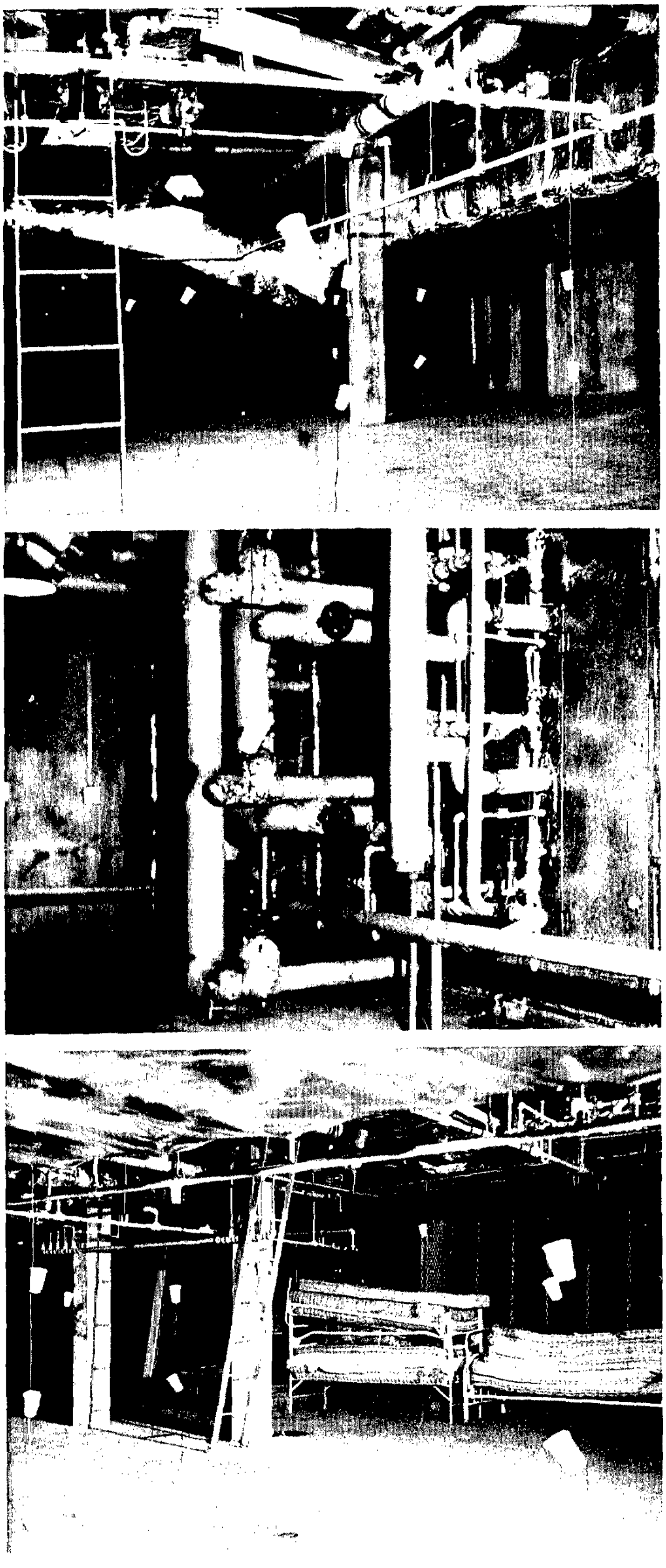

Fig. C.1—Some detector positions in relation to equipment in the basement.