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CIVIL EFFECTS STUDY

EXPERIMENTAL EVALUATION OF THE
FALLOUT-RADIATION PROTECTION
PROVIDED BY STRUCTURES IN THE
CONTROL POINT AREA OF THE
NEVADA TEST SITE

Zolin G. Burson

Issuance Date: October 1970

CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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EXPERIMENTAL EVALUATION OF THE FALLOUT-RADIATION PROTECTION PROVIDED BY STRUCTURES IN THE CONTROL POINT AREA OF THE NEVADA TEST SITE

By

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U. S. Atomic Energy Commission
May 1969

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ABSTRACT

Fallout-radiation protection factors (PF's) were determined for six buildings within the CP complex of the U. S. Atomic Energy Commission's Nevada Test Site, four from experimental data with fallout simulation techniques and two derived from calculations. Data using ^{60}Co are applicable to a deposited 1-hr fission-product condition. Results are presented as PF contours on floor plans. These PF values at locations away from entrances are:

Building	PF range
CP-40, Communication Building	15 to 25
CP-45, Light Laboratory	
Upstairs	50 to 100
Downstairs	100 to 1000
CP-1, Main Control Building	
Upstairs	30 to 50
Downstairs	250 to 500
CP-1B, Main Control Building Addition	
Main floor	100 to 600
Basement	300 to 10,000
CP-2, Rad-Safe Building	
Upstairs	20 to 40
Downstairs	50 to 300
CP-14, Programmatic Building	2 to 3
CP-50, Radiological Sciences Building	5 to 10

Protection from 1-day-old fission products and from cloud passage was also estimated. These values are about the same for lightly constructed buildings (CP-14 and CP-50) but increase to as much as a factor of 3 higher for heavily constructed buildings (CP-1B). 13 ref. etc

Construction of a baffle wall around the west entrance to the main floor of CP-1B and provision of sandbags or concrete blocks to block up the north entrance to the basement are recommended to significantly improve protection factors in the Test Manager's Operations Room and the downstairs briefing room, respectively.

In addition to obtaining protection-factor values for the buildings of concern, the experiment yielded much valuable information useful to a variety of radiation and shielding studies.

PREFACE

For the past several years EG&G, Inc., under the sponsorship of the U. S. Atomic Energy Commission, Division of Biology and Medicine, has been developing and using a system for simulating a fallout-radiation condition. This system has been developed to perform radiation-shielding measurements for almost any configuration from busses to buildings. More important than the physical hardware for this system has been the development of operational and analytical techniques for obtaining meaningful information.

Measurements of radiation-protection factors for Control Point-1 and associated buildings at the Nevada Test Site were performed at the request of R. H. Thalgott, Test Manager, U. S. Atomic Energy Commission, Nevada Operations Office. Mr. Thalgott's interest was to support the original design calculations with actual measurements taken with the system described in the preceding paragraph. The study includes several new buildings which have just been completed, such as the Light Laboratory and the Communications Building.

The information reported in this study should prove useful in future determinations of permissible hazard levels around the Control Point complex. Because of the variety of buildings studied, other investigators may also find the information useful. Finally, the study provided additional useful experience in the operational aspects of performing such measurements.

The reader may be particularly interested in protection-factor contours shown in Figs. 3.2, 3.5, 3.6, 3.11, 3.12, and 3.14.

ACKNOWLEDGMENTS

The author wishes to acknowledge the many valuable contributions made by the following: Don Hendricks, his staff, and the organizational structure of the U. S. Atomic Energy Commission's Nevada Operations Office and Nevada Test Site Support Operations for their overall support; L. J. Deal and the Division of Biology and Medicine, U. S. Atomic Energy Commission, for the use of the Mobile Radiological Measuring Unit; Peery Bernhard, Ted Russ, and Joe Gatt, Reynolds Electrical and Engineering Co., Inc., Radiological Sciences Department, for their participation in all phases of the experiment; William Poe, John Miller, and Rodney Fowler, EG&G, Inc., for their technical participation in the planning and executing of the program; Robert Summers, EG&G, Inc., for his assistance in analyzing and reducing portions of the data; John Tappen, Reynolds Electrical and Engineering Co., Inc., Radiological Sciences Department, for drafting a portion of Appendix A; and Dee Jared, Editorial Branch, U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, for her meticulous final editing of the manuscript.

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Chapter 1

INTRODUCTION

1.1 GENERAL

Several key buildings are located in the Control Point (CP) complex, Area 6, U. S. Atomic Energy Commission (AEC), Nevada Test Site (NTS), where essential functions are performed relating to the operations and safety of all programs and testing at the NTS. Fallout-radiation-protection factors afforded by these buildings were needed to allow an evaluation of the feasibility of permitting essential personnel to remain within these structures during radiologically hazardous situations.

1.2 BACKGROUND

In recent years much effort has been directed toward the development of an adequate fallout shielding technology. The current calculational methodology¹ is capable of predicting the protection factors (PF) within a probable error of about 30% for ideal buildings of PF values of less than 100. Consideration of the actual conditions for such light structures, terrain effects, nearby buildings, ground roughness, structural configuration, and all internal contents would increase the probable error to 50 to 60% (Ref. 2).

However, the calculational technology is still rather poor for massive structures providing high radiation protection. Based only on calculations, the uncertainty in determining actual PF values for some of the CP buildings (CP-1 and CP-45) would be about a factor of 3.

Therefore experiments were performed by using fallout simulation techniques on four of the six key buildings. Two buildings, CP-14 and CP-50, were of light construction. Protection factors based on calculations only are considered reliable for these buildings.

1.3 OBJECTIVES

The general objective was to determine fallout-radiation-protection factors throughout six buildings in the CP area. Some specific objectives were:

1. To provide experimental data to aid in determining the protection factors for four of the six buildings.
2. To determine by calculations the protection factors for two buildings.
3. To estimate the degree of protection provided by these buildings during a radioactive-cloud passage.

Some secondary objectives were:

1. To determine the feasibility of using reciprocity* for structure shielding studies.

*Reciprocity refers to interchanging the position of source and detector.

2. To determine the thickness of several walls of the buildings by radiation attenuation measurements.
3. To compare the measurement of whole-body dose with isolated dosimeter measurements.
4. To provide measurements for comparison with calculations for full-scale, complicated structures.
5. To compare data from ^{60}Co and ^{137}Cs for the same source and shield geometry.

Chapter 2

EXPERIMENTAL METHOD

2.1 GENERAL

The experimental method consisted in simulating a finite, idealized fallout field by pumping a radioactive source through tubing placed on the roof of and on the ground around the structure being tested. Radiation levels inside were measured by appropriately placed ionization chambers or thermoluminescent dosimeters (TLD). The detectors were placed in paper cups attached to chairs. Approximately 300 detectors were used to ensure full coverage throughout each structure.

2.2 SOURCE-HANDLING SYSTEM

The Mobile Radiological Measuring Unit was used for the measurements. It has been used for many experiments of this nature^{3,4} sponsored by the Civil Effects Test Organization (CETO) and is thoroughly described in Ref. 5. The system consists of a remotely controlled hydraulic pumping unit that uses water to pump a radioactive source from its shield through associated tubing and back into the shield. Movable magnetic switch indicators attached to the tubing arrays and electrically connected to lights on the remote-control console enable the operator to locate the source position at all times.

The control console was located several hundred feet away for radiation safety. From the console the movement of the source capsule was started, stopped, reversed, or oscillated at will. A hand pump at the hydraulic pumping trailer was located 100 ft from the source-shield trailer to provide an emergency mechanism for returning the source capsule to its shield if necessary. Figure 2.1 is a photograph of the source-handling system.

To simulate a uniformly contaminated area, we pumped a source capsule at uniform speed through the polyethylene tubing, which had been evenly distributed over either the roof or the ground next to the building concerned.

2.3 SOURCES AND INSTRUMENTATION

The experimental measurements described here were carried out with ^{60}Co and ^{137}Cs sources of the following approximate activities:

^{60}Co	593, 105, and 10.6 Ci
^{137}Cs	293 and 3.78 Ci

Other sources were available but were not used.

All sources were encapsulated in magnetic stainless steel. Calibrations were performed both before and after the program by pumping a source into position a given distance from

Fig. 2.1—Hydraulic pumping system trailer and radioactive-source shield.

Fig. 2.2—Assembly and detail of 105-Ci ^{60}Co source capsule.

calibrated ion chambers and TLD's. Similar calibration details are presented in Ref. 5 along with angular source output. The activity of the sources at the time of the measurements was obtained from standard decay curves, assuming 1.305 R/hr at 1 m from the 1-Ci ^{60}Co source and 0.32 R/hr at 1 m from the 1-Ci ^{137}Cs source. A photograph and cutaway drawing of one of the ^{60}Co sources appear in Fig. 2.2.

Cobalt-60 was used as the prime radioactive source because its 1.17- and 1.33-MeV gamma rays have a penetrating power similar to 1-hr-old fission-product gamma rays. Cesium-137 was used to allow estimates to be made of the attenuation of gamma rays from 1-day-old, or fractionated, fission products.

The radiation detectors used in this experiment were of two types, integrating ionization chambers and thermoluminescent dosimeters (Fig. 2.3). Angular response of the ion chambers (0- to 10-mR Victoreen Model 239 stray radiation chambers) is described in Ref. 5. The TLD's (EG&G Model TL-12) are described in Ref. 6. All detectors were calibrated by placing them 1 m from a National Bureau of Standards calibrated ^{60}Co source. Energy response of both types of detectors is shown in Fig. 2.4. Errors due to calibration, energy, angular response, and detector orientation are discussed in Appendix B.

2.4 EXPERIMENTAL TECHNIQUE

2.4.1 General

The experimental technique consisted in creating simulated smooth planes of uniform contamination on and around the structure and measuring the radiation levels at selected locations within. The radiation levels were produced 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. The use of integrating detectors within the building made the total radiation exposure appear to be from an area source. This technique had the advantage of averaging local features of the terrain and the building under test, features that would be of significance in a true fallout-radiation field.

General procedures followed at a given building were essentially the same regardless of the complexity of the structure. These procedures consisted of the following steps, though not necessarily in this order:

1. The equipment was moved to the structure, set up, and checked out.
2. Detector positions were established inside the structure at selected locations by placing marked tape on the floor. Paper cups were attached to the back of chairs as detector holders.
3. Appropriate roads and parking lots were barricaded to prevent parked cars from interfering with the tubing distribution.
4. The polyethylene tubing was distributed over the desired area according to a predetermined plan.
5. A dummy source (containing no radioactivity) was pumped through the tubing to assure that it had not been damaged and to make sure there were no restrictions that would prevent the actual source from maintaining constant speed throughout the experimental tubing layout.
6. All dosimeters were charged and placed in the paper cups at their appropriate locations.
7. An area surrounding the structure (up to a 700-ft radius) was cleared of all unauthorized personnel by NTS Security. Appropriate roadblocks and monitoring stations were set up.
8. When clearance was given by the Test Manager, the pumping system was energized and the source pumped through the tubing.
9. At the end of the source exposure, the source was secured in its container, the dosimeters were read, and their readings were recorded.
10. After testing of a building was completed, standard wrap-up procedures in handling the source system and related equipment were carried out prior to moving to another building.

Fig. 2.3—Ion chambers and TLD's used in the experiment.

Fig. 2.4—Energy response of both types of detectors used in experiment.

In general, the exposures were made on weekends to minimize the inconvenience to all concerned. A radiological-safety plan, described in Appendix A, was formulated and followed for each test to assure maximum safety to personnel. Wherever possible, two dosimeters were placed at each location to obtain more accurate results. The dosimeters were placed 3 ft above the floor. Figure 2.5 shows the location of all the buildings in the CP complex.

2.4.2 CP-40, Communications Building

The communications building is a rectangular, one-story structure measuring 80 by 100 ft. It has a 4-in. concrete roof and 8-in. concrete walls. A plot plan showing ground contours is given in Fig. 2.6, and a photograph of the structure appears in Fig. 2.7.

Since the roof was relatively thin compared with the walls, the roof contribution was expected to dominate the protection-factor determinations. Therefore only a roof source was simulated. However, both ^{60}Co and ^{137}Cs were used to provide data for comparison purposes. A photograph and a sketch of the tubing layout appear in Figs. 2.8 and 2.9. The tubing was placed 3 ft apart.

Sources of low activity were used since the building was small and the roof was of thin material. No TLD's were used, only 10-mR chambers. Dosimeter positions, plotted on floor plans, appear in Chap. 3. More detailed structural information and photographs appear in Appendix C.

2.4.3 CP-45, Light Laboratory

The Light Laboratory is a two-story laboratory structure measuring 80 by 120 ft. The ground level is at first-floor ceiling level on the west side and at floor level on the other three sides (Fig. 2.10). The lower wall is 10 in. of concrete, and the upper wall is 8 in. of concrete. A few small windows are located on the upper east side. Floor and roof thicknesses are $7\frac{1}{2}$ in. of concrete. Internal partitions are of lightweight material except the stair well, which is concrete.

The tubing was placed 4 ft apart over the roof for the roof exposure (Figs. 2.11 and 2.12). The many air-conditioning units made the placement difficult. The tubing distribution on the ground surrounded the building on three sides (Figs. 2.13 and 2.14). Each tube was placed 5 ft apart, the first being $2\frac{1}{2}$ ft from the edge of the wall and the last being $57\frac{1}{2}$ ft away. A 593-Ci ^{60}Co source was used for both exposures. Exposure times of more than an hour were necessary for both source distributions to obtain minimum detectable levels of radiation in high-protection areas. Both 10-mR ion chambers and TLD's were used. The source and detectors were interchanged for both roof and ground tubing at this building to investigate the use of reciprocity. The details are presented in Appendix D.

2.4.4 CP-1, 1A, and 1B, Main Control Building

This large, complex structure required four separate measurements, three ground sources surrounding the building and a roof source.

The original two-story CP-1 has 10-in. concrete walls downstairs and 8-in. concrete walls upstairs. The roof and floor are of 4-in. concrete. Steep ground contours occur on the north side (Fig. 2.15). A new addition, CP-1B, has 16-in. concrete walls, a 12-in. concrete roof, and 6-in. concrete floors.

The tubing was placed 4 ft apart for the roof source and 5 ft apart for all three ground sources. Tubing layouts and photographs appear in Figs. 2.16 to 2.21. Much material and equipment to the north and east of CP-1 made the tubing layout difficult. Personal judgment was made as to whether to place tubing over or around obstructions. Figure 2.19 shows the problem on the north side of CP-1.

Exposure times varied from about $\frac{1}{2}$ to 2 hr. Even with the 593-Ci ^{60}Co source, exposure times up to 2 hr were necessary to obtain 0.5 mR in the heavily protected areas in the basement of CP-1B.

Up to 300 dosimeters, both ion chambers and TLD's, were distributed throughout the building for maximum coverage. Because of the many locations, it was not possible to put two

(Text continues on p. 26.)

Fig. 2.5—Location of test buildings in the CP complex.

Fig. 2.6—Plot plan of CP-40 showing ground contours.

Fig. 2.7—CP-40.

Fig. 2.8—Tubing distribution on roof of CP-40.

Fig. 2.9—Tubing-distribution plan for roof of CP-40.

detectors at each location. A few positions, where the results would be the most useful, were chosen for double detectors.

During the tests it was necessary that key personnel remain in CP-1B. These personnel were fully instrumented with TLD's to determine the whole-body dose received. These results, as compared to static dosimeter readings, are discussed in Appendix E.

2.4.5 CP-2, Rad-Safe Building

The Rad-Safe Building has a 4-in. concrete roof and 8-in. concrete walls. A basement storage area in the east end is exposed to ground level through the doorway. Ground contours are noted in Fig. 2.22.

Tubing was distributed on the roof 4 ft apart (Figs. 2.23 and 2.24). The 105-Ci ^{60}Co source was used for an exposure time of about 30 min.

Tubing was placed 5 ft apart for the ground distribution, the last tube being $57\frac{1}{2}$ ft from the edge of the building. The areas north and east of CP-2 were used (Figs. 2.25 and 2.26). It was estimated that the roof contribution would dominate the determination of the protection factors upstairs and that the east side contribution would do so for the basement. Ground contributions for the west and south sides could be estimated by symmetry. Two ground exposures were made. The 105-Ci ^{60}Co source was used for an exposure time of a little over 1 hr, and a 293-Ci ^{137}Cs source was used for an exposure time of a little over 2 hr. Comparisons are discussed in Chap. 3.

Fig. 2.10—Plot plan of CP-45 showing ground contours.

Fig. 2.11—Tubing distribution on roof of CP-45.

Fig. 2.12—Tubing-distribution plan on roof of CP-45.

Fig. 2.13—Tubing distribution on the ground around CP-45.

Fig. 2.14—CP-45 ground tubing-distribution plan.

Fig. 2.15 — Plot plan of CP-1 showing ground contours.

Fig. 2.16—Tubing distribution on roof of CP-1 and CP-1B.

Fig. 2.17—Tubing-layout plan on roof of CP-1, CP-1A, and CP-1B.

Fig. 2.18—Tubing distribution on roof of CP-1.

Fig. 2.19—Tubing distribution on north side of CP-1.

Fig. 2.20—Tubing-layout for ground measurements around CP-1, CP-1A, and CP-1B.

Fig. 2.21—Tubing distribution on the parking lot to the west and south of CP-1B.

Fig. 2.22—Plot plan of CP-2 showing ground contours.

Fig. 2.23—Tubing distribution on roof of CP-2.

Fig. 2.24—Tubing-layout plan for roof measurements on CP-2.

Fig. 2.25—Tubing distribution on the ground around CP-2.

Fig. 2.26—Tubing-layout plan for ground measurements at CP-2.

Chapter 3

RESULTS

3.1 GENERAL

To evaluate radiation protective qualities and to give this protection quantitative expression, we commonly use the term protection factor (PF), which is a number that indicates the protective potential of a structure and provides a measure of how much less the radiation level would be inside the structure than outside in an open, unprotected area in an extended fallout field. In technical terms the PF is the ratio of the exposure rate 3 ft above a smooth, infinite plane uniformly contaminated with radioactive material to the exposure rate at a specific point in question, assuming the same source distribution. Accordingly,

$$PF_i = \frac{E_\infty}{E_i} \quad (3.1)$$

where E_∞ is the free-field infinite-plane exposure rate and E_i is the exposure rate at the point in question.

The infinite-plane exposure rate, E_∞ , has been evaluated recently by Clarke⁷ in his review of the scattering near the interface. The various calculations and experiments seem to agree to within a few percent of the total value. Values of 482 mR/hr and 113.6 mR/hr are taken for ⁶⁰Co and ¹³⁷Cs, respectively, when the isotope is distributed to a source density of 1 mCi/sq ft. Source activities assume an exposure rate of 1.305 R/hr and of 0.32 R/hr at a distance of 1 m from a 1-Ci source of ⁶⁰Co or ¹³⁷Cs, respectively.

To measure a protection factor accurately, we would have to create a radiation field on the roof and on the ground surrounding the structure out to an infinite distance. Since this is impractical, simulation of fallout radiation in these experiments was limited to the immediate vicinity of the structure where the results were most helpful in determining the protection factors. The contribution from areas not simulated was analytically estimated by using experimental data as guidelines (Appendix F).

When we determined the value of E_i in Eq. 3.1, it was convenient to consider its total value to be made up of several parts:

$$E_i = R + G_1 + G_2 \dots \quad (3.2)$$

where R is the exposure rate from simulated contamination on the roof and the other terms represent exposure rates from various portions of the ground surrounding the structure.

3.2 DATA-REDUCTION AND -HANDLING PROCEDURE

The raw data from each TLD was first corrected for calibration (Appendix G). Individual calibration correction factors were applied to each TLD to obtain an equivalent exposure. The

readings of the 10-mR ion chambers were corrected for temperature and pressure; no calibration correction was needed. If more than one detector was located at one point, the corrected readings were averaged. However, the data from the two types of detectors were kept separate (Appendix H).

It was convenient to normalize all the experimental data from a particular test to a standard source density so that the results could be properly combined and evaluated. The data were normalized by multiplying the corrected readings (D_c , in milliroentgens) by the total area (A , in square feet) over which the tubing was distributed and dividing by the exposure time (T , in hours) and by source activity (S , in millicuries). Accordingly,

$$\text{Normalized data} = \frac{D_c \times A}{T \times S} \quad [(\text{mR/hr})/(\text{mCi/sq ft})] \quad (3.3)$$

The resulting exposure rate at a particular point is the same as it would be if the same area were contaminated to a source density of 1 mCi/sq ft.

In most cases the normalized-data value for a particular test was divided by the infinite-plane exposure rate ($E_\infty = 482 \text{ (mR/hr)/(mCi/sq ft)}$ for ^{60}Co) to obtain reduction factors. These reduction factors, therefore, represent fractions of the exposure rates in an unprotected area. For example, the reduction factor near the center of CP-40 from contamination on the roof is about 0.03. If the exposure rate in an unprotected area was 1000 R/hr, the exposure rate at that point inside CP-40 from contamination on the roof only would be 30 R/hr.

The data and resulting protection factors are discussed separately for each structure. Table 3.1 contains operational and technical information used to reduce the data. Protection factors were determined for ^{60}Co , which corresponds to fallout radiation of 1-hr-old fission products. Protection from older fission products and from cloud passage are discussed separately.

3.3 CP-40

Detector positions plotted on a floor plan of CP-40 are presented in Fig. 3.1. The letter W denotes the location where wall-thickness measurements were made (Appendix I). Table 3.2 contains the normalized data for determination of protection factors using ^{60}Co . The columns labeled "Reduction Factor" contain fractions of the infinite-plane exposure rate, D_∞ , for each area designated as previously mentioned. The protection factor is therefore the reciprocal of the total reduction factor. Reduction factors for the ground contribution were estimated by rough calculations and by examining experimental data from a similar building, CP-2. See Appendix F for details of radiation contributions from those areas not measured. The ^{60}Co -source activity was 10,570 mCi (S); the area covered by the tubing on the roof was 8000 sq ft (A); and the exposure time was 0.188 hr (T).

Measured values in Table 3.2 for the roof contribution are expected to be accurate to $\pm 10\%$. Appendix B discusses errors in detail. The rough calculations for the ground contribution are expected to be reliable to within a factor of 2. At positions away from doors, the roof and ground contributions are nearly equal. This results in protection factors reliable to within a PF value of about ± 5 .

Values of the PF's for ^{60}Co were plotted on a floor plan and are shown in Fig. 3.2. Approximate PF contours are also shown. Most of the inside area of CP-40 away from doors and the vehicle service area offers a protection factor of about 20 from early fallout radiation.

Table 3.3 contains the normalized data for the determination of protection factors using ^{137}Cs . Source activity was 3,780 mCi (S); the area covered was again 8000 sq ft (A); and the exposure time was 2.083 hr (T). The reduction factors for ^{137}Cs appear to be about half those for ^{60}Co for the roof exposure on CP-40. This difference is further discussed in Sec. 3.8.

3.4 CP-45

Detector positions are plotted on floor plans of CP-45 and presented in Figs. 3.3 and 3.4. Again the letter W indicates the location of wall-thickness measurements.

(Text continues on p. 45.)

TABLE 3.1—OPERATIONAL INFORMATION FOR THE CP MEASUREMENTS

Location	Date	Tubing length, ft	Source activity, Ci	Source type	Exposure time, hr	Pumping speed setting	Number of one-way passes	Start time	Stop time	Location and area exposed, sq ft	Remarks
CP-40	6-8-68	2600	10.6	⁶⁰ Co	0.188	950	1	10:55	11:06	Roof, 8000	
CP-40	6-8-68	2600	3.78	¹³⁷ Cs	2.083	400	5	11:35	13:40	Roof, 8000	
CP-45	6-22-68	3200	593	⁶⁰ Co	1.028	850	2	15:37	16:32	Roof, 9600	
						1000					
CP-45	6-22-68	3200	593	⁶⁰ Co	0.760	750	2	18:37	19:35	Roof reciprocal lower	5 TLD's were pumped through roof tubing
CP-45	6-23-68	4700	593	⁶⁰ Co	1.469	750	2	10:23	11:51	Ground reciprocal upper	5 TLD's were pumped through ground tubing
CP-45	6-23-68	4700	593	⁶⁰ Co	1.350	1000	2	14:23	15:45	East side ground, 24,000	
CP-1	6-29-68	4700	593	⁶⁰ Co	0.992	1000	2	15:48	16:48	Roof, 19,174	
CP-1	6-30-68	4000	593	⁶⁰ Co	0.899	1000	2	13:17	14:11	East side ground, 15,800	Changed speed at end of first pass
CP-1	7-6-68	3200	593	⁶⁰ Co	1.804	900	4	10:30	12:33	North side ground, 19,200	First cycle not enough; ran another cycle
CP-1	7-7-68	3400	593	⁶⁰ Co	0.600 1.930	1000	6	10:38	13:45	West side ground, 16,375	First cycle not enough; ran two more cycles after retrieving some detectors
CP-2	7-13-68	2100	105	⁶⁰ Co	0.475	700	2	10:11	10:40	Roof, 8496	
CP-2	7-13-68	3000	105	⁶⁰ Co	1.223	900	4	15:17	16:32	North side ground, 15,000	
CP-2	7-14-68	3000	293	¹³⁷ Cs	2.19	750	6	09:44	11:57	North side ground, 15,000

Fig. 3.1—Detector positions, CP-40.

TABLE 3.2—NORMALIZED DATA AND PROTECTION FACTORS FOR CP-40
WITH ^{60}Co SOURCE

Position number	Normalized roof data, (mR/hr)/(mCi/sq ft)	Reduction factor for roof	Reduction factor for ground	Total reduction factor	Protection factor
1	8.94	0.019	0.186	0.205	5
2	9.42	0.020	0.036	0.056	18
3	9.42	0.020	0.020	0.040	25
4	8.21	0.017	0.026	0.043	23
5	10.99	0.023	0.025	0.048	21
6	13.89	0.029	0.036	0.065	15
7	14.13	0.029	0.022	0.051	20
8	14.61	0.030	0.025	0.055	18
9	11.76	0.024	0.025	0.049	20
10	11.23	0.023	0.050	0.073	14
11	14.86	0.031	0.022	0.053	19
13	11.76	0.024	0.022	0.046	22
14	10.75	0.022	0.036	0.058	17
15	14.49	0.030	0.015	0.045	22
16	10.71	0.022	0.020	0.042	24
17	12.72	0.026	0.030	0.056	18
18	9.02	0.019	0.026	0.045	22
19	7.17	0.015	0.025	0.040	25
20	10.11	0.021	0.190	0.211	5
31	14.98	0.031	0.013	0.044	23
32	15.34	0.032	0.018	0.050	20
33	13.17	0.027	0.039	0.066	15
34	16.51	0.034	0.024	0.058	17
35	15.46	0.032	0.025	0.057	18
36	10.11	0.021	0.036	0.057	18
37	11.35	0.024	0.027	0.051	20
38	16.99	0.035	0.016	0.051	20
39	15.90	0.033	0.024	0.057	18
40	9.74	0.020	0.023	0.043	23
41	15.46	0.032	0.025	0.057	18
42	11.88	0.025	0.015	0.040	25
43	13.17	0.027	0.013	0.040	25
45	15.46	0.032	0.027	0.059	17
46	15.78	0.033	0.077	0.110	9
47	16.14	0.033	0.077	0.110	9
48	13.08	0.027	0.077	0.100	10
49	9.22	0.019	0.040	0.059	17
50	8.21	0.017	0.035	0.052	19
51	10.99	0.023	0.18	0.203	5
52	14.61	0.030	0.18	0.210	5
53	14.98	0.031	0.030	0.061	16
54	14.49	0.030	0.025	0.055	18
55	10.99	0.023	0.036	0.059	17
56	11.15	0.023	0.038	0.061	16
57	10.87	0.023	0.190	0.210	5
58	13.89	0.029	0.022	0.051	20
59	8.21	0.017	0.036	0.053	19
60	13.53	0.028	0.022	0.050	20
61	11.76	0.024	0.025	0.049	20
62	6.60	0.014	0.025	0.039	26
63	4.51	0.009	0.026	0.035	29
64	13.53	0.028	0.020	0.048	21
65	14.86	0.031	0.018	0.049	20
66	13.29	0.028	0.020	0.048	21
68	14.01	0.029	0.017	0.046	22
69	13.08	0.027	0.025	0.051	20
70	14.37	0.030	0.015	0.045	22

Fig. 3.2—Protection-factor values and PF contours for ^{60}Co (CP-40).

TABLE 3.3—NORMALIZED DATA FOR ROOF EXPOSURE AT CP-40
WITH ^{137}Cs SOURCE

Position number	Normalized roof data, (mR/hr)/(mCi/sq ft)	Reduction factor for roof	Position number	Normalized roof data, (mR/hr)/(mCi/sq ft)	Reduction factor for roof
1	1.14	0.010	41	2.44	0.022
2	1.17	0.010	42	1.41	0.012
3	1.63	0.014	43	1.58	0.014
4	1.07	0.009	45	1.94	0.017
5	1.38	0.012	46	2.09	0.018
6	1.78	0.016	47	2.83	0.025
7	1.88	0.017	48	2.10	0.019
8	1.91	0.017	49	1.44	0.013
9	1.54	0.014	50	0.92	0.008
10	1.83	0.016	51	1.38	0.012
11	1.97	0.017	52	2.00	0.018
13	1.46	0.013	53	1.80	0.016
14	1.43	0.013	54	1.75	0.015
15	1.80	0.016	55	1.23	0.011
16	1.35	0.012	56	1.29	0.011
17	1.68	0.015	57	2.12	0.019
18	1.26	0.011	58	1.69	0.015
19	0.89	0.008	59	0.89	0.008
20	1.32	0.012	60	1.72	0.015
31	1.84	0.016	61	1.32	0.012
32	1.97	0.017	62	0.71	0.006
33	1.65	0.015	63	0.52	0.005
34	2.34	0.021	64	1.57	0.014
35	1.87	0.017	65	1.82	0.016
36	1.29	0.011	66	1.62	0.014
37	1.35	0.012	68	1.83	0.016
38	2.14	0.019	69	1.73	0.015
39	1.99	0.018	70	1.80	0.016
40	1.13	0.010

Fig. 3.3—Detector locations, CP-45 (lower level).

Fig. 3.4—Detector positions, CP-45 (upper level).

Table 3.4 contains the data from the measurements, estimated contributions from those areas not measured, and resulting protection factors. Both sets of data from the roof and ground exposures are given as reduction factors. The ^{60}Co source activity for the roof exposure was 593,000 mCi (S); the area covered was 9600 sq ft (A); and the exposure time was 1.028 hr (T). The ^{60}Co source activity for the ground exposure was again 593,000 mCi (S); the area was 24,000 sq ft (A); and the time was 1.35 hr (T). The corrected data from the ground exposure were multiplied by a factor of 1.19 to correct for anisotropy of the source (see Appendix B) before normalization and calculation of reduction factors. Some of the data points in Table 3.4 are given to several significant figures. This was only for convenience of analysis and should not imply that the data are accurate to that degree.

Data in the fourth column of Table 3.4 are estimates of the radiation contribution originating beyond the measurement area to the north, south, and east. These values were obtained by multiplying the values in the third column by 0.38 for data on the lower floor and by 1.00 for data on the upper floor. (See Appendix F for details.) The west contribution, the fifth column, was obtained by examining ground contributions into CP-2 at similar positions.

Values of the PF's for ^{60}Co were plotted on floor plans and shown in Figs. 3.5 and 3.6. Approximate PF contours are also shown. Values of the protection factors for ^{60}Co are expected to be reliable to within $\pm 25\%$. Values of PF's are generally between 100 and 500 on the lower floor and reach above 1000 in the west end of the building where the ground level is at first-floor level. Upper level PF's are around 70; this is much better than at CP-40. The difference is caused primarily by the extra thickness of roof cover, $7\frac{1}{2}$ in. at CP-45 as compared to 4 in. at CP-40.

3.5 CP-1

Floor plans showing detector positions for CP-1 are presented in Figs. 3.7 to 3.10. The floor plans for the old building of CP-1 and CP-1A are not necessarily correct. As-built drawings were not available; however, the detector position numbers shown in the plans are within 2 or 3 ft of where the actual detectors were placed. At any rate, errors in detector placement do not affect the resulting PF contours. Any changes in rooms have been made with lightweight partitions. Internal concrete walls have not been changed or added since the original construction.

Table 3.5 contains the data (in units of reduction factors), far-field contributions, and protection factors for all 214 locations in CP-1, CP-1A, and CP-1B. Source activities, exposure times, and areas covered for the four sets of measurements (all with the same ^{60}Co source) are as follows:

Tubing location	Source activity (S), mCi	Exposure time (T), hr	Area (A), sq ft
Roof	593,000	0.992	19,174
North side	593,000	1.804	19,200
East and south sides	593,000	0.899	15,800
West and south sides			
1	593,000	0.600	16,375
2	593,000	1.930	16,375

For the west and south ground test, after 0.600 hr of exposure, all 10-mR chambers and a few high-range ion chambers (200 mR) were retrieved to avoid overexposure. These dosimeters were located at positions 1 to 87, plus a few other selected locations.

The 10-mR ion chambers were used primarily in the basement of CP-1B for all runs. They were also distributed to a few other selected locations where minimum radiation levels were expected.

The tubing was distributed around the building in three separate configurations out to at least 60 ft from the walls. These measured contributions account for at least half of the total ground contribution. The contribution from those areas not measured (far-field) was estimated by multiplying the data by a constant factor (0.38 for lower floors and 1.00 for upper floors).

(Text continues on p. 60.)

TABLE 3.4—RADIATION CONTRIBUTIONS (REDUCTION FACTORS)
AND PROTECTION FACTORS FOR CP-45

Detector position	Roof contribution (measured)*	Ground† contribution (measured)*	Far-field‡ contribution north, east, and south* (estimated)	Ground contribution west* (estimated)	Total contributions*	Protection factor
1	2.4§	6.8	2.6	1.2	13.0	750
2	3.2§	98.8	38.1	0.6	140.6	70
3	3.4	293.9	111.9	0.2	409.4	25
4	3.9	75	28.6	0.2	107.7	90
5	3.3	65.5	25.0	0.2	94.0	100
6	2.4	98.8	38.1	0.2	39.5	70
7	3.0	69.0	26.2	0.2	98.4	100
8	3.5	35.7	13.1	0.2	52.5	200
9	4.1	46.4	17.9	0.2	68.6	150
10	4.3¶	102.3	39.3	0.2	146.1	70
11	3.4¶	6.2	2.4	1.2	13.2	750
12	3.2	6.7	2.5	0.6	13.0	750
13	5.0	16.7	6.3	0.2	28.2	350
14	4.9	25.0	9.5	0.2	39.6	250
15	4.3	28.6	10.8	0.2	43.9	225
16	3.4	47.6	17.9	0.2	69.1	150
17	5.0¶	16.7	6.3	0.2	28.2	350
18	5.2	13.1	5.0	0.2	23.5	425
19	3.4¶	2.3	0.9	1.2	7.7	1300
20	5.0¶	3.0	1.1	0.6	9.7	1000
21	5.2¶	4.0	1.5	0.6	11.4	900
22	5.5	16.7	6.3	0.2	28.7	350
23	7.0	9.0	3.5	0.2	19.7	500
24	7.0¶	10.6	4.0	0.2	21.9	450
25	3.9	25.0	9.5	0.2	38.6	250
26	3.4	48.8	19.0	0.2	71.5	140
27	3.5	22.6	8.6	0.2	34.9	275
28	6.6	8.4	3.2	0.2	18.5	550
29	6.6	4.2	1.5	0.2	12.6	900
30	6.5	13.1	5.0	0.2	24.8	400
31	2.8	1.7	0.6	0.6	5.7	1800
32	3.2	1.5	0.6	1.2	6.5	1500
33	2.3	1.9	0.7	1.2	6.1	1600
34	5.0¶	2.4	0.9	0.2	8.5	1200
35	6.6¶	4.9	1.9	0.2	13.6	750
36	5.5¶			0.2		
37	3.7	16.7	6.3	0.2	26.9	375
38	3.4	50.0	19.0	0.2	72.7	140
39	6.1	9.9	3.8	0.2	20.0	500
40	6.9	7.3	2.7	0.2	17.1	600
41		3.5	1.3	0.2		
42	3.7	2.5	1.0	1.2	8.3	1200
43	3.7	11.1	4.2	0.2	19.2	500
44	4.8	26.2	10.0	0.2	41.2	250
45	3.8	8.0	3.0	0.2	15.0	650
46	4.5	22.6	8.6	0.2	35.9	275
47	2.6	48.8	19.0	0.2	70.7	140
48	2.3	72.6	27.4	0.2	102.5	98
49	2.3	40.5	15.5	0.2	58.5	170
50	2.2	20.2	7.7	0.2	30.4	325

TABLE 3.4—(Continued)

Detector position	Roof contribution (measured)*	Ground† contribution (measured)*	Far-field‡ contribution north, east, and south* (estimated)	Ground contribution west* (estimated)	Total contributions*	Protection factor
51	2.4	15.5	5.8	0.2	23.9	400
52	2.8	108.3	41.7	0.2	153.0	63
53	2.6	6.9	2.6	0.2	12.4	800
54	2.0	1.0	0.4	1.2	4.6	2200
55	5.2	12.0	4.5	0.2	22.0	450
56	4.3	44.0	16.7	0.6	65.6	150
57	3.0	21.4	8.1	0.6	33.1	300
58	4.8	33.3	13.1	0.2	51.4	190
59	2.7	2.9	1.1	0.2	6.9	1450
60	66.0	13.1	13.1	119.0	211.2	47
61	97.0	14.3	14.3	59.5	185.1	54
62	110.0	20.2	20.2	59.5	210.0	48
63	110.0	23.8	23.8	35.7	193.3	52
64	106.0	22.6	22.6	3.6	154.8	65
65	64.0	42.8	42.8	2.4	152.1	66
66	66.0	27.4	27.4	2.4	123.1	81
67	89.0	10.7	10.7	3.6	114.0	88
68	108.0	6.0	6.0	11.9	131.8	76
69	114.0	3.8	3.8	130.9	252.5	40
70	74.0	3.2	3.2	1071.0	1151.4	9
71	94.0	1.9	1.9	35.7	133.5	75
72	117.0	3.5	3.5	23.8	147.7	68
73	126.0	4.5	4.5	4.2	139.2	72
74	106.0	6.2	6.2	3.6	121.9	82
75	61.0	25.0	25.0	2.4	113.4	88
76	125.0	4.0	4.0	11.9	145.0	69
77	117.0	3.3	3.3	23.8	147.5	68
78	81.0	2.0	2.0	29.8	114.8	87
79	74.0	1.8	1.8	119.0	196.6	51
80	59.0	3.0	3.0	29.8	94.7	105
81	93.0	4.3	4.3	23.8	125.4	80
82	128.0	3.8	3.8	11.9	147.5	68
83	113.0	8.7	8.7	3.0	133.3	75
84	61.0	30.9	30.9	2.4	125.3	80
85	70.0	45.2	45.2	3.0	163.4	61
86	89.0	10.4	10.4	3.0	112.7	89
87	113.0	6.1	6.1	14.3	139.4	72
88	106.0	3.1	3.1	119.0	231.2	43
89	114.0	16.7	16.7	59.5	206.8	48
90	65.0	5.7	5.7	119.0	195.4	51
91	76.0	16.7	16.7	95.2	204.5	49
92	85.0	38.1	38.1	119.0	280.2	36
93	83.0	13.1	13.1	41.7	150.8	66
94	72.0	21.4	21.4	59.5	174.3	57
95	120.0	4.0	4.0	35.7	163.8	61
96	85.0	3.6	3.6	595.0	687.1	15
97	62.0	55.9	55.9	59.5	233.4	43

*Multiply data by 10^{-4} .

†Corrected for source anisotropy, correction factor = 1.19.

‡Far-field estimation = $0.38 \times$ data for lower floor and $1.00 \times$ data for upper floor.

§From 10-mR chambers only. All other data points are from TLD's.

¶Estimated from symmetry.

Fig. 3.5—Protection factors and PF contours for CP-45 (lower level).

Fig. 3,6—Protection factors and PF contours for CP-45 (upper level).

(a)

(b)

Fig. 3.8—Detector positions, CP-1A. (a) Main floor. (b) Basement.

Fig. 3.9—Detector positions, CP-1B (mezzanine).

Fig. 3.10—Detector positions,
CP-1 and CP-1B (basement).

TABLE 3.5—RADIATION CONTRIBUTIONS (REDUCTION FACTORS) AND PROTECTION FACTORS
FOR CP-1, CP-1A, AND CP-1B

Position number	Roof contribution* (measured)	North-side ground contribution* (measured) †	North-side far-field* contribution (estimated) ‡	East- and south-side ground contribution* (measured) †	East- and south-side far-field* contribution (estimated) ‡	West- and south-side ground contribution* (measured) †	West- and south-side far-field* contribution (estimated) ‡	Total contribution*	Protection factor
CP-1B Mezzanine									
1	28.0	0.48	0.48	0	0	0.88	0.88	30.7	325
2	28.0	1.4	1.4	0	0	1.09	1.09	33.0	300
3	25.0	0.46	0.46	0	0	6.5	6.5	38.9	250
4	25.0	1.4	1.4	0	0	8.0	8.0	43.8	225
5	25.0	0.19	0.19	0	0	3.9	3.9	33.2	300
6	15.0	0.15	0.15	0	0	8.3	8.3	31.9	300
7	19.0	0.42	0.42	0	0	3.8	3.8	27.4	350
8	20.0	0.43	0.43	0	0	6.2	6.2	33.3	300
9	21.0	0.49	0.49	0	0	10.6	10.6	43.2	225
10	30.0	0.03	0.03	0	0	1.9	1.9	33.9	300
11	9.3	0	0	0	0	8.1	8.1	25.5	400
CP-1B Main Floor									
12	2.3	3.8	1.4	0	0	3.9	1.5	12.9	800
13	2.4	2.3	0.9	0	0	6.2	2.4	14.2	700
14	2.3	2.6	1.0	0	0	5.6	2.1	13.6	750
15	2.3	4.4	1.7	0	0	5.0	1.9	15.3	650
16	3.3	4.2	1.6	0	0	6.5	2.5	18.1	550
17	3.3	2.6	1.0	0	0	6.0	2.3	15.2	650
18	3.8	2.7	1.0	0	0	5.8	2.2	15.5	650
19	4.1	2.9	1.1	0	0	7.1	2.7	17.9	550
21	12.0	3.8	1.4	0	0	3.2	1.2	21.6	450
22	15.0	3.2	1.2	0	0	1.4	0.5	21.3	450
23	9.2	9.6	3.6	0	0	1.3	0.5	24.2	400
24	14.0	7.1	2.7	0	0	1.7	0.6	26.1	400
25	13.0	7.1	2.7	0	0	2.4	0.9	26.1	400
26	13.0	6.4	2.4	0	0	5.2	2.0	29.0	350
27	22.0	2.0	0.8	0	0	12.0	4.6	41.4	250
28	19.0	1.9	0.7	0	0	15.0	5.7	42.3	250
29	16.0	1.4	0.5	0	0	17.0	6.5	41.4	250
30	24.0	1.2	0.5	0	0	13.0	4.9	43.6	250
31	21.0	1.2	0.5	0	0				
32	19.0	1.2	0.5	0	0	38.0	14.0	72.7	140
33	27.0	1.2	0.5	0	0	18.0	6.8	53.5	200
34	22.0	1.1	0.4	0	0	26.0	9.9	59.4	170

35	12.0	4.9	1.9	0	0	5.2	2.0	29.9	350
36	15.0	4.9	1.9	0	0	5.6	2.1	29.5	350
37	17.0	3.8	1.4	0	0	11.5	4.4	38.1	250
38	14.0	1.8	0.7	0	0	36.0	14.0	66.5	150
39	21.0	2.3	0.9	0	0	37.0	14.0	75.2	125
40	18.0	0.9	0.3	0	0	76.0	29.0	124.0	80
41	17.0	1.3	0.5	0	0	107.0	41.0	167.0	60
42	16.0	1.4	0.5	0	0	619.0	235.0	872	11
43	21.0	6.0	3.0	0	0	86.0	33.0	149.0	70
44	20.0	0.7	0.3	0	0	17.0	6.5	44.5	225
45	14.0	3.3	1.3	0	0	20.0	7.6	46.2	225
46	19.0	2.5	1.0	0	0	32.0	12.0	66.5	150
47	5.6	0.7	0.3	0	0	11.5	4.4	22.5	150
48	14.0	0.3	0.1	0	0	30.0	11.0	55.4	175
49	13.0	0.5	0.2	0	0	19.0	7.2	39.9	250
50	2.2	1.0	0.4	0	0	18.0	6.8	28.4	350
51	2.7	2.3	0.9	0	0	6.0	2.3	14.2	700
52	1.5	0.2	0.1	0	0	10.6	4.0	16.4	600
53	12.0	1.3	0.5	0.3	0.1	3.5	1.3	19.0	550
54	0.47	0.05	0.02	0	0	10.6	4.0	15.2	650
88	25.0	13.0	5.0	0.7	0.3	488.0	185.0	717.0	14
89	16.0	46.0	17.0	0.5	0.2	109.0	41.0	230	40

CP-1B Basement

55	0.25	0.09	0.03	0	0	0.71	0.27	1.35	7000
56	0.33	3.9	1.5	0	0	0.13	0.05	5.91	1700
57	0.86	0.40	0.15	0	0	0.60	0.23	2.24	4500
58	0.29	1.9	0.72	0	0	0.62	0.24	3.77	2500
59	0.70	0.12	0.05	0	0	0.51	0.19	1.57	6000
60	2.0	0.02	0.01	0	0	0.62	0.24	2.89	3500
61	2.3	0.10	0.04	0	0	1.00	0.38	3.82	2500
62	3.0	0.12	0.05	0	0	1.15	0.44	4.76	2000
63	2.8	0.17	0.06	0	0	1.5	0.57	5.10	2000
64	2.2	0.21	0.08	0	0	0.80	0.30	3.59	3000
65	1.5	0.39	0.15	0	0	0.58	0.22	2.84	3500
66	0.32	0.38	0.14	0	0	0	0	0.84	12,000
67	0.42	0.45	0.17	0	0	0.13	0.05	1.22	8000
68	0.50	0.35	0.13	0	0	0	0	0.98	10,000
69	0.57	0.18	0.07	0	0	0	0	0.82	12,000
70	0.99	1.5	0.57	0	0	0	0	3.06	3000
71	1.5	4.4	1.67	0	0	0	0	7.57	1300
72	1.4			0	0	0.15	0.06		
73	0.89			0	0	0.14	0.05		
74	1.5	0.98	0.37	0	0	0.43	0.16	3.44	3000

Table continues on p. 56.

TABLE 3.5— (Continued)

Position number	Roof contribution* (measured)	North-side ground contribution* (measured) †	North-side far-field* contribution (estimated) ‡	East- and south-side ground contribution* (measured) †	East- and south-side far-field* contribution (estimated) ‡	West- and south-side ground contribution* (measured) †	West- and south-side far-field* contribution (estimated) ‡	Total contribution*	Protection factor
75	2.3	1.17	0.44	0	0	0.33	0.13	4.37	2500
76	2.2	1.8	0.68	0	0	0.31	0.12	5.11	2000
77	1.6	3.1	1.18	0	0	0.06	0.02	5.96	1700
78	1.7	21.0	8.0	0	0	0.06	0.02	30.8	325
79	2.2	6.5	2.5	0	0	0.19	0.07	11.5	850
80	2.0§	500.0	190.0	0	0	0.46	0.17	693.0	14
81	1.6	274.0	104.0	0	0	0.55	0.21	380.0	26
82	0.91	0.46	0.17	0	0	0.15§	0.06§	1.75	6000
83	0.51	0.39	0.15	0	0	0	0	1.05	10,000
84	1.3	50.0	19.0	0	0	0.04	0.02	70.4	140
85	1.5	4.8	1.8	0	0	0.19	0.07	8.36	1200
86	2.0§	1.3	0.49	0	0	0.40	0.15	4.34	2300
87	2.0	0.62	0.24	0	0	0.57	0.22	3.65	2700
CP-1 and CP-1A Main Floor									
90	190.0	28.0§	28.0	0.33	0.33	26.0	9.9	283.0	35
91	150.0	2.1	2.1	0.37	0.37	67.0	25.0	247.0	40
92	120.0	0.73	0.73	0.97	0.97	510.0	194.0	827.0	12
93	200.0	0.90	0.90	0.83	0.83	155.0	59.0	417.0	25
94	230.0	0.98	0.98	2.4	2.4	79.0	30.0	346.0	30
95	200.0	0.39	0.39	0.81	0.81	23.0	8.7	234.0	40
96	170.0	0.42	0.42	2.6	2.6	21.0	8.0	205.0	50
97	230.0	0.20	0.20	5.4	5.4	31.0	12.0	284.0	35
98	100.0	0.07	0.07	3.2	3.2	131.0	50.0	288.0	35
99	270.0	0.14	0.14	12.0	12.0	35.0	13.0	342.0	30
100	130.0	0	0	357.0	357.0	45.0	17.0	908.0	11
101	200.0	0	0	16.0	16.0	95.0	36.0	363.0	30
102	210.0	0	0	65.0	65.0	119.00	45.0	504.0	20
103	180.0	0	0	75.0	75.0	20.0§	7.6	358.0	30
104	190.0	0	0	55.0	55.0	9.6	3.6	313.0	30
105	190.0	0	0	118.0	118.0	1.9	0.7	429.0	25
106	75.0	0	0	250.0	250.0	11.0	4.2	590.0	17
107	180.0	0	0	96.0	96.0	1.2	0.5	374.0	25
108	240.0	0	0	24.0	24.0	1.9	0.7	291.0	35
109	170.0	0	0	80.0	80.0	1.1	0.4	332.0	30

110	230.0	0	0	17.0	17.0	1.4	0.5	266.0	40
111	260.0	0	0	81.0	81.0	3.7	1.4	427.0	25
112	230.0	0	0	17.0	17.0	6.2	2.4	273.0	35
113	210.0	0	0	13.0	13.0	7.0\$	2.7	246.0	40
114	230.0\$	0	0	4.3	4.3	8.5	3.2	250.0	40
115	230.0	0	0	4.3	4.3	17.0	6.5	262.0	40
116	220	0	0	4.3	4.3	40.0	15.0	284.0	35
117	220.0\$	0	0	5.7	5.7	10.0	3.8	245.0	40
118	240.0	0	0	6.7	6.7	5.1	1.9	260.0	40
119	180.0	0	0	40.0	40.0	1.2	0.5	262.0	40
120	220.0\$	0	0	15.0	15.0	2.0\$	0.8	253.0	40
121	220.0	0	0	6.2	6.2	3.3	1.3	237.0	40
122	230.0\$	0	0	1.7	1.7	5.5	2.1	241.0	40
123	250.0	0	0	4.5	4.5				
124	250.0\$	0	0	7.1	7.1	2.7	1.0	268.0	35
125	320.0	0	0	3.9	3.9	2.3	0.9	331.0	30
126	190.0	0	0	64.0	64.0	2.0	0.8	321.0	30
127	200.0	0	0	63.0	63.0	1.7	0.7	328.0	30
128	250.0\$	0.64	0.64	2.3	2.3	35.0	13.0	304.0	35
129	250.0\$	0.50\$	0.50	4.0	4.0	22.0\$	8.4	289.0	35
130	250.0\$	0.41	0.41	4.4	4.4	17.0	6.5	283.0	35
131	270.0	0.58	0.58	5.8	5.8	12.0	4.6	299.0	35
132	320.0	0.95	0.95	6.5	6.5	6.0	2.3	343.0	30
133	250.0\$	0.44	0.44	4.0\$	4.0	8.9	3.4	271.0	35
134	250.0\$	0.67	0.67	2.6	2.6	14.0	5.3	276.0	35
135	180.0	1.9	1.9	0.92	0.92	15.0	5.7	206.0	50
136	180.0\$	0.74	0.74	2.4	2.4	10.0	3.8	200.0	50
137	160.0	2.0\$	2.0	2.4	2.4	1.9	0.7	171.0	60
138	200.0\$	2.3	2.3	4.9	4.9	0.92	0.4	216.0	45
139	190.0\$	1.9	1.9	6.4	6.4	0	0	207.0	50
140	88.0	2.5	2.5	52.0	52.0	0	0	197.0	50
141	130.0	6.5\$	6.5	36.0	36.0	0	0	215.0	45
142	130.0\$	20.0	20.0	20.0	20.0	0	0	210.0	50
143	110.0	150.0	150.0	40.0	40.0	0	0	490.0	20
144	160.0	29.0	29.0	8.8	8.8	0	0	236.0	40
145	160.0	20.0\$	20.0	20.0\$	20.0	0	0	240.0	40
146	160.0	6.5	6.5	18.0	18.0	0	0	209.0	50
147	120.0	2.1	2.1	52.0\$	52.0	0	0	228.0	45
148	440.0	32.0	32.0	0.3\$	0.3	0	0	505.0	20
149	190.0\$	2.7	2.7	1.4	1.4	0	0	198.0	50
150	140.0	130.0	130.0	0.27	0.27	0	0	401.0	25
151	140.0\$	45.0	45.0	0.3\$	0.3	0.5\$	0.2	231.0	43
152	250.0	3.7	3.7	3.0\$	3.0	0\$	0	263.0	40
153	230.0\$	4.8	4.8	2.1	2.1	0.5\$	0.2	245.0	40

Table continues on p. 58.

TABLE 3.5—(Continued)

Position number	Roof contribution* (measured)	North-side ground contribution* (measured)†	North-side far-field* contribution (estimated)‡	East- and south-side ground contribution* (measured)†	East- and south-side far-field* contribution (estimated)‡	West- and south-side ground contribution* (measured)†	West- and south-side far-field* contribution (estimated)‡	Total contribution*	Protection factor
154	160.0	9.0	9.0	0.3§	0.3	0.5§	0.2	179.0	55
155	230.0	3.5	3.5	0.33	0.33	0.5§	0.2	238.0	40
156	230.0	4.8	4.8	0.52	0.52	6.8	2.6	250.0	40
157	230.0§	13.0	13.0	0.43	0.43	4.3	1.6	263.0	40
158	230.0	13.0	13.0	0§	0	9.6	3.6	269.0	35
159	160.0	83.0	83.0	0.15	0.15	0.46	0.17	327.0	30
160	140.0	56.0	56.0	0.13	0.13	0.54	0.21	253.0	40
161	190.0	31.0	31.0	0.26	0.26	2.0§	0.76	255.0	40
162	170.0	42.0	42.0	0§	0	1.3	0.49	256.0	40
CP-1 and CP-1A Basement									
163	52.0	0.86	0.33	0.17	0.06				
164	8.7	0.18	0.07	0.35	0.13	2.3	0.87	12.6	800
165	12.0	0.05	0.02	0.12	0.05	2.1	0.80	15.1	650
166	15.0	0.07	0.03	0.29	0.11	3.6	1.4	20.5	500
167	15.0	0.12	0.05	0.39	0.15	1.5	0.57	17.8	550
168	17.0	0.60	0.23	0.64	0.24	0.21	0.08	19.0	550
169	16.0	0.06§	0.02	0.21	0.08	4.0§	1.5	21.9	450
170	13.0	0.06§	0.02	0.18	0.07	4.0§	1.5	18.8	550
173	30.0	0.96	0.36	0.42	0.16	0	0	31.9	300
174	26.0	1.3	0.49	0.63	0.24	0.02	0	28.7	350
175	22.0	0.77	0.29	0.03	0.01	0§	0	23.1	450
176	24.0	1.0	0.38	0.05	0.02	0§	0	25.5	400
177	29.0	1.4	0.53	0.07	0.03	0§	0	31.0	300
178	27.0	5.5	2.09	0.69	0.26	0§	0	35.5	300
179	26.0	11.0	4.2	0.39	0.15	0§	0	41.7	250
180	21.0	1.3	0.49	0.95	0.36	0.1	0	24.1	400
181	22.0§	1.2§	0.46	0.90	0.34	0.01§	0	24.9	400
182	24.0	4.0	1.5	0.33	0.13	0§	0	30.0	350
183	22.0	4.2§	1.6	1.03	0.38	0§	0	29.2	350
184	24.0	1.1	0.42	1.7	0.65	0§	0	27.9	350

185	30.0	1.0	0.38	25.0	9.5	0\$	0	65.9	150
186	23.0	0.83	0.32	8.8	3.3	0\$	0	36.3	300
187	27.0	1.2	0.46	3.8	1.4	0\$	0	33.9	300
188	23.0	4.8	1.8	0.51	0.19	0\$	0	30.3	350
189	24.0	10.0	3.8	0.44	0.17	0\$	0	38.4	250
190	15.0	9.9	3.8	2.0\$	0.76	0\$	0	31.5	300
191	21.0	1.4	0.53	2.9	1.1	0\$	0	26.9	350
192	26.0	5.0	1.9	0.64	0.24	0\$	0	33.8	300
193	25.0	0.18	0.07	155.0	59.0	0\$	0	239.0	40
194	26.0	0.49	0.19	458.0	174.0	0\$	0	659.0	15
195	26.0	0.14	0.05	118.0	45.0	0\$	0	189.0	50
196	22.0	0.20	0.08	88.0	33.0	0\$	0	143.0	70
197	29.0	0.11	0.04	12.0	4.6	0.30\$	0.11	46.2	200
198	20.0	0.07	0.03	1.5	0.57	0.57	0.22	23.0	450
199	19.0	0.13	0.05	1.7	0.65	0.21	0.08	21.8	450
200	25.0	0.12	0.05	1.1	0.42	0.40\$	0.15	27.2	350
201	32.0	0.12	0.05	9.0	3.4	0.30\$	0.11	45.0	200
202	40.0	0.14	0.05	33.0	13.0	0\$	~ 0	86.2	125
203	30.0	0.26	0.10	44.0	17.0	0\$	~ 0	91.4	100
204	22.0	0.18	0.07	24.0	9.1	0.30\$	0.11\$	55.8	175
205	21.0	0.13	0.05	0.73	0.28	0.06	0.02	22.3	450
206	31.0	0.10	0.04	25.0	9.5	0\$	0	65.6	150
207	30.0	0.11	0.04	2.1	0.80	0.40	0.15	33.6	300
208	47.0	24.0	9.1	6.8	2.6	0\$	0	89.5	100
209	19.0	2.3	0.87	179.0	68.0	0\$	0	269.0	35
210	21.0	2.9	1.1	62.0	24.0	0\$	0	111.0	90
211	17.0	40.0	15.0	25.0	9.5	0\$	0	106.5	95
212	19.0	24.0	9.1	20.0	7.6	0\$	0	79.7	125
213	15.0	6.4	2.4	64.0	21.0	0\$	0	111.8	90
214	16.0					1.7	0.65		

* Multiply data by 10^{-4} .

† Corrected for source anisotropy and tubing spacing, CF = 1.19.

‡ Far-field estimation = $1.00 \times$ data for locations in mezzanine from all ground exposures; $1.00 \times$ data for locations in main floor of CP-1 and CP-1A from north and east ground exposures; and $0.38 \times$ data for all other locations for all ground exposures.

§ Estimated from other data points.

A few PF values for ^{60}Co plotted on floor plans are shown in Figs. 3.11 and 3.12 along with approximate PF contours. As seen in Table 3.5, protection-factor values on the mezzanine of CP-1B range from 225 to 400. Generally, the PF's varied from 30 to 50 throughout the main floor of CP-1; these were a little higher than the PF's at CP-40. In the basement of CP-1, the PF's ranged from 250 outside the mechanical equipment rooms up to around 500 in the west end where the ground level was at basement ceiling level. These PF's were considerably less than those at similar positions in CP-45. Both structures have 8-in. concrete outside walls; but CP-45 has a 7½-in. floor whereas CP-1 has only a 4-in. floor. From contamination on the ground, radiation must scatter in through the outside wall and then penetrate down through the first floor to reach those detectors near the southwest corner of the CP-1 basement.

The PF contours range up to 600 in the main floor of CP-1B. The influence of the door in the center of the west wall is obvious in Fig. 3.11. The wall is 16 in. of concrete. If a baffle wall were constructed to reduce the radiation streaming through this entranceway, the PF's would increase from the present 100 to 250 to around 300 throughout the Test Manager's Operations Room. Protection factors around 600 exist in the Operations Coordination Center.

The two entrance doors in the north end of the basement of CP-1B strongly influence the PF contours, as seen in Fig. 3.12. The PF's are around 2000 in the men's dormitory and range from 300 to 10,000 in the briefing room. Again, if a baffle wall were constructed at the outside entrance, the PF's throughout the briefing room would probably be above 3000. However, it is difficult to envision an instance where a PF greater than 300 is needed. On the other hand, a net gain of a factor of 10 (300 to 3000) could be accomplished with a small effort. Sandbags or concrete blocks, to be moved into the doorways, could be considered. If these were used, blocking up the outside entrance would be the most effective. However, that location would be the most hazardous to work in if protection in the briefing room required a PF greater than 300. Therefore it is recommended that sandbags or concrete blocks be provided to block the north entrance to the briefing room.

An anomaly seems to exist for the radiation contribution to position 59, the small dormitory in the basement of CP-1B. A PF of 6000 was noted there, but a similar position, 58, showed a PF of 2500. An examination of the individual contributions to these two positions, as shown in Table 3.5, indicates that the north ground contribution is responsible for the difference. Radiation from the north comes through the entrance door and through the entire length of the basement to the south side, contributing 10 times more exposure to position 58 than to 59.

As shown in Fig. 3.7, a tissue-equivalent phantom was placed in a chair between positions 13 and 14. Depth-dose measurements were made within this phantom. In addition, the Operations Coordination Center (OCC) man on duty was fully instrumented. The comparison of these sets of data with those from unperturbed dosimeters is discussed in Appendix E.

3.6 CP-2

Detector positions plotted on floor plans of CP-2 are presented in Fig. 3.13. The position marked "A" was on the midpoint of the north wall, outside, and 3 ft above the tubing. The purpose of detectors at this location was to determine the correction factor (to apply to ground measurements) to correct for the nonisotropic output of the radioactive source and possible errors due to tubing spacing. These corrections are discussed in Appendix B.

Table 3.6 contains measured radiation contributions in units of reduction factors from a roof source and from a limited ground source on the north and east sides of CP-2, estimated far-field contributions from the north and east sides of the building, and estimated ground contribution from the west and south sides. Summation of these contributions and the protection factors for ^{60}Co are also given.

Only two source geometries (roof and ground on two sides) were measured on this structure for the following reasons: (1) The roof was thin (4 in. of concrete) compared to the walls (8 in. of concrete). The results of the two sets of measurements, therefore, contribute much more than half of the total contribution to most points on the main floor. (2) Materials and supplies stored on the south side of the building made tubing placement on this side operationally impractical. (3) Protection factors in the partial basement depend almost completely on the roof

(Text continues on p. 66.)

Fig. 3.11—Protection factors and PF contours for CP-1 and CP-1B (main floor).

Fig. 3.12—Protection factors and PF contours for CP-1 (basement).

Fig. 3.13—Detector positions, CP-2.

TABLE 3.6—RADIATION CONTRIBUTIONS (REDUCTION FACTORS)
AND PROTECTION FACTORS FOR CP-2 FROM ^{60}Co SOURCE

Detector position	Roof contribution (measured)*	North and east contribution† (measured)*	North and east far-out contribution‡ (estimated)*	West and south ground contribution§ (estimated)*	Total contribution*	Protection factor
1	112.0	155.0	59.0	180.0	506.0	20
2	238.0	167.0	63.0	166.0	634.0	16
3	161.0	821.0	312.0	11.0	1305.0	8
4	217.0	131.0	50.0	166.0	564.0	18
5	138.0	30.0	11.0	276.0	455.0	22
6	176.0	9.5	3.6	69.0	258.0	39
7	171.0	10.4	4.0	207.0	392.0	26
8	143.0	3.5¶	1.3	345.0	493.0	20
9	107.0	1.0¶	0.38	1000.0	1108.0	9
10	222.0	9.0¶	3.4	76.0	310.0	32
11	190.0	2.7¶	1.0	138.0	332.0	30
12	128.0	0.67¶	0.25	257.0	386.0	26
13	187.0	0.89¶	0.34	414.0	603.0	17
14	113.0	2.4¶	0.91	700.0	816.0	12
15	118.0	4.6¶	1.7	235.0	359.0	28
16	109.0	2.4¶	0.91	213.0	325.0	31
17	140.0	7.5¶	2.9	150.0	300.0	33
18	170.0	1.8¶	0.68	197.0	369.0	27
19	186.0	4.4¶	1.7	123.0	315.0	32
20	172.0	24.0	9.1	26.0	231.0	43
21	173.0	57.0	22.0	16.0	268.0	37
22	182.0	179.0	68.0	4.9	434.0	23
23	251.0	111.0	42.0	4.9	409.0	24
24	296.0	38.0	14.0	10.0	358.0	28
25	284.0	37.0	14.0	5.2	340.0	29
26	314.0	99.0	38.0	5.0	456.0	22
27	264.0	88.0	33.0	5.0	390.0	26
28	167.0	143.0	54.0	4.9	369.0	27
29	205.0	15.0	5.7	33.0	259.0	39
30	178.0	5.1	1.9	41.0	226.0	44
31	255.0	63.0	24.0	6.6	349.0	29
32	214.0	29.0	11.0	13.0	267.0	37
33	188.0	6.3	2.4	115.0	312.0	32
34	152.0	7.9¶	3.0	230.0	393.0	25
35	92.0	4.8¶	1.8	1132.0	1230.0	8
36	172.0	3.0¶	1.1	300.0	476.0	21
37	177.0	1.3¶	0.49	250.0	429.0	23
38	221.0	20.0	7.6			
39	199.0	36.0	14.0	33.0	282.0	35
41	125.0	3.0	1.1	40.0	169.0	59
42	166.0	71.0	27.0	213.0	477.0	21
43	229.0	96.0	36.0	50.0	411.0	24

TABLE 3.6-- (Continued)

Detector position	Roof contribution (measured)*	North and east contribution† (measured)*	North and east far-out contribution‡ (estimated)*	West and south ground contribution§ (estimated)*	Total contribution*	Protection factor
44	248.0	23.0¶	8.7	153.0	433.0	23
45	250.0	29.0	11.0	79.0	369.0	27
46	193.0	38.0	14.0	33.0	278.0	36
47	205.0	226.0	86.0	14.0	531.0	19
48	267.0	58.0	22.0	14.0	361.0	28
49	264.0	86.0	33.0	4.9	388.0	26
50	107.0	111.0	42.0	3.3	263.0	38
51	330.0	89.0	34.0	8.4	461.0	22
52	222.0	583.0	222.0	4.9	1032.0	10
53	184.0	785.0	298.0	4.9	1272.0	8
54	203.0	12.0¶	4.6	16.0	236.0	42
55	188.0	2.5¶	0.95	250.0	441.0	23
56	288.0	46.0	17.0	5.2	356.0	28
57	236.0	93.0	35.0	5.0	369.0	27
58	323.0	238.0	90.0	5.0	656.0	15
60	27.0¶	10.7¶	4.1	2.0	43.8	250
61	33.0¶	12.0¶	4.6	2.0	51.6	200
62	25.0¶	2.5¶	0.95	2.0	30.5	350
63	19.0¶	0.35¶	0.13	2.0	21.5	450
64	7.7¶	4.5¶	1.7	2.0	15.9	650
65	14.0¶	4.3¶	1.6	2.0	21.9	450
66	13.0¶	7.5¶	2.9	2.0	25.4	400
67	26.0¶	18.0	6.8	2.0	52.8	200
68	27.0¶	38.0	14.0	2.0	81.0	125
69	24.0¶	73.0	28.0	2.0	127.0	75
70	30.0¶	405.0	154.0	2.0	591.0	17
71	39.0¶	167.0	63.0	2.0	271.0	37
72	21.0¶	15.0	5.7	2.0	43.7	225
73	23.0¶	23.0	8.7	2.0	56.7	175
74	29.0¶	61.0	23.0	2.0	115.0	85
75	18.0¶	3.8	1.4	2.0	25.2	400
76	25.0¶	7.1	2.7	2.0	36.8	275
77	32.0¶	9.4	3.6	2.0	47.0	225
78	39.0¶	25.0	9.5	2.0	75.5	130
79	24.0¶	20.0	7.6	2.0	53.6	185
80	27.0¶	8.6	3.3	2.0	40.9	250
81	27.0¶	8.1	3.1	2.0	40.2	250

*Multiply data by 10^{-4} .

†Corrected for source anisotropy and tubing spacing (CF = 1.19).

‡Estimated by multiplying column 3 by 0.38.

§Estimated by examining north and east contributions at similar positions.

¶10-mR chambers only. All other data from TLD's.

contribution and the east ground contribution. On the other three sides, the ground level was above basement-ceiling level.

Table 3.7 contains data from the ground exposure on the north and east sides of CP-2 using ^{137}Cs . For informational purposes the data are listed as corrected data, normalized exposure rates, and reduction factors. These data do not include corrections for source anisotropy. Data from TLD's and 10-mR chambers are listed separately.

TABLE 3.7—NORMALIZED EXPOSURE RATE FROM GROUND
SOURCE ON NORTH AND EAST SIDES OF CP-2
FROM ^{137}Cs SOURCE

Detector position	Corrected data, mR	Normalized exposure rate, (mR/hr)/(mCi/sq ft)	Reduction factor*
TLD's			
1	29.8	0.697	6.1
2	64.6	1.51	13.0
3	230.0	5.38	47.0
4	38.4	0.898	7.9
5	7.18	0.168	1.5
6	2.30	0.0538	0.48
7	2.18	0.0510	0.45
11	0.89	0.0208	0.18
20	4.74	0.111	0.98
21	11.4	0.267	2.3
22	33.5	0.783	6.9
23	23.8	0.556	4.9
24	8.88	0.208	1.8
25	6.23	0.146	1.3
26	17.8	0.416	3.7
27	15.0	0.351	3.1
28	23.2	0.542	4.8
29	2.78	0.0650	0.57
30	1.05	0.0245	0.22
31	16.5	0.386	3.4
32	10.9	0.255	2.2
33	3.82	0.0893	0.78
38	3.26	0.0762	0.67
39	7.59	0.177	1.6
41	0.78	0.0182	0.16
42	16.9	0.395	3.5
43	22.6	0.528	4.6
45	7.0	0.164	1.4
46	8.34	0.195	1.7
47	91.4	2.14	19.0
48	18.4	0.430	3.8
49	18.2	0.426	3.7
50	19.7	0.461	4.1
51	25.9	0.606	5.3
52	185.0	4.33	38.0
53	248.0	5.79	51.0
56	9.53	0.223	2.0
57	15.9	0.372	3.3
58	68.3	1.60	14.0
67	4.34	0.101	0.89
68	15.0	0.351	3.1
69	17.5	0.409	3.6
70	137.0	3.20	28.0
71	61.5	1.44	13.0
72	4.41	0.103	0.91
73	5.81	0.136	1.2
74	19.3	0.451	4.0
75	1.06	0.0248	0.22

TABLE 3.7— (Continued)

Detector position	Corrected data, mR	Normalized exposure rate, (mR/hr)/(mCi/sq ft)	Reduction factor*
76	1.31	0.306	0.27
77	2.11	0.0493	0.43
78	8.14	0.190	1.7
79	6.43	0.150	1.3
80	2.26	0.0528	0.47
81	1.96	0.0458	0.40
A (outside)	1336.0	31.2	275.0
10-mR Chambers			
8	0.97	0.0227	0.20
9	0.51	0.0119	0.10
10	2.42	0.0566	0.50
12	0.41	0.0096	0.084
13	0.53	0.0124	0.11
14	1.64	0.0383	0.34
15	2.20	0.0514	0.45
16	1.61	0.0376	0.33
17	4.48	0.105	0.92
18	1.43	0.0334	0.29
19	1.07	0.0250	0.22
34	2.27	0.0531	0.47
35	1.43	0.0334	0.29
36	0.98	0.0229	0.20
37	0.59	0.0138	0.12
44	6.84	0.160	1.4
54	2.90	0.0678	0.60
55	0.96	0.0224	0.20
60	3.18	0.0743	0.65
61	3.53	0.0825	0.73
62	0.90	0.0210	0.18
63	0.29	0.0068	0.060
64	1.79	0.0419	0.37
65	1.55	0.0362	0.32
66	2.38	0.0556	0.49

*Multiply data by 10^{-3} .

Source activities, exposure times, and areas covered for the three sets of measurements on CP-2 are listed below:

Tubing location	Source activity (S), mCi	Exposure time (T), hr	Area (A), sq ft
Roof	105,000 ^{60}Co	0.475	8,496
North and east sides	105,000 ^{60}Co	1.223	15,000
North and east sides	293,000 ^{137}Cs	2.19	15,000

Selected PF values plotted on floor plans are presented in Fig. 3.14. Approximate PF contours were also drawn. Generally, the PF's range between 20 and 40 on the main floor; this is a little more than PF's for CP-40. Both structures have a 4-in. concrete roof and 8-in. concrete walls. However, there are large, heavy concrete roof beams on CP-2, which reduce the roof contribution to the main floor. Considerable amount of storage and mechanical equipment in the basement provided added shielding from radiation coming from the east side. Resulting PF values were above 100 except near the entrance.

The reduction factors from the north and east ground experiment for ^{137}Cs are slightly more than half those from ^{60}Co . The same thing was noted for roof sources at CP-40. This suggests

MAIN FLOOR

BASEMENT

Fig. 3.14—Protection factors and PF contours for CP-2.

that buildings like CP-2 and CP-40 offer nearly twice the protection from ^{137}Cs as from ^{60}Co . The application of this information to 1-day-old fission products is discussed in Sec. 3.8.

3.7 CP-14 AND CP-50

The Programmatic Building, CP-14, located near CP-1, is constructed of lightweight material. Its wood frame structure offers very little protection from fallout radiation. Calculations using the Engineering Manual prescribed by the Office of Civil Defense¹ (OCD) indicate a PF of about 2 in the center of the structure assuming an infinite smooth plane. If we consider terrain contours and ground roughness, the PF may reach 3. For planning purposes we recommend that PF values of 2 to 3 be assigned to CP-14 for both fallout radiation and cloud passage.

The Radiological Sciences Building, CP-50, is a one-story structure, 81 by 121 ft, having 8-in. concrete walls and a $2\frac{1}{2}$ -in. concrete roof. The mass thickness of the roof is assumed to be 40 lb/sq ft and of the walls, 110 lb/sq ft. Using the Engineering Manual, we calculated the roof contribution to be about 0.10 and the ground contribution, about 0.02. This gives a PF of 8 in the center of the structure. Because of the thin roof, the roof contribution dominates the protection-factor value. For this building, then, PF values range between 2 and 5 near outside openings and between 5 and 10 throughout the main part of the building. Protection from cloud passage would be expected to be about the same.

3.8 ^{137}Cs MEASUREMENTS AND APPLICATION TO FALLOUT

One of the objectives of this experiment was to obtain comparative measurements from both ^{137}Cs and ^{60}Co for two simulated area source geometries, a roof source and a ground source. Other objectives in using the ^{137}Cs source were to obtain data to use as guidelines for predicting protection factors from 1-day-old fallout and for estimating protection from cloud passage.

An examination of the reduction factors at selected locations from both ^{137}Cs and ^{60}Co for the roof source at CP-40 shows a constant difference. The results from ^{137}Cs are an average of 44% lower than results from ^{60}Co . This is consistent for all detector locations.

If we assume a concrete density of 171 lb/cu ft (Appendix I), the 4-in. roof presents a mass thickness of 57 lb/sq ft. If we estimate that the built-up roof, the air-conditioning system, and the internal walls contribute another 23 lb/sq ft, the roof offers an effective mass thickness of about 80 lb/sq ft. Theoretical calculation for 80 lb/sq ft (a large roof) with ^{60}Co (Fig. B-43, Ref. 8) gives a roof reduction factor of 0.0295. The same calculations for ^{137}Cs (Fig. B-44, Ref. 8) yields a reduction factor of 0.018, a 39% reduction. The agreement between calculations and experiment for the reduction-factor ratios for ^{60}Co to ^{137}Cs from a large roof source is, therefore, satisfactory.

An examination of the reduction factor at selected locations from both ^{137}Cs and ^{60}Co for the ground source at CP-2 also shows a constant difference at those locations where the readings were large enough to be accurate. The results from ^{137}Cs are an average of 53% lower than results for ^{60}Co . If we assume a wall mass thickness of 110 lb/sq ft, theoretical calculations of vertical wall attenuation for ^{60}Co give a reduction of 0.0627 from Fig. B-25, Ref. 8. The same calculations for ^{137}Cs yield an attenuation of 0.030, a 52% reduction from ^{60}Co . Again the agreement between calculations and experiment for ^{60}Co to ^{137}Cs reduction-factor ratios from a ground source is satisfactory.

Spencer⁸ calculated the penetration through concrete of fallout gamma rays at different times after fission as well as for ^{60}Co . The penetrations for ^{60}Co and for 1-hr fission products are nearly the same up to about 16 in. of concrete. Therefore for practical purposes protection factors determined for ^{60}Co can apply to 1-hr fission products. The calculations show that 1-day-old fission products, composed of lower-energy radiation, result in 1.5 times less penetration through 8-in. (110 lb/sq ft) concrete and about 2.5 times less penetration through 16-in. (207 lb/sq ft) concrete. Note that ^{137}Cs radiation results show still less penetration. Ratios of experimental penetrations from ^{60}Co and ^{137}Cs agreed with similar calculations;

therefore we can confidently use Spencer's calculations to predict protection from 1-day-old fission products.

Considering the mass thickness of the walls and roofs of the structures tested, to obtain protection factors from 1-day-old fission products, we multiply the PF values on the contours by a factor of 2.5 for all of CP-1B, a factor of 2.0 for the basement of CP-45, and a factor of 1.5 for all other buildings and locations.

3.9 PROTECTION FROM CLOUD PASSAGE

It is feasible that the structures in the CP complex could be exposed to a radiological hazard from cloud passage in addition to (or instead of) deposited fallout. Estimates of protective qualities of the structures from cloud passage were made rather crudely. Nevertheless, the results may be useful as guidelines for emergency planning.

The cloud is assumed to be uniformly composed of radioactive, fractionated fission products, to be infinite in extent, and to exist only outside the structures. The geometry of this situation is such that the directionality of the radiation arriving at a point 3 ft above the ground outside would be uniform over all polar angles above the horizon. This is in contrast to the highly directional radiation from the horizontal for a uniform plane source situation. This results in a domination of radiation coming through the roof (except on lower floors near doorways) for the cloud passage case. As an example, let us take a point 3 ft above the floor in the center of CP-40 and assume that the walls and roof are of zero mass thickness. In a fallout situation 50% of the radiation would come through the roof and 50% would come through the walls. In a cloud passage, however, about 80% would come through the roof and only 20% through the walls.

The spectrum of partially fractionated fission products that could be representative of those causing a radioactive hazard during cloud passage is somewhat lower in energy than standard fission products. The EG&G Aerial Radiological Measuring Surveys (ARMS) sampled the cloud from PIKE 3.55 hr after the event. The dominating isotopes present appeared to be those of iodine and a few noble gases; the effective energy spectrum (for penetrating purposes) corresponded somewhat to that of ^{137}Cs .

Using the ^{137}Cs measurements as guidelines and considering the dominance of the roof contribution for cloud passage, we estimated the protection factors for CP-40 to range from 20 to 40 away from doors and windows, or to be about a factor of 1.5 more than those from ^{60}Co in Fig. 3.2. In positions away from doors and windows in the basement of CP-45, the PF's would probably range from 70 to 120.

Because of the massiveness of construction of the new addition of CP-1 (CP-1B), the PF values for cloud passage are estimated to be about a factor of 3 higher than those derived from ^{60}Co measurements throughout the new addition and away from entrances. Upstairs in CP-1 the PF's for cloud passage are expected to be about 1.5 times those from ^{60}Co and downstairs, about double. In CP-2 the PF's are estimated to be about 1.5 times those from ^{60}Co .

A sparse amount of experimental data⁹ on protection from cloud passage is available. On Jan. 18, 1968, an effluent release occurred at NTS, and the radioactive cloud passed directly over the Nuclear Rocket Development Station. Pan American Health and Safety personnel obtained a few radiation measurements both inside and outside the buildings during cloud passage. One building of interest was the Administration and Engineering Building. Many measurements were made throughout this building while measurements were being taken 3 ft above the center of the helicopter pad. Protection factors varied from 2 to 3 in the penthouse and from 4.5 to 23 on the first and second floors.

Calculations using the method presented in this section show protection from cloud passage in the center of the penthouse to be about 3; at positions near windows, 2 to 3; at locations on the second floor (away from windows), 4 to 6; and at locations downstairs (away from windows), 10 to 20. The agreement of measurements and calculations for this building is satisfactory.

The calculation of protection from cloud passage assumes that all contaminants are outside. Ingress of radioactivity and consequent inhalation hazards were not considered. This is beyond

the scope of this report since it would require a detailed analysis of the filtering and air-conditioning system and air-flow rates.

It is recommended, however, that all air-conditioning systems be shut down during cloud passage.

Chapter 4

SUMMARY AND DISCUSSION

Six key buildings located in the CP complex of the NTS were evaluated as to their fallout-protection potential. Experimental measurements were made on four of the buildings using fallout simulation techniques. Protection factors were calculated directly for the other two.

The Communications Building, CP-40, offers protection factors from 15 to 25 throughout the inside away from outside entrances. Values of protection factors for CP-45, the Light Laboratory, are generally between 100 and 500 on the lower floor and reach above 1000 in the west end of the building. Upper level PF's are around 70. In the Main Control Building, CP-1, the PF's vary from 30 to 50 upstairs and from 250 to 500 downstairs.

In the new addition of the main Control Building, CP-1B, the PF's range up to 600 on the main floor. However, radiation streaming in the doorway in the west wall reduces the PF values to 100 in the Test Manager's Operations Room. The PF's in the basement of CP-1B range from 300 to 10,000 in the briefing room. Again radiation streaming through the north entrance strongly influences the PF values.

For CP-2, the Rad-Safe Building, the PF's range between 20 and 40 on the main floor and are generally above 100 in the basement.

Calculations were made of the protection provided by CP-14, the Programmatic Building, and CP-50, the Radiological Sciences Building. Protection-factor values from 2 to 3 were assigned to CP-14 and values from 5 to 10 to CP-50.

These PF values are applicable to deposited 1-hr-old fission products. Two measurements were made using ^{137}Cs to allow guidelines for predicting protection from 1-day-old fission products and from cloud passage. To obtain PF values from 1-day-old fission products, multiply the PF values previously given by a factor of 2.5 for all of CP-1B, a factor of 2.0 for the basement of CP-45, and a factor of 1.5 for all other buildings and locations tested. For CP-14 and CP-50, the PF values would be about the same.

To obtain estimated PF values applicable to cloud passage, multiply the PF values previously given for 1-hr-fission products by a factor of 3.0 for all of CP-1B, a factor of 2.0 for the basements of CP-45 and CP-1, and a factor of 1.5 for all other buildings and locations tested. Again, for CP-14 and CP-50, the PF values would be about the same.

The PF values given for ^{60}Co are estimated to be reliable to within $\pm 25\%$ for CP-45, CP-1, CP-1B, and CP-2 and to within about $\pm 50\%$ for CP-40.

To obtain a net gain of a factor of 10 (300 to 3000) in PF value in the basement briefing room of CP-1B, we recommend provision of sandbags or concrete blocks to block up the north entrances.

It is also recommended that a baffle wall be constructed around the west entrance into the main floor of CP-1B if PF values of 300 (rather than the present values of 100 to 250) are desired throughout the Test Manager's Operation Room.

In addition to obtaining protection-factor values for the buildings of concern, valuable information was obtained for (1) determining the feasibility of using reciprocity for structure-shielding studies, (2) comparing data from ^{60}Co and ^{137}Cs for the same source and shield

geometry, (3) determining mass thicknesses of concrete walls by radiation measurements, (4) comparing results obtained from ion chambers and TLD's, and (5) comparing depth-dose distributions in a tissue-equivalent phantom with isolated dosimeter measurements.

The test objectives were met, and the tests were conducted safely with minimum inconvenience to personnel working in the buildings. The safety of personnel was the guiding criterion of the project.

Appendix A

RADIOLOGICAL SAFETY

The radiological safety of the operation was divided into two areas, the safety of those involved in the experiment and the safety of personnel working in the area but not involved in the experiment.

The safety of operational personnel directly associated with the experiment was the responsibility of EG&G through the Project Officer. As a licensed AEC group, EG&G was the custodian of the radioactive sources and was responsible for their proper use and storage.

Reynolds Electrical and Engineering Co., Inc. (REECo), Radiological Sciences Department (R/S), was responsible for the radiation safety of personnel not involved in the experiment. In general, this included placing restricted area and roadblock signs; issuing film badges, survey meters, and pocket chambers to appropriate personnel; and continuous checking of the test area for unauthorized personnel during an actual exposure.

A.1 SOURCE-HANDLING AND SAFETY PROCEDURES

The Mobile Radiological Measuring Unit (MRMU) was used in handling the radioactive sources. The MRMU is a hydraulic pumping system used to pump a radioactive source encapsulated in a stainless-steel container through a length of plastic tubing to simulate the desired source configuration. It consists of a hydraulic pumping unit, associated tubing, source-position indicators, remote-control console, multisource shield, radioactive sources, and interconnecting cables.

Radiation-safety features in operating the MRMU consisted of the following:

1. All motion of the radioactive source, including starting, stopping, and reversing, was controlled from a remote location to ensure minimum radiation exposure to operating personnel.
2. The position of the source in the tubing was known at all times by electronic means.
3. In case of power or pump failure, a hand pump located 100 ft away from the test area could have been used to pump the source back into its shield.
4. The system incorporated many safety features, such as radiation alarms, to ensure maximum safety and convenience of operation in case of component failure.

Health-physics regulations were strictly adhered to during operation of the MRMU system. These regulations consisted of the following:

1. All personnel connected with the MRMU were cognizant of health-physics aspects associated with the operation of the unit as well as existing rules and regulations governing radiation hazards. (*Code of Federal Regulations*, Title 10, U. S. Atomic Energy Commission, January 1962.)
2. Two low-range (0 to 200 mR) pocket dosimeters were worn at all times by all personnel working at or near the source vehicle.
3. NTS film badges were worn by operating personnel.
4. Adequate survey instruments were provided for use at and around the source vehicle.

5. One member of the MRMU team was a qualified health-physics technician who was responsible for the general health physics of the group.
6. Whenever a person approached the source vehicle for any reason, he had in his possession pocket dosimeters, a film badge, and a functioning survey meter. Upon arriving at the vehicle, he made certain that the gamma alarm was in operating condition.
7. As soon as the system was located at an experiment site, and while tubing was being connected for a "hot" run, the control-console operator was responsible for the following items:
 - a. Turning off all power at the console.
 - b. Removing the key from the console.
 - c. Keeping the key in his personal possession as long as anyone was near the source vehicle.
 - d. Keeping the radiation alarm monitor in the hydraulic trailer on.
8. Two persons were required to prepare for a hot run. One man acted as monitor only, while the other connected tubing to appropriate shield outlets. No other persons were permitted near the source vehicle while preparations were being made for a hot run.
9. Upon completion of tubing connections and approval from the AEC Operations Officer, the monitor stood by while the other team member opened appropriate valves to permit the run to be made.
10. The control-console operator and the health-physics monitor ensured that all personnel were in a safe area before the key was inserted into the key lock switch and the hot run was started.
11. Upon completion of the hot run, the control-console operator visually noted the survey-meter readings to make certain the source was in its shield.
12. When approaching the source vehicle immediately after a hot run, personnel:
 - a. Monitored their approach with appropriate instruments in their possession.
 - b. Consulted with the health-physics monitor who accompanied them.
 - c. Noted that the radiation alarm at the hydraulic trailer was not sounding and flashing an alarm.
13. One person, accompanied by the health-physics monitor, approached the source vehicle to close appropriate valves and disconnect tubing from the shield. At this time mechanical locks were inserted and the shield was padlocked. The AEC Operations Officer was informed of the safe condition of the source.
14. At the end of the day, padlocks on the source shield were rechecked to see that they were securely locked.

A.2 AREA CONTROL

In view of the source activities involved, it was necessary to maintain rigid access control at surrounding work areas during source exposure periods.

The REECO, R/S, was responsible for:

1. Ensuring that personnel exposure to ionizing radiation was maintained below maximum permissible levels.
2. Coordinating area evacuations through the AEC Operations Coordination Center (OCC).
3. Providing appropriate dosimetric devices for personnel involved.
4. Providing adequate portable radiation-detection equipment.
5. Providing and placing appropriate road barricades and radiation warning signs.
6. Providing adequate personnel to maintain continuous surveillance of "stay-in" stations and area access points.
7. Assisting EG&G personnel in placement and collection of technical equipment associated with the operation.

The EG&G program coordinator was responsible for ensuring radiological safety of their personnel during all periods of source exposure. The OCC was responsible for coordinating all area evacuation efforts and subsequently determining when it was safe to commence with source-exposure operations.

One hour before the time of anticipated source exposure, the R/S representative notified OCC to commence area evacuation. The OCC coordinated evacuation efforts with the Security Agency (WSI) and ensured that only the personnel discussed in the following paragraph remained within the area of concern. A 7.5-mR/hr line (area of concern) was calculated, referencing maximum planned source activity associated with each building exposure.

Those individuals considered essential in NTS operations, who had to man a location within the area of concern, were issued stay-in authorizations. A list of these individuals was provided to OCC prior to commencing the area sweep. The OCC subsequently provided a copy of this list to WSI, who commenced with the area sweep.

Radiological-safety barricades equipped with appropriate radiation warning signs were placed at all feasible access points immediately following area evacuation. These barricades were located at the 7.5 mR/hr line. After the area was evacuated and barricades were placed, approval to proceed with source-exposure operations was given to EG&G by OCC.

A 0- to 200-mR-range pencil dosimeter was issued to all stay-in and perimeter-access control personnel. Additionally, a check was made to ensure that these individuals were properly wearing a current-issue film badge. A qualified R/S monitor equipped with appropriate portable instruments was assigned with each stay-in individual to ensure that exposure rates did not exceed tolerable levels (approximately 50 mR/hr average).

The primary access points were manned by qualified R/S monitors at approximately the 7.5 mR/hr line. These monitors ensured that no entry was made into the area of concern. No emergency situation demanding entry into the area, which would have closed down the tests, arose.

A Net Number 3 simplex radio set was issued to the EG&G source operator and to the R/S monitors at each stay-in station and primary access point. These radios facilitated communications between all involved personnel. Liaison between EG&G, OCC, and R/S was maintained throughout each source-exposure period to ensure that maximum personnel safety precautions were effected.

Upon completion of the source exposure, the R/S representative entered the evacuated area and performed a radiation survey. When this survey confirmed that the source was properly secured in the appropriate shield, the R/S monitor informed OCC that the area could be returned to normal operations.

The operation was performed well within the safety criteria established for the tests. There were no emergency incidents. Radiation exposures to all personnel, including operating personnel, were well below maximum permissible levels.

Appendix B

DISCUSSION OF ERRORS

B.1 GENERAL

It is difficult to obtain protection factors with a high degree of accuracy (reliable to within a few percent) because of the complicated geometry and conglomerate shielding materials in a building, because of the inherent uncertainties in the calculational methodology, and because of the compromise necessary in attempting to simulate fallout conditions for experimental measurements. Obtaining high accuracy in protection factors is usually not justified, because of the unknown factors, such as radiation levels and nonuniform distribution of fallout. Estimates of PF values (reliable to within $\pm 50\%$, for example) can be useful, and relative, point-to-point protection values within a structure allow realistic planning in case of a radiologically hazardous condition.

Most of the PF values in this report are reliable to within $\pm 25\%$ for ^{60}Co , the results being applicable to 1-hr fission products. Some errors and corrections are discussed in this appendix. A more thorough discussion of errors from a similar experiment can be found in Ref. 3.

B.2 CORRECTION FOR SOURCE ANISOTROPY AND TUBING SPACING

As can be seen in Fig. B.1, the source output was not completely isotropic. The quantity of radiation emerging through the end of the source was only about half that through the sides.

The tubing was placed 5 ft apart for the ground measurements. The closer the tubing is placed together, the closer uniform contamination is simulated. A tubing separation of 5 ft was chosen to conserve tubing and operational time.

During measurements on the CP-2 structure, some TLD's were placed on the outside of the wall 3 ft above the ground and at the midpoint of the north wall, position A in Fig. 3.13. The detectors at this location could "see" all the tubing placed on the ground on the north side of the building. These measurements were made to determine the correction needed to account for source anisotropy and tubing separation.

In the sketch of Fig. B.2, the detectors were placed at the edge of a rectangular source 60 by 120 ft. The effective radius of an equivalent circular area for radiation contribution is 67.2 ft. The radiation contribution arriving at a point 3 ft above the center of a circular contaminated area of radius of 67.2 ft is $291 \text{ (mR/hr)/(mCi/sq ft)}$ for ^{60}Co . Half of this would then be $145.5 \text{ (mR/hr)/(mCi/sq ft)}$ or 0.303 of an infinite plane. The reduction factor measured was 0.255. Therefore a correction factor of 1.19 was applied to all ground-source data to correct for source anisotropy and tubing spacing. This assumed that all radiation exposure inside, due to the ground source, was relative to the amount of radiation impinging on the outside wall at a height of 3 ft. This assumption is valid for positions away from doorways and at positions where most of the radiation arriving has been scattered by the lower wall adjacent to the tubing. Most positions are in this category. At other locations the correction factor would vary from 1.00 to 1.19. However, the correction factor of 1.19 was applied to all data for convenience of data reduction.

Fig. B.1—Relative angular response for 593-Ci ^{60}Co source calibration (TLD's).

Fig. B.2—Sketch of conditions for determining corrections for source anisotropy and tubing spacing.

B.3 ERRORS IN THE BASIC DATA

In a similar experiment³ all known sources of error related to the reliability of the basic measurements were investigated. The magnitude of some errors was well known; others were given as the author's best judgment. Using this information and adding known errors specifically related to this experiment, we prepared a table of error estimates of several contributing factors. Roof contributions and ground contributions for all positions were grouped together for convenience. The estimates in Table B.1 are to be taken as approximate rather than precise values in evaluating the reliability of the data as a whole.

The combined error for the use of the 10-mR chambers show that the data are expected to be accurate to within a standard deviation of about $\pm 10\%$ and for the TLD's, to $\pm 23\%$. This means that the basic normalized data are reliable to that degree.

TABLE B.1—ERROR ESTIMATE IN PERCENT FOR THE BASIC DATA

Item	Error for ion chambers, %	Error for TLD's, %
Source calibrations	5.0	5.0
Source anisotropy (after corrections)	5.0	5.0
Tubing spacing (after corrections)	2.0	2.0
Contribution while source was traveling from its shield to the area of interest	0.5	0.5
Detector calibrations	3.2	3.2
Detector reproductivity	3.5	7.0
Detector orientation	5.0	0
Detector energy response	1.0	20.0
Air-density corrections	0.7	0
Combined error	±10	±23

The largest error for the TLD's is their energy response. A 20% error was assigned as an estimate to obtain a correct exposure. The large contribution of low-energy radiation is discussed in Appendix H. This component of low-energy photons is important in determining the exposure (ionization in air). Its importance in assessing the hazard (dose to tissue) is not as clear, however. Clifford¹⁰ studied the ratio between the absorbed dose and the exposure for several shielding conditions typical of radiation shelters. Low-energy photons and direction of penetrations could cause marked changes in this ratio when absorbed dose to the bone marrow or midline are considered. It is interesting to note that the average rad/roentgen for bone marrow in a phantom indicates about the same energy response as the TLD's (Fig. 1, Ref. 10). For these reasons the TLD results were not corrected for energy response.

B.4 ERRORS IN THE FINAL PROTECTION FACTORS

As is stated in Appendix F, the reliability of estimates of the radiation contribution from those areas not measured is probably within a factor of 2. Since the ratio of measured to estimated contribution varied from floor to floor and from structure to structure, the resulting accuracies of the PF values are different. Table B.2 gives the estimated accuracy of PF's at

TABLE B.2—ERROR ESTIMATES IN PF VALUES

Location	Estimated error, ±%
CP-40	
Center	30
Corner	60
Vehicle service	70
CP-45	
Lower level, center	25
Lower level, west side	35
Upper level, center	20
CP-1B	
Downstairs, center of briefing room	25
Downstairs, men's dormitory	20
Upstairs, OCC	25
Upstairs, conference room	25
CP-1	
Downstairs, hallway	20
Downstairs, dining room	20
Upstairs, center	20
CP-2	
Upstairs, center	25
Downstairs, center	25

a few locations, generally away from entrances. These apply to ^{60}Co PF's or 1-hr fission-product PF's.

The error values given in Table B.2 generally range from 20 to 30% for all the buildings where measurements were made. At positions near corners and outside entrances in CP-40 where no ground measurements were made, the uncertainties increase to above $\pm 50\%$.

Appendix C

ADDITIONAL PHOTOGRAPHS AND STRUCTURAL DESCRIPTIONS

To make calculations of protection factors with any degree of thoroughness, we need details of the structure and terrain features. Photographs showing some tubing distributions, terrain features, and outside structural components and a few sketches showing thicknesses of roofs, floors, and walls (Figs. C.1 to C.27) are given in this appendix. This information is presented here to give the reader an overview of the scope of the experiment. Detailed structural drawings, which are too voluminous to repeat in this report, can be obtained from the author upon request.

Fig. C.1—CP-40, view toward the east.

Fig. C.2—CP-40, view toward the northwest.

Fig. C.3—CP-40, view toward the south.

Fig. C.4—CP-40, view toward the north.

Fig. C.5—Tubing distribution on roof of CP-45.

Fig. C.6—Tubing distribution on roof of CP-45.

Fig. C.7—CP-45, view toward the south.

Fig. C.8—CP-45, view toward the north, showing partial tubing distribution.

Fig. C.9—CP-45, view toward the west, showing partial tubing distribution.

Fig. C.10—CP-45, view toward the north.

Fig. C.11—Tubing distribution on the roof of CP-1 and CP-1A.

Fig. C.12—Tubing distribution on the roof of CP-1 and CP-1B.

Fig. C.13—CP-1, view toward the west.

Fig. C.14—CP-1A, view toward the north.

Fig. C.15—Ground tubing distribution around CP-1, view toward the east.

Fig. C.16—Ground tubing distribution around CP-1, view toward the south.

Fig. C.17—Tubing distribution on the north side of CP-1B.

Fig. C.18—Tubing distribution on the west side of CP-1B.

Fig. C.19—Tubing distribution north of CP-1A, view toward the east.

Fig. C.20—Tubing distribution on the roof of CP-2.

Fig. C.21—Tubing distribution around CP-2, view toward the north.

Fig. C.22—Tubing distribution on east side of CP-2, view toward the south.

Fig. C.23—Structural sketch of CP-40.

Fig. C.25—Structural sketch of CP-1B.

Fig. C.26—Structural sketch of CP-1.

Fig. C.27—Structural sketch of CP-2.

Appendix D

RECIPROCITY EXPERIMENT

As a part of the experimental measurements on the CP buildings, the use of reciprocity in shielding experiments, as related to fallout-radiation protection, was investigated.

The structure used was the 80- by 120-ft two-story Light Laboratory (CP-45). The ground level on one side was at first-floor level and on the other three sides, at basement-floor level. Figure 2.13 is a photograph of the building, and Fig. D.1 is a structural sketch. All inside partitions were of lightweight material.

Fig. D.1—Structural sketch of CP-45 (end view).

Tubing was distributed on the roof to determine the roof exposure. The 593-Ci ^{60}Co source was pumped through the tubing, and the exposure was measured several places inside the structure. Five TLD's (EG&G Model TL-12—spiral element, vacuum-tube type), were wrapped in 0.016 in. of lead and placed at position 30 downstairs (Fig. D.1). Their average reading was 31.4 mR/hr. The source was then pumped into position 30 (long axis of source parallel with long axis of building) by using a short piece of tubing. When the source was in place, the short tubing was disconnected, and the same five TLD's were then pumped through the tubing on top of the roof. Their average reading was 28.3 mR/hr. The exposure received by the TLD's while the source was being inserted and removed from the tubing was negligible compared to that received while they were on the roof. The "train" of TLD's is shown in Fig. D.2. A dummy source capsule led the train to pull the TLD's through the tubing.

Next the tubing was distributed on the ground on three sides of the building extending out to 60 ft from its edge. Tubing distribution is shown in Figs. 2.13 and 2.14. The 593-Ci ^{60}Co source was pumped through the tubing, and exposures were measured at several points throughout the structure, including position 77 (Fig. D.1). The train of TLD's read an average of 3.48 mR/hr at position 77. The source and TLD's were reversed, and the TLD's read an average of 5.03 mR/hr. This does not include any correction for source anisotropy.

Corrections for nonisotropic output of the source were not necessary for the roof source. However, for the ground source some corrections were needed. The relative angular emission

Fig. D.2—Train of TLD's sent through tubing.

of the source as measured by TLD's is shown in Fig. 3.14. As mentioned in Appendix B, detector readings inside the structure should be multiplied by a correction factor of 1.19 to correct for source anisotropy for source distributions on the ground. The corrected exposure rate at position 77 would then be $3.48 \times 1.19 = 4.14$ mR/hr.

For the reciprocal measurements, when the source is inside the building, the correction for source anisotropy should correspond to the output of the source in the direction of the structure walls to the north, east, and south. The relative emission, direction, and fraction of parameter walls are as follows:

Angle, degrees	Relative emission	Fraction of parameter	Weighted output
65 to 70	0.80	0.0217	0.0174
70 to 75	0.75	0.0217	0.0163
75 to 80	0.70	0.0217	0.0152
80 to 85	0.65	0.0217	0.0141
85 to 90 (looking north)	0.58	0.0217	0.0126
90 to 95	0.58	0.0217	0.0126
95 to 100	0.65	0.0217	0.0141
100 to 105	0.70	0.0217	0.0152
105 to 110	0.75	0.0217	0.0163
110 to 115	0.80	0.0217	0.0217
115 to 120	0.85	0.0217	0.0184
120 to 130	0.90	0.0435	0.0392
130 to 140	0.98	0.0435	0.0426
140 to 220	1.00	0.3478	0.3478
220 to 230	0.98	0.0435	0.0426
230 to 240	0.90	0.0435	0.0392
240 to 245	0.85	0.0217	0.0184
245 to 250	0.80	0.0217	0.0174
250 to 255	0.75	0.0217	0.0163
255 to 260	0.70	0.0217	0.0152
260 to 265	0.65	0.0217	0.0141
265 to 270 (looking south)	0.58	0.0217	0.0126
270 to 275	0.58	0.0217	0.0126
275 to 280	0.65	0.0217	0.0141
280 to 285	0.70	0.0217	0.0152
285 to 290	0.75	0.0217	0.0163
290 to 295	0.80	0.0217	0.0174
		1.0000	0.8506

The last column is a weighted output obtained by multiplying the second column by the third column. The addition of this column indicates that the correction factor should be about 1.18. The corrected exposure rate for the TLD's pumped through the ground tubing, therefore, is 5.94 mR/hr.

Figure 2.4 shows the energy response of these types of TLD's surrounded by 0.0095 in. of tin and 0.025 in. of lead. (Standard 10-mR ion-chamber response is shown for comparison.) There was space enough for only 0.016 in. of lead shielding for the TLD's used in this experiment in order to allow the detectors to flow smoothly through the tubing. Energy response of these TLD's with only 0.016 in. of lead shielding is not known. It should be noted, however, that the results for this experiment were obtained with the same set of detectors, both for the reciprocity measurements and for the standard measurements.

For the roof source, interchanging the source and detector resulted in only 10% less exposure. This was less difference than expected considering the mass of material (15 in. of concrete in two layers) and the distance (21 ft) between source and detector.

For the ground source, however, putting the source inside and the detector outside resulted in an increase of about 45%. Many possible explanations may account for the difference. It was hypothesized that the shielding geometry of the test was such that nearly all the radiation received by the detector had been scattered by the upper, outside wall. The difference of the two

results, then, would be caused by the difference of the attenuation provided by the internal, upper walls. We assume that these internal walls contain about 20 lb/sq ft mass thickness between position 77 and the outside wall. With the source on the ground, the emerging radiation from the inside upper wall, toward position 77, is of low energy, such as 400 keV or less. Attenuation through 20 lb/sq ft would be about 0.50. With the source at position 77, the radiation (1.25 MeV) would be attenuated only about 0.75, allowing 50% more radiation to arrive at the detectors outside.

In summary, the use of reciprocity for a roof source resulted in 10% less exposure. From a ground source, where mostly multiple scattered radiation was detected, a 45% increase was noted after the source and the detector were reversed.

Appendix E

TISSUE-DEPTH-DOSE MEASUREMENTS

During measurements on the main control building, CP-1B, a tissue-equivalent man phantom made of a plexiglass container with $\frac{1}{4}$ -in. walls filled with tissue-equivalent fluid (fluid simulating tissue for radiation penetration) was placed in a chair in the OCC office. TLD's were positioned 1 in. apart along both the long and the short axes at a depth of about 9 in. from the top. Figure E.1 shows the location of the TLD's. Positions 1, 13, 14, and 23 were outside the plexiglass.

It was necessary that a man be located in the OCC office during the test to answer the telephone and radios. During the time the tests were being conducted, he was seated in a chair, positioned identically to that of the phantom, facing the conference room and located between positions 14 and 17. (See Figs. 3.7 and E.2.) The phantom was located between positions 13 and 14. TLD's were placed around the man's chest and waist for the measurements. Figure E.3 shows these locations.

The data, in units of dose-reduction factors, for both the phantom and man are presented in Tables E.1 and E.2. As mentioned in the text, the normalized data in units of milliroentgens per hour per millicurie per square foot were divided by $482 \text{ (mR/hr)/(mCi/sq ft)}$ (exposure rate 3 ft above an infinite smooth plane) to obtain exposure reduction factors. This was done in the main body of the report for convenience. Dose reduction factors in this appendix were obtained in like manner by assuming a dose rate in air of $482 \text{ (mrad/hr)/(mCi/sq ft)}$ for the infinite smooth plane.

Data from the individual runs plotted vs. depth in the phantom are shown in Fig. E.4 for data along the long axis and in Fig. E.5 for data along the short axis. Some of the data are rather poor (west and south ground exposure) because of the low doses received by the TLD's. The roof data are good.

The phantom was facing west. The depth-dose distributions along the short axis (Fig. E.6) for the west and south ground source demonstrate that most of the radiation came through the entrance door in the west wall.

Figure E.7 shows data vs. depth for the combined roof and ground sources. The dose reduction factors are about 5×10^{-4} in the center of the phantom, increasing to about 8×10^{-4} on either side, about 7×10^{-4} in front, and about 6×10^{-4} in back. The average of positions 1, 13, 14, and 23 shows a surface dose of 7.4×10^{-4} .

The average of positions 1, 3, 5, and 7 on the chest of the man for the combined data is 8.6×10^{-4} . The average of positions 8, 11, 13, and 15 on his waist is 7.8×10^{-4} . The average of all data around the chest and waist of the man is 8.4×10^{-4} . The surface dose to the man, then, was a little higher than the surface dose to the phantom. His location and his movements in answering phones and radios during the tests probably accounted for this small difference.

As read by a static, unperturbed dosimeter at similar locations, the dose in air (or the dose in a small unit volume of tissue) from the combined sources was, however, about 12.5×10^{-4} , about 50% higher than the surface dose on the man and about 65% higher than the surface dose on the phantom. This illustrates the self-shielding provided by the body.

Fig. E.1— Tissue-equivalent phantom used for depth-dose measurements.

Fig. E.2—Phantom and man locations for CP-1B measurements.

Fig. E.3—TLD positions around the man's chest and waist.

TABLE E.1—NORMALIZED TLD DATA (DOSE-REDUCTION FACTORS)
IN THE TISSUE-EQUIVALENT PHANTOM IN CP-1B

Position	Roof source (measured)*	North† side (measured)*	North‡ far-field (estimated)*	West and† south (measured)*	West and‡ south far-field (estimated)*	Total contributions*
P-1	2.00	2.1	0.80	2.9	1.1	8.9
P-2	1.40	1.3	0.49	2.3	0.87	6.4
P-3	1.25	0.83	0.32	2.3	0.87	5.6
P-4	1.2§	0.81	0.31	2.6	0.99	6.9
P-5	1.06	0.94	0.36	1.5	0.57	4.4
P-6	1.17	0.83	0.32	2.4	0.91	5.6
P-7	1.17	0.64	0.24	1.9	0.72	4.7
P-8	1.09	0.81	0.31	2.1	0.80	5.1
P-9	1.21	0.43	0.16	2.1	0.80	4.7
P-10	1.22	0.76	0.29	2.3	0.87	5.4
P-11	1.12	0.71	0.27	1.7	0.65	4.5
P-12	1.35§	0.68	0.26	2.4	0.91	5.6
P-13	1.90	1.19	0.45	3.1	1.2	7.8
P-14	1.44	0.44	0.17	3.7	1.4	7.2
P-15	1.79	0.37	0.14	3.1	1.2	6.6
P-16	1.39	0.37	0.14	3.2	1.2	6.3
P-17	1.25	0.089	0.034	3.2	1.2	5.8
P-18	1.15§	0.62	0.24	1.9	0.72	4.6
P-19	1.00	1.14	0.43	1.9	0.72	5.2
P-20	0.99	0.84	0.32	1.4	0.53	4.1
P-21	1.01	0.98	0.37	1.4	0.53	4.3
P-22	1.05	2.02	0.77	1.3	0.49	5.6
P-23	1.91	1.67	0.63	1.1	0.42	5.7

*Multiply data by 10^{-4} .

†Corrected for source anisotropy (CF = 1.19).

‡Far-field estimates = $0.38 \times$ data.

§Estimated.

TABLE E.2—NORMALIZED TLD DATA (DOSE-REDUCTION FACTORS)
AROUND THE MAN FOR RADIATION MEASUREMENTS IN CP-1B

Position	Roof source (measured)*	North† side (measured)*	North‡ far-field (estimated)*	West and† south (measured)*	West and‡ south far-field (estimated)*	Total contributions*
M-1	2.14	1.14	0.43	4.64	1.76	10.11
M-2	1.98	1.19	0.45	3.93	1.49	9.04
M-3	1.97	1.55	0.58	3.21	1.22	8.53
M-4	2.18	2.38	0.90	3.09	1.17	9.72
M-5	2.20	2.14	0.81	2.26	0.86	8.27
M-6	2.06	2.02	0.76	2.14	0.81	7.79
M-7	1.62	1.43	0.55	2.98	1.13	7.71
M-8	1.89	1.43	0.55	4.76	1.81	10.44
M-9	1.72	0.82	0.31	2.74	1.04	6.63
M-10	1.46	0.94	0.36	3.57	1.36	7.69
M-11	1.58	2.26	0.86	3.81	1.45	9.96
M-12	1.76	1.79	0.68	2.86	1.09	8.18
M-13	1.76	1.90	0.73	2.38	0.90	7.67
M-14	1.77	1.55	0.58	2.38	0.90	7.18
M-15	1.71	1.31	0.50	2.38	0.90	6.80
M-16	1.72	0.95	0.36			

*Multiply data by 10^{-4} .

†Corrected for source anisotropy (CF = 1.19).

‡Far-field estimation = $0.38 \times$ data.

Fig. E.4—Relative exposure vs. depth in tissue-equivalent phantom along long axis. (a) North ground source. (b) West and south ground source. (c) Roof source.

Fig. E.5—Relative exposure vs. depth in tissue-equivalent phantom along short axis. (a) North ground source. (b) West and south ground source. (c) Roof source.

Fig. E.6—Relative exposure vs. depth in tissue-equivalent phantom, total contribution. (a) Long axis. (b) Short axis.

Fig. E.7—Setup for wall-thickness measurements.

Appendix F

RADIATION CONTRIBUTIONS FROM AREAS NOT MEASURED

F.1 GENERAL

It is impossible to distribute tubing to an infinite distance to simulate the radiation from an infinite plane. Therefore for this experiment the tubing was distributed over areas such that the results would be most useful in determining the protection factors. Contributions from areas not simulated were estimated by analytical computations using the experimental data as guidelines.

F.2 CONTRIBUTION FROM BEYOND THE MEASUREMENT AREA

In determining the radiation contribution originating beyond the measurement area to points inside the building, we assumed that the quantity of radiation striking the mid-height of the shielding wall was proportional to that reaching the inside. We determined the amount arriving at the wall from the measurement area and that which would have arrived from beyond. The ratio striking the mid-height of the wall of interest was then applied to each data point.

If the measurement area for the long wall is taken to be 60 by 120 ft, the calculated contribution to the mid-height of the lower wall is 0.333. (This value differs from that determined in Appendix B because of a different height and because of the uncertainties of the Engineering Manual¹). The calculated contribution from beyond the measurement area is 0.101, assuming that the uncollided radiation is reduced 50% by ground roughness and terrain effects. The ratio for the broad wall is then 0.30 $[(0.101/0.333) = 0.30]$.

For a short wall the measurement area was assumed to be 60 by 80 ft. The contribution from the measurement area was calculated to be 0.278, and that from beyond the measurement area, 0.128. The ratio is 0.46. Many of the ground tubing distributions surrounded both long and short walls. Therefore an average ratio of 0.38 was used. This means that, if we multiply the data from the ground measurement by a factor of 0.38, we obtain an estimate of the contribution originating from beyond the measurement areas. This factor (0.38) is applicable and valid for positions away from entrances and for positions where most of the radiation arriving has been scattered by the lower wall next to the tubing. The assumption that the uncollided component will be reduced by a factor of 2 by ground roughness is also valid for rough estimates.¹¹

The same type of calculations were made for positions upstairs. The contribution from the measurement area to the midpoint of the upper long wall is 0.253, and from areas beyond, 0.185. For this condition a 25% reduction of the uncollided component due to ground roughness was assumed. The ratio for the long upper wall would be 0.73. For the short wall upstairs, ground-area contribution would be 0.188, and contribution from areas beyond, 0.234, for a ratio of 1.24. The average ratio would be about 1.00. Therefore for positions upstairs, where most of the radiation has been scattered by the upper wall, the far-out radiation contribution is estimated to be equal to the data taken from the ground measurement.

The approach described is sufficient for rough estimates of the radiation contributions from those areas beyond the measurement areas. The concept is valid for positions where most of the radiation received has been scattered by the nearest wall. This approach probably overestimates the contribution near entrances where most of the radiation has not been scattered. However, when groups of data points are examined, the overall protection factors are little affected. Because of the inaccuracies of the calculational technique and the estimates of ground roughness effects, the far-out contributions are estimated to be reliable to within a factor of 2. This sounds like a large error, but in most cases this contribution influences the protection factors very little.

F.3 CONTRIBUTION FROM SIDES NOT MEASURED

No ground measurements were made around CP-40, to the west side of CP-45, nor to the south and west sides of CP-2. These contributions were estimated by calculations and by using data in CP-2 from the north ground measurements as guidelines.

The north wall of CP-2 was 108 lb/sq ft in mass thickness. This gives an attenuation as a horizontal barrier against a plane ^{60}Co source as 0.079. The wall of CP-40 and the upper wall of CP-45 both are of about 119 lb/sq ft mass thickness. This gives an attenuation of 0.062. Therefore, if the total ground contribution into CP-2 were reduced by 0.785, the result could apply to similar positions in CP-40 and CP-45. Since the far-out plus the ground-area data on the north side of CP-2 equals $1.38 \times$ ground data, then the total ground contribution from the west side of CP-45 would equal 1.07 times the ground data into CP-2 ($1.38 \times 0.785 = 1.07$).

Therefore, to obtain the total ground contribution from the west side into the upper floor of CP-45, we used the corrected data at similar positions in CP-2 from the north ground measurement. For positions near entrances, CP-2 data were multiplied by 1.38 since no attenuation through walls was involved.

For positions downstairs in CP-45, the west ground contribution was calculated to be about 0.2×10^{-4} .

For the south and west ground contributions into CP-2, the data from the north and east ground measurement were used directly at similar positions.

For the ground contribution into CP-40, calculations were made using the OCD Engineering Manual for positions in the center, corner, and side. For other positions estimates were made based on the calculated values and on the experimental data in CP-2 at similar positions.

The ground contributions from the sides of the buildings not measured (south and west of CP-2, west of CP-45, and all of CP-40) are estimated to be valid to within a factor of 2.

Appendix G

EXAMPLES OF DATA REDUCTION

As was mentioned in the main body of this report, two detectors were placed at each location wherever possible. Examples are given in this appendix of raw data, corrections, and data reduction.

Table G.1 shows some examples of TLD data for the roof source on CP-1. The normalized exposure rates were determined by using Eq. 3.3, Chap. 3. The following values were used:

$$S = 593,000 \text{ mCi}$$

$$T = 0.992 \text{ hr}$$

$$A = 19,174 \text{ sq ft}$$

Reduction factors were calculated by dividing the normalized data by 482 (mR/hr)/(mCi/sq ft).

TABLE G.1—EXAMPLES OF TLD DATA FOR ROOF SOURCE ON CP-1

TLD No.	Position No.	Raw data, mR	Calibration correction factor*	Corrected data, mR	Average, mR	Normalized exposure rate, (mR/hr)/(mCi/sq ft)	Reduction factor†
I 56	1	45.0	0.919	41.4	41.7	1.36	28
I 90	1	47.5	0.887	42.1			
I 120	2	48.8	0.858	41.9	41.8	1.36	28
I 140	2	45.0	0.926	41.7			
I 315	3	48.8	0.754	36.8	36.5	1.19	25
I 325	3	47.5	0.763	36.2			
I 117	4	41.9	0.860	36.0	35.0	1.14	25
I 197	4	46.2	0.736	34.0			
I 650	5	41.8	0.855	35.7	35.5	1.16	25
I 663	5	44.8	0.787	35.3			
I 561	6	24.2	0.930	22.5	22.4	0.730	15
I 562	6	23.8	0.941	22.4			

*Calibration correction factors as determined from ^{60}Co and applicable to TLD reader No. 42945.

†Multiply data by 10^{-4} .

Table G.2 shows some examples of 10-mR chamber data also for the roof source on CP-1. These data points were in the basement where exposure levels were low. Nevertheless, adequate and reliable data were obtained.

All other data for the experiments were reduced in the same fashion.

TABLE G.2—EXAMPLES OF 10-mR ION-CHAMBER DATA
FOR ROOF SOURCE ON CP-1

Detector No.	Position No.	Raw data, mR	Corrected data,* mR	Average, mR	Normalized data (mR/hr)/(mCi/sq ft)	Reduction factor†
108	69	0.84	0.90	0.84	0.0274	0.57
122	69	0.64	0.67			
5	70	1.38	1.53	1.46	0.0476	0.99
47	70	1.25	1.38			
126	71	2.00	2.26	2.22	0.0724	1.5
101	71	1.93	2.18			
6	72	1.82	2.05	2.11	0.0688	1.4
7	72	1.92	2.16			
115	73	1.24	1.37	1.32	0.0430	0.89
116	73	1.15	1.26			
14	74	1.96	2.21	2.24	0.0730	1.5
11	74	2.00	2.26			
21	75	3.10	3.55	3.55	0.109	2.3
19	75					

*Corrected for detector leakage and air density. To correct for leakage, we subtracted 0.07 mR. Air-density correction consisted in multiplying the data by 1.17. No calibration correction was necessary.

†Multiply data by 10^{-4} .

Appendix H

COMPARISON OF TLD AND 10-mR CHAMBER RESULTS

In many instances both TLD's and 10-mR ion chambers were placed at the same location for the tests. The purpose was to assure full coverage of the locations in case the exposure exceeded 10 mR. The resulting data provide some interesting comparisons. Tables H.1 to H.4 contain corrected data for several positions for the CP-45 roof source, the CP-45 ground source, and the CP-1 roof source. The fourth column compares the responses in terms of percentage deviation from the 10-mR chamber data.

In each set of comparisons, the TLD's consistently responded less than the 10-mR chambers. It is hypothesized that the difference is caused by the high contribution of low-energy photons and the difference of the energy responses of the two detectors. Figure 2.4 shows relative response vs. energy of the detectors. Both sets of data were obtained by the EG&G Santa Barbara Office. Note that the TLD response is higher by 15% at 60 keV, decreasing to the same response at 200 keV. However, below 50 keV the TLD response decreases very rapidly. It is hypothesized that a significant portion of radiation arriving at the detector is below 50 keV, being read by the 10-mR chambers but not by the TLD's.

The mass thickness between source and detector for data in Table H.1, CP-45 roof sources, was about 15 in. of concrete or 225 lb/sq ft. The average TLD response was 13.7% less than the average 10-mR chamber response.

In the case in Table H.2, where the detectors were beneath the mezzanine, there was a mass thickness of 18 in. of concrete (233 lb/sq ft) between source and detector. The TLD's responded an average of 29% less than the 10-mR chambers. However, the individual differences varied considerably, from ± 0.1 to 60.0%. The inconsistency is probably due to the low radiation levels. The 10-mR chambers are considered reliable ($\pm 5\%$) down to 0.5 mR. The TLD readout was linear from 0 to 50 mR. Readings at 5 mR were considered reliable to $\pm 10\%$, but readings at 1 mR were considered accurate to only about $\pm 50\%$. The more sensitive scale, 0 to 5 mR, was not functioning properly for this experiment.

The TLD's in the lower floor of CP-45 responded 13.5% lower than the 10-mR chambers for the ground source (Table H.3). The lower outside wall was of 10-in. concrete (149 lb/sq ft). Considering the many internal walls in CP-45, the mass thickness between source and detector was about 190 lb/sq ft. For the detectors on the upper floor, the differences were greater, -24.8% for the TLD's. For this source-detector geometry, we assumed that nearly all radiation received had been scattered in the upper wall. A single 90° scatter of a 1.2-MeV gamma ray results in a photon of energy about 400 keV. Therefore all radiation received by the detectors would be 400 keV and below. A sizable portion of this is probably below 50 keV.

Calculations¹² of deep penetrations from plane sources show a significant portion of radiation in low-energy regions.

In summary, TLD's responded up to 30% less than 10-mR chambers when both kinds of detectors were at the same location. It is hypothesized that this difference is caused by a significant portion of the radiation below 50 keV arriving at the detectors being read by the 10-mR chambers but not by the TLD's.

TABLE H.1—COMPARISON OF TLD AND 10-mR CHAMBER
RESPONSES FOR CP-45 ROOF SOURCE

Position	10-mR chamber, mR	TLD, mR	Difference in TLD from 10-mR chamber, %
5	12.09	10.0	-17.3
6	8.55	7.3	-14.6
7	10.45	9.1	-12.9
26	11.85	10.4	-12.2
31	10.40	8.7	-16.3
32	9.73	9.9	+2.4
38	11.12	10.5	-5.6
48	8.69	7.2	-17.1
50	7.71	6.6	-14.4
51	8.62	7.5	-13.0
53	9.55	8.1	-15.2
54	8.51	6.0	-29.4
57	10.45	9.2	-12.0
Average			-13.7

TABLE H.2—COMPARISON OF TLD AND 10-mR CHAMBER
RESPONSES FOR CP-1 ROOF SOURCE

Position	10-mR chamber, mR	TLD, mR	Difference in TLD from 10-mR chamber, %
12	3.37	3.53	+4.7
14	3.43	2.37	-23.1
15	3.43	1.80	-47.5
16	4.89	2.77	-43.3
17	4.95	3.61	-27.1
18	5.57	5.61	+0.1
19	6.06	4.31	-28.9
47	8.34	6.39	-23.4
50	3.31	2.19	-33.8
51	3.95	2.58	-34.7
52	2.18	0.86	-60.6
Average			-28.9

TABLE H.3—COMPARISON OF TLD AND 10-mR CHAMBER
RESPONSES AT DOWNSTAIRS POSITIONS FOR CP-45
GROUND SOURCE

Position	10-mR chamber, mR	TLD, mR	Difference in TLD from 10-mR chamber, %
1	10.28	9.1	-11.5
11	10.51	8.3	-21.0
12	9.78	9.0	-8.0
19	3.43	3.1	-9.6
21	7.24	5.5	-24.0
31	2.61	2.3	-11.9
32	2.50	2.1	-16.0
33	2.51	2.5	0
34	3.88	3.2	-17.5
41	6.64	5.6	-15.7
Average			-13.5

TABLE H.4—COMPARISON OF TLD AND 10-mR CHAMBER
RESPONSES AT UPSTAIRS POSITIONS FOR CP-45
GROUND SOURCE

Position	10-mR chamber, mR	TLD, mR	Difference in TLD from 10-mR chamber, %
68	11.50	8.1	-29.6
69	7.36	5.1	-30.7
70	5.77	4.4	-23.7
71	3.81	2.6	-31.8
72	6.73	4.7	-30.2
73	8.76	6.0	-31.5
74	11.70	8.4	-28.2
76	7.52	5.5	-26.9
77	5.76	4.5	-21.9
78	3.56	2.8	-21.3
79	2.15	2.4	+16.2
80	4.44	4.0	-9.9
81	7.74	5.8	-25.1
82	6.80	5.1	-25.0
87	10.82	8.2	-24.2
88	5.40	4.2	-22.2
90	9.46	7.7	-18.6
95	9.61	7.2	-25.1
96	5.45	4.8	-11.9
Average			-24.8

Appendix I

WALL-THICKNESS DATA

The density of concrete varies with locality and individual construction. An average value of 144 lbs/cu ft is generally used if no details of the structural composition are known. However, a 10% error in estimating the density of a 12-in.-thick concrete wall results in a 30% error in radiation attenuation.

To provide information as to the actual mass density of the walls and floors of the structure tested, radiation attenuation measurements were made. A National Bureau of Standards calibrated ^{60}Co source, reading 1632 mR/hr at 1 ft distance was placed on the outside of a wall at a height of about 3 ft above the floor level. Ion chambers (10 mR) were placed 3 ft above the floor and 2 ft apart on a line parallel to the wall at a distance generally 6 ft from the wall. Figure E.7 (p. 108) shows a sketch of the setup. Two chambers were placed at each position. Exposure times were usually 30 min.

The resulting data were averaged at each position, corrected for air density, and converted to milliroentgens per hour. The slant attenuation was then determined at each position, assuming no air attenuation. The slant mass thickness was then determined by point-source attenuation curves (Fig. B-21, Ref. 8). Effective normal thickness was then determined by multiplying by $\cos \theta$. Equations used in the reduction of data are as follows:

$$\tan \theta = \frac{Y}{Z + X} \quad (\text{I.1})$$

$$b = \frac{Y}{\sin \theta} \quad (\text{I.2})$$

$$\text{attenuation} = \frac{b^2 \times E}{144 \times (1620 + S)} \quad (\text{I.3})$$

where S is an estimate of the floor backscatter component and E is the measured exposure rate.

$$t \text{ (effective thickness)} = t' \text{ (slant thickness} \times \cos \theta) \quad (\text{I.4})$$

Table I.1 presents the results for the wall-thickness measurements on CP-40. A value of S of 6%, or 97 mR/hr, was chosen for this geometry, i.e., a source and detector height of 3 ft and a separation distance of 6 ft. A degradation of source spectrum was also considered in determining this value. The effective mass thickness for the 8-in. wall varies from 112 to 124. The value of 117 lb/sq ft from the position 2 detectors was chosen. A graph of t vs. angle (θ) appears in Fig. I.1. The exact locations of wall-thickness measurements are noted on floor plans in Chap. 3.

Nearly identical measurements were made of the upstairs 8-in. wall of CP-45. Detectors were again placed 2 ft apart. However, their height above the floor was 24 in. and the distance from the wall was 56 in. The value of S was again taken as 97 mR/hr. Results are presented in Table I.2 and plotted in Fig. I.2. The wall mass thickness was taken as 119 lb/sq ft, nearly the same as CP-40.

The same geometry was used for the upper 8-in. wall of the old CP-1 structure. Results are presented in Table I.3 and plotted in Fig. I.3. A wall mass thickness of 110 lb/sq ft was chosen.

Measurements on the 16-in. wall of CP-1B were made with detectors 3 ft off the floor and 15 in. from the wall. Only three data points were valid. Floor backscattering (S) was assumed to be 0. Results are presented in Table I.4 and plotted in Fig. I.4. A wall mass thickness of 208 lb/sq ft was chosen.

The mass thickness of the first floor of CP-1B was measured. The source was placed against the ceiling of the basement, and detectors were positioned 36 in. off the floor, 24 in. apart. The 6-in. concrete floor was separated from the basement roof by 31.5 in. of duct space for the air-conditioning system. The value of X was taken as 37.5 in. The value of S was again taken as 0. Results are given in Table I.5 and plotted in Fig. I.5. An effective floor mass thickness was taken as 79 lb/sq ft.

The same geometry was used for the upper 8-in. wall of CP-2 as for CP-40. Results are presented in Table I.6 and plotted in Fig. I.6. Effective mass thickness of the wall was taken as 106 lb/sq ft.

In examining the plotted data in Figs. I.1 to I.6, we note a consistent trend. The effective mass thickness generally decreases with increasing angle. The same thing was noticed by Clarke¹³ in a similar experiment. This trend indicates the influence of the scattered radiation emerging from the wall. An indication of a slight hump in the data from 15 to 30° could be attributable to the same thing. If both detectors and source were imbedded in an infinite medium of concrete, the trend would be expected to disappear.

A summary of the resulting wall mass thicknesses and subsequent concrete densities appears in Table I.7. The two buildings, CP-40 and CP-45, are new structures. The resulting concrete densities are nearly the same, 176 and 178 lb/cu ft; this is well within the uncertainties of this technique of determining densities. The results indicate that both the wall and the floor of CP-1B are of nearly the same density, 156 and 158 lb/cu ft. The older structures, CP-1 and CP-2, also have quite similar densities, 165 and 159 lb/cu ft. It is interesting to note that all the densities are higher than the standard density of 144 lb/cu ft.

TABLE I.1—WALL-MASS-THICKNESS DATA AND INFORMATION
USED IN DATA REDUCTION FOR CP-40

Position	Exposure rate, mR/hr	Y, in.	Z, in.	X, in.	θ , degrees	b, in.	b ² , sq in.	Attenuation	Slant mass thickness (t'), lb/sq ft	Effective mass thickness (t), lb/sq ft
1	5.08	24	72	8	16.6	83.9	7039	0.145	127	122
2	6.93	0	72	8	0	80.5	6480	0.182	117	117
3	4.93	24	72	8	16.6	83.9	7039	0.140	129	124
4	3.11	48	72	8	30.9	93.4	8724	0.110	140	120
5	1.51	72	72	8	41.9	107.8	11,621	0.0711	162	121
6	0.87	96	72	8	50.0	125.2	15,675	0.0552	174	112

Fig. I.1—Effective wall-mass-thickness measurements, CP-40.

Fig. I.2—Effective wall- (upper) mass-thickness measurements, CP-45.

Fig. I.3—Effective wall- (upper) mass-thickness measurements, CP-1.

Fig. I.4—Effective wall-mass-thickness measurements, CP-1B.

Fig. I.5—Effective floor-mass-thickness measurements, CP-1B.

Fig. I.6—Effective wall-mass-thickness data for upper wall of CP-2.

TABLE I.2—WALL-MASS-THICKNESS DATA
FOR UPPER WALL OF CP-45

Position	Exposure rate, mR/hr	Angle, degrees	Effective thickness (t), lb/sq ft
1	8.06	20.42	117
2	9.08	0	119
3	8.90	20.42	112
4	5.04	36.68	106
5	2.16	48.12	103
6	1.36	56.12	89

TABLE I.4—WALL-MASS-THICKNESS DATA
FOR CP-1B

Position	Exposure rate, mR/hr	Angle, degrees	Effective thickness (t), lb/sq ft
1	1.99	37.30	192
2	6.24	0	208
3	1.17	37.30	212

TABLE I.6—WALL-MASS-THICKNESS DATA
FOR UPPER WALL OF CP-2

Position	Exposure rate, mR/hr	Angle, degrees	Effective thickness (t), lb/sq ft
1	8.00	16.60	98
2	8.34	0	106
3	6.32	16.60	112
4	4.36	30.80	106
5	2.32	41.72	96
6	1.46	50.00	96

TABLE I.3—WALL-MASS-THICKNESS DATA
FOR UPPER WALL OF CP-1

Position	Exposure rate, mR/hr	Angle, degrees	Effective thickness (t), lb/sq ft
1	9.19	20.42	111
2	12.30	0	110
3	8.86	20.42	112
4	4.42	36.68	111
5	2.86	48.12	14
6	1.08	56.12	100

TABLE I.5—FLOOR-MASS-THICKNESS DATA
FOR CP-1B

Position	Exposure rate, mR/hr	Angle, degrees	Effective thickness (t), lb/sq ft
1	11.12	18.00	88
2	15.48	0	79
3	13.92	18.00	76
4	8.80	32.95	76
5	4.81	44.23	77
6	3.18	52.33	68

TABLE I.7—SUMMARY OF WALL MASS THICKNESS
AND CONCRETE DENSITIES

Structure	Thickness		Density, lb/cu ft
	in.	lb/sq ft	
CP-40 wall	8	117	176
CP-45 upper wall	8	119	178
CP-1B wall	16	208	156
CP-1B floor	6	79	158
CP-1 upper wall	8	110	165
CP-2 upper wall	8	106	159

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CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations, the Atomic Energy Commission conducts technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the facts useful in the design of countermeasures against weapons effects. These studies do not require nuclear detonations. A partial list of reports on completed studies follows. These reports are available, at \$3.00 each, from the National Technical Information Service, U. S. Department of Commerce, Springfield, Va. 22151.

- CEX-58.1, Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, 1959.
 CEX-58.7, AEC Group Shelter, AEC Facilities Division, 1960.
 CEX-58.8, Comparative Nuclear Effects of Biomedical Interest, 1961.
 CEX-58.9, A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves, 1961.
 CEX-59.1, An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, 1960.
 CEX-59.7B (Pt. I), Experimental Radiation Measurements in Conventional Structures. Part I. Radiation Measurements in Two Two-Story and Three One-Story Typical Residential Structures Before and After Modification, 1966.
 CEX-59.7B (Pt. II), Experimental Radiation Measurements in Conventional Structures. Part II. Comparison of Measurements in Above-Ground and Below-Ground Structures from Simulated and Actual Fallout Radiation, 1964.
 CEX-59.7B (Pt. III), Experimental Radiation Measurements in Conventional Structures. Part III. The Attenuation of Air-Scattered Radiation in a Basement, 1965.
 CEX-59.13, Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, 1960.
 CEX-59.14, Determinations of Aerodynamic-Drag Parameters of Small Irregular Objects by Means of Drop Tests, 1961.
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