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CEX-65.5

CIVIL EFFECTS STUDY

EXPERIMENTAL EVALUATION OF
TECHNIQUES FOR IMPROVING
FALLOUT PROTECTION IN HOME BASEMENTS

R. L. Summers and Z. G. Burson

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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CIVIL EFFECTS TEST OPERATIONS
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EXPERIMENTAL EVALUATION OF TECHNIQUES FOR IMPROVING FALLOUT PROTECTION IN HOME BASEMENTS

By
R. L. Summers and Z. G. Burson

Approved by: L. J. DEAL, Chief
Civil Effects Branch

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ABSTRACT

Radiation measurements were made in the basement of an existing two-story wood frame house in Area 1 at the USAEC Nevada Test Site to evaluate and verify some simple and convenient techniques for improving fallout radiation protection in homes with basements.

Fallout radiation was simulated by hydraulically pumping a sealed radioactive source of ^{60}Co at a uniform speed through tubing placed over the area of interest. Measurements were made by integrating ionization chambers.

The project was divided into six phases consisting of the following:

Phase 1	Bare basement with and without shielded basement windows.
Phase 2	Overhead barrier shield provided by supporting bricks placed between the ceiling joists. Several variations to this technique were tested.
Phase 3	Small shelters consisting of a concrete block sit-down shelter, a lean-to shelter and a workbench.
Phase 4	A tilt-up storage unit shelter and workbench variations.
Phase 5	An alternate variation to the overhead barrier shield technique in Phase 2.
Phase 6	Supplemental investigations: (1) three incremental layers of concrete blocks placed on the floor of the first floor, (2) a simulated brick veneer, and (3) typical first-floor furniture distributed realistically and then stacked in one corner.

The protection factors ranged from 11 to 25 in the bare basement. Shielding the basement windows had very little effect on the protection.

The overhead barrier technique provided the desired protection in the two-story house, but not for the simulated one-story house. The vertical position of the overhead mass is relatively more significant than

its thickness. Consequently, using this technique would not achieve the desired protection for basements where a significant portion of the basement wall is exposed above ground.

The small shelters and tilt-up shelter provided very good protection. The lean-to and tilt-up shelters were considered difficult to construct by unskilled labor. The sit-down shelter and workbench were considered easy.

Household furniture stacked in one corner of the first floor provided only a small amount of increased protection in the same corner of the basement.

Engineering calculations of the bare basement were about 30% higher than corrected experimental data for roof contributions, and up to 50% lower for ground contributions.

The protection factors, derived from corrected experimental data, are expected to be accurate to within a standard deviation of $\pm 8\%$.

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Chapter 1

INTRODUCTION

1.1 . BACKGROUND

The Office of Civil Defense (OCD) has prepared a booklet (see Appendix A) entitled, "Fallout Protection for Homes with Basements." The booklet contains construction methods to improve existing fallout protection in basements. The Civil Effects Test Operations (CETO) of the Division of Biology and Medicine (DBM) of the U.S. Atomic Energy Commission undertook a joint program with the OCD to experimentally evaluate the ideas presented in the booklet and to determine the shielding by experimental radiation measurements.

A two-story wood frame house containing a basement located in Area 1 at the USAEC Nevada Test Site was chosen for the tests. This house had been constructed in 1955 for use in Operation Teapot¹ and has been used several other times for radiation attenuation studies.²⁻⁴

1.2 OBJECTIVES

The overall objective was to experimentally evaluate the techniques presented in Appendix A for improving fallout protection in homes with basements. Specific objectives were:

1. To determine experimentally protection factors in various locations in the basement of a two-story wood frame house and simulated one-story house.
2. To determine experimentally protection factors in various shelters constructed in the basement of the two-story and simulated one-story wood frame house.
3. To evaluate the work, effort, and time required for each shelter to be built by the homeowner and to ascertain the material needed.
4. To compare results based on measurements with results obtained by engineering calculations.

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Chapter 2

EXPERIMENTAL METHOD

2.1 GENERAL DESCRIPTION

The experimental method consisted of simulating a finite, idealized fallout field by pumping a ^{60}Co source through tubing placed on the roof of and around the structure being tested to determine the exposure inside by appropriately placed ionization chambers.

2.2 SOURCE-HANDLING SYSTEM

The source-pumping system used for this project has been used for other experiments of this nature.¹⁻³ It is thoroughly described in Ref. 4. The system consisted of a remotely controlled hydraulic pumping unit which used water to pump a radioactive source from its shield through associated tubing and back into the shield. Movable magnetic indicators attached to the tubing arrays and connected to control lights on the remote control console enabled the operator to pinpoint the source position at all times and to oscillate the source back and forth automatically.

Since the outside diameter of the source capsule was slightly less than the inside diameter of the tubing, a flow system rather than a pressure-differential system was used. Internal pressures of about 150 psi produced a source speed of approximately 120 ft/min. From the console in the laboratory trailer situated 1000 ft from the pumping system, the movement of the source capsule was started, stopped, reversed or oscillated. Moreover, a handpump located 100 ft from the source-pig trailer provided an emergency mechanism for returning the source capsule to its shield. Figure 2.1 is a photograph of the source-handling system.

For simulating an area source, the ^{60}Co source capsule was pumped at uniform speed through tubing that had been evenly distributed over either the roof or the ground next to the building concerned. Measurements were also made with the tubing placed on the circumference of a 200 ft-radius circle, concentric with the center of the two-story wood frame house for simulating a ring source.

2.3 SOURCES AND INSTRUMENTATION

The investigations described here were carried out with ^{60}Co sources of the following approximate activities:

1. 800 curies
2. 150 curies
3. 8 curies
4. 500 millicuries
5. 15 millicuries

All sources were encapsulated in magnetic, stainless steel capsules. Calibrations were performed by pumping the source into position at a height of 10 ft above ground and measuring the exposure rate 10 ft away by NBS-calibrated Victoreen condenser R-chambers. Calibration details are presented in Ref. 4. The activity of the sources at the time of measurements was obtained from standard decay curves. A photograph and drawing of the 150-curie ^{60}Co source appear in Fig. 2.2.

Cobalt-60 was used because the attenuation of the radiation emitted (1.17 and 1.33 Mev) is nearly the same for thin shields as that from 1-hr fission products.

The instruments used in this experiment were integrating ionization chambers with associated charger-readers. The ionization chambers were 0- to 10-mr Victoreen model 239 stray radiation chambers. Victoreen model 287 minometers were used for charging and reading the ionization chambers. Calibration, energy, angular response, and detector orientation are discussed in the error analysis in Appendix B.

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

Fig. 2.2 - 150-curie ^{60}Co source capsule assembly and detail.

Chapter 3

EXPERIMENTAL TECHNIQUE

3.1 GENERAL

The experimental technique consisted of creating simulated smooth planes of uniform contamination on and around the structure and measuring the radiation levels at selected locations within. Five separate configurations were simulated, the results of which were used to obtain radiation levels (and thus protection factors) from a smooth infinite plane of ^{60}Co contamination. These five source configurations are listed as test runs:

Run 1	Second-story roof contribution	(Story 2)
Run 2	Simulated first-story roof contribution	(Story 1)
Run 3	First close-in ground contribution	(Ground 1)
Run 4	Second close-in ground contribution	(Ground 2)
Run 5	Far-out ground contribution	(Ground FO)

To measure the second-story roof contribution, the polyethylene tubing was distributed 2 ft apart (perpendicular to the roof joists and rafters) on the roof of the house. To minimize exposure while the source was between its shield and the roof, the tubing was buried under 2 ft of earth between the shield and the house and then was placed on the outside of the chimney from the ground to the roof. Figures 3.1 and 3.2 show the tubing distribution.

Tubing was distributed on the second floor to simulate the roof contribution from a one-story house. Holes were cut in the partitions to obtain a constant 2-ft separation of the tubing. It was laid perpendicular to the floor joists and covered an area of 21.9 by 29.6 ft. These dimensions were chosen to correspond to the same solid-angle projection to a point 3 ft above the center of the basement floor as would the horizontal projection (located 2 ft above the base of the eave height) of a one-story roof to the same point. Figure 3.3 shows this tubing layout. The source always exited in the same tube as it entered the simulated one-story house tubing distribution. For both the two-story and simulated one-story roof runs a minimum 15-min exposure time was used to minimize the exposure while the source was between the ground and the roof. The possible errors caused by these effects are discussed in Appendix B.

The tubing was laid on the ground as uniformly as possible with a 1-ft separation covering an area from 0 to 10 ft from the edge of the house to produce the first close-in ground contribution. The first tube was placed 6 in. from the edge of the house. The tubing was placed over the outside basement stairway entrance as if the entrance were not there. Previous experiments had shown this compromise had a negligible effect on the ground contribution to points in the basement beyond the vicinity (one quarter

of basement floor area) of the entrance. Again, the tubing was buried between the shield (located about 70 ft south of the house) and the beginning of the area.

The second close-in ground contribution was produced by distributing the tubing 4 ft apart from 10 to 68 ft from the edge of the building. The tubing distribution was rectangular (see Fig. 3.2).

To provide experimental data as a basis for estimating the far-out ground contribution (contribution from contamination beyond the close-in measurement areas) a ring source of 200-ft radius from the center of the building was used. Even though the ground had been smoothed as much as practical before the tests began, a portion of the ring source (about 25%) had to be raised from 0 to 6 in. above the ground so that the source could "see" the exposed basement wall.

Detector locations are shown on a floor plan in Fig. 3.4 and physical locations are noted in Table 3.1. At each location two dosimeters were placed in paper cups attached to a string hung from the ceiling. The average reading of dosimeters placed at one location was taken as the exposure at that location and height above the basement floor. In general, all positions contained dosimeters at a 3-ft height. Some positions also contained 1, 2, 4, and 5-ft heights. The time of exposure varied from 15 min to 4 hrs.

For each test run of the experiment, the following general procedures were observed:

1. All dosimeters were charged and placed in position while a dummy source capsule 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.

2. After radiological safety clearance was given, the hydraulic system was energized and the experimental run was made. After the test exposure, the source was secured in its shield, dosimeters were read and readings were recorded. Temperature, pressure, and source exposure time were also recorded.

3.2 TEST SEQUENCE

The experiment consisted of six complete test phases with a total of eighteen variations. Test sequence, phase variations and test runs are described in this section.

3.2.1 Phase 1 - Bare Basement

- (a) Bare basement with unshielded basement windows: Runs 1 through 5.
- (b) Bare basement with shielded basement windows: Runs 3 through 5.

3.2.2 Phase 2 - Overhead Barrier (Plan A)*

- (a) 12 x 12-ft overhead barrier with standard cross bracing between the joists: Runs 1, 3, 4, and 5.
- (b) 12 x 12-ft overhead barrier with simulated duct between two joists: Runs 1, 3, 4, and 5.

*All plans refer to those in Appendix A.

- (c, d) 12 x 12-ft solid overhead barrier: Runs 1 through 5.
- (e) 12 x 12-ft solid overhead barrier with all basement windows shielded: Runs 3, 4, and 5.
- (f) 12 x 16-ft solid overhead barrier: Runs 1 through 5.
- (g) 12 x 16-ft solid overhead barrier with all basement windows shielded: Runs 1 through 5.

3.2.3 Phase 3 - Small Shelters

Concrete block sit-down shelter (Plan C); lean-to-shelter (Plan F); and workbench shelter covered with magazines and books (Plan W*): Runs 1 through 5.

3.2.4 Phase 4 - Tilt-up Shelter and Workbench Variations

- (a) Tilt-up storage unit shelter with entrance unshielded (Plan E) and workbench shelter with concrete blocks on sides and top (Plan W*): Runs 1 through 5.
- (b) Tilt-up storage unit shelter with entrance shielded (Plan E): Runs 1 through 5.

3.2.5 Phase 5 - Alternate Overhead Barrier (Plan B)

12 x 12-ft alternate to the dual purpose basement shelter (Plan B): Runs 1 through 5.

3.2.6 Phase 6 - Supplemental Investigations

Several variations to this phase were tested. These are:

- (a) 12 x 12-ft x 2.25-in. -thick concrete overhead barrier: Runs 1 through 5.
- (b) 12 x 12-ft x 4.50-in. -thick concrete overhead barrier: Runs 1 through 5.
- (c) 12 x 12-ft x 6.75-in. -thick concrete overhead barrier: Runs 1 through 5.
- (d) Simulated brick veneer: Runs 1 through 5.
- (e) Typical first-floor furniture: Runs 1 through 5.
- (f) Furniture stacked in one corner of first floor: Runs 1 through 5.

3.3 SHELTER DESCRIPTION AND DESIGNS

This section presents detail drawings and photographs of the shelters tested. Refer to Appendix A for a brief description and sketched drawings.

Before the experiment began, all previous shelters were removed from the basement of the house, and the ground area out to a 200-ft radius was scraped and smoothed.

3.3.1 Phase 1 - Bare Basement

Phase 1 consisted of the determinations of protection factors in the bare basement of the two-story wood frame house. Figures 3.5 and 3.6 show the detector layout in the best corner of the basement. Figures 3.7 and 3.8 show the structural drawings of the house.

*Plan W is the author's designation for clarity.

3.3.2 Phase 2 - Overhead Barrier (Plan A)

Phase 2 shelter area is shown in Fig. 3.9, incorporating all shelter variations A through E. Variations F and G are shown in Fig. 3.10. Figure 3.11 shows the "as-built" shelter.

For Phases 1B, 2E, and 2G, five sandbags were stacked in the window wells of each basement window for shielding.

Phase 2A is the standard cross bracing between the joists. This bracing was located 6 in. south of the screw-jack column.

Phase 2B is the simulated duct between two joists. In actuality this duct was positioned perpendicular to the joists. It was simulated by leaving a voided area approximately 13-1/2 in. wide and 12 ft 4 in. long. The edge of this duct was located 8 in. south of the screw-jack column.

3.3.3 Phase 3 - Small Shelters

Phase 3 shelter designs are shown in Figs. 3.12 to 3.14. Figure 3.12 is the sit-down shelter, Fig. 3.13 is the lean-to shelter and Fig. 3.14 is a workbench shelter. Figures 3.15 to 3.17 show the sit-down shelter. Figures 3.18 to 3.20 show the lean-to shelter. Figure 3.21 shows the workbench shelter, the top of which was covered with books, magazines and newspapers.

3.3.4 Phase 4 - Tilt-up Shelter and Workbench Variations

Phase 4 shelter designs are shown in Figs. 3.22 and 3.23. The tilt-up unit shelter which was tested both with the doorway open and closed is shown in Figs. 3.24 and 3.25. The workbench shelter, in which the top and sides were covered with concrete blocks is shown in Fig. 3.26.

3.3.5 Phase 5 - Alternate Overhead Barrier (Plan B)

Phase 5 shelter design is shown in Fig. 3.27. This shelter is similar to the shelter in Phase 2, but instead of using the existing 2 x 10 joists, 2 x 12 joists were installed. Photographs of this shelter are shown in Figs. 3.28 and 3.29.

3.3.6 Phase 6 - Supplemental Investigations

Phase 6 consisted of three complete parts: (1) Three incremental layers of concrete blocks were positioned on the floor of the first floor, covering a 12 x 12-ft corner area. The protection afforded in the basement was measured for each layer. Figure 3.30 shows all three layers in place. (2) A simulation of a 4-ft-high x 2-1/4-in. -thick brick veneer was placed on the inside of the outside walls of the house throughout and is shown in Figs. 3.31 and 3.32. (3) Typical first-floor furniture was distributed realistically and protection factors were determined. Figures 3.33 to 3.38 show these furnishings. All movable furniture was then stacked in the corner and protection factors were again determined. Figure 3.39 shows this layout.

(Text continued on page 34)

TABLE 3.1 - PHYSICAL LOCATION OF DETECTORS

Plan	Detector position	Distance from wall, ft			W
		N	S	E	
A	1		11	1	
A	2		6	1	
A	3		1	1	
A	4		1	6	
A	5		1	11	
A	6		9	3	
A	7		6	3	
A	8		3	3	
A	9		3	6	
A	10		3	9	
A	11		6	6	
A	12		9	9	
B	13		8	6	
B	14		12	6	
C	15		10	2	
C	16		5 $\frac{1}{2}$	2	
C	17		1	2	
C	18		9	2	
F	19	5			1 $\frac{1}{2}$
F	20	1			1 $\frac{1}{2}$
W	21		1		1
W	22		4		1
E	23		9 $\frac{1}{2}$	3	
E	24		5	3	
E	25		1	3	
Aux.*	26		8		6 $\frac{1}{2}$
Aux.	27	8			6 $\frac{1}{2}$
Aux.	28	8		6	
Aux.	29	16		11 $\frac{1}{2}$	
Aux.	30	16			1
Aux.	31	8		11 $\frac{1}{2}$	
Aux.	32	1		11 $\frac{1}{2}$	
Aux.	33	2		1	
Aux.	34	16		1	
F	35	8			1 $\frac{1}{2}$

*Auxiliary

Fig. 3.1 - Tubing distribution at the two-story wood frame house.

Fig. 3.2 - Typical rectangular tubing distribution for ground contribution.

Fig. 3.3 - Simulated one-story house tubing distribution.

Fig. 3.4 - Detector locations in basement.

Fig. 3.5 - Typical detector locations in the bare basement of the two-story wood frame house.

Fig. 3.6 - Typical detector locations in the bare basement of the two-story wood frame house.

FRONT ELEVATION

CROSS SECTION

LONGITUDINAL SECTION

Fig. 3.7 - Two-story wood frame house, showing front elevation, cross section, and longitudinal section.

BASEMENT PLAN

FIRST FLOOR PLAN

SECOND FLOOR PLAN

Fig. 3.8 - Two-story wood frame house, showing basement, first-floor, and second-floor plans.

Fig. 3.9 - 12 x 12-ft solid overhead barrier (Plan A) shelter.

Fig. 3.10 - 12 x 16-ft solid overhead barrier (Plan A) shelter.

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Fig. 3.12 - As-built concrete block sit-down shelter.

Fig. 3.13 - Plan for lean-to unit shelter.

Fig. 3.14 - Table workbench plan.

Fig. 3.15 - Front wall of the sit-down shelter (Plan C).

Fig. 3.16 - Corner of the sit-down shelter (Plan C).

Fig. 3.17 - Detector location inside the sit-down shelter (Plan C).

Fig. 3.18 - Lean-to shelter (Plan F).

Fig. 3.19 - Modified entrance shield for the lean-to shelter (Plan F).

Fig. 3.20 - Typical detector position in the lean-to shelter (Plan F).

Fig. 3.21 - Improvised workbench shelter (Plan W) with magazines, newspapers and books stacked on top.

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Fig. 3.24 - Tilt-up unit shelter (Plan E) with entrance shield removed.

Fig. 3.25 - Tilt-up unit shelter (Plan E) with entrance shield in place.

Fig. 3.26 - Workbench shelter (Plan W) with concrete shield on top and sides.

SECTION A

SECTION B

Fig. 3.27 - Plan B for 12 x 12 shelter.

Fig. 3.28 - 12 x 12-ft overhead barrier shelter
(Plan B) modified with screw-jack column in place.

Fig. 3.29 - 12 x 12-ft overhead barrier shelter (Plan B)
modified with screw-jack column in place.

Fig. 3.30 - Supplemental investigation of incremental mass placed on the floor of the first floor.

Fig. 3.31 - Supplemental investigation of simulated brick veneer, typically placed inside of the outside walls of the first floor.

Fig. 3.32 - Supplemental investigation of simulated brick veneer, typically placed inside of the outside walls of the first floor.

Fig. 3.33 - Living-room furniture realistically distributed.

Fig. 3.34 - Living-room furniture realistically distributed.

Fig. 3.35 - Dining-room furniture realistically distributed.

Fig. 3.36 - Kitchen furniture realistically distributed.

Fig. 3.37 - Kitchen furniture realistically distributed.

Fig. 3.38 - Kitchen furniture realistically distributed.

Fig. 3.39 - All movable furniture stacked in the corner of the living room.

Chapter 4

PRESENTATION OF DATA

4.1 GENERAL

Because of the volume of data collected and the necessary corrections, normalization, and calculations performed, the data were processed through a 1604 digital computer for an appropriate output. All normalized data appear in Tables 4.1 to 4.17. Following each table appears a corresponding figure number showing protection factors at 3 ft above the basement floor, plotted on floor plans.

4.2 DATA EXPLANATION AND HANDLING PROCEDURE

The input data for the computer program are itemized in Table 4.18. The computer program averaged the raw detector response. This average response was then corrected for calibration, temperature and pressure, and source exposure time and then normalized to a standard source density according to the equation

$$E_n = \frac{E_c \times A}{T \times S} \quad (1)$$

where E_n = normalized exposure rate in mr/hr per mc/sq ft
 E_c = averaged corrected detector response in mr
 A = total area of contamination in sq ft
 T = exposure time in hours
 S = source activity in millicuries

These normalized data appear in data columns: second-story roof (story 2), first-story roof (story 1), ground 1, and ground 2. The ground far-out (FO) column refers to the contribution from contamination beyond the close-in measurement areas. This contribution was estimated by experimental data from a ring source at a 200-ft radius and the free-field (no-structure) exposure. The equation used to estimate the far-out contribution is

$$\text{Ground (FO)} = \frac{D_c \times E_m}{I_c} \quad (2)$$

where Ground (FO) = far-out ground contribution (mr/hr per mc/sq ft) to a particular point in the structure

D_c = free-field exposure rate (mr/hr per mc/sq ft) at 3 ft above ground from contamination beyond the close-in measurement area

E_m = measured exposure rate (mr/hr per mc/ft of circumference) at the point in question from a ring source at a 200-ft radius

I_c = measured free-field exposure ring (mr/hr per mc/ft of circumference) above ground from a ring source at a 200-ft radius

Equation 2 can apply if the energy and angular distribution of D_c are the same as those of I_c . With the source geometries used in these experiments, errors incurred are expected to be small (see Appendix B).

The value of D_c was taken as 175 mr/hr per mc/sq ft (derived from Rexroad's measurement),¹ assuming an effective² radius of 81.06 ft to the outside edge of Ground 2 tubing distribution. The value of I_c was measured at the experimental site immediately after the experiment; it was 0.373 mr/hr per mc/ft of circumference.

The data column entitled "Total Ground" is the summation of Ground 1, 2, and FO. The "Total 1st Story" and "2nd Story" are summations of columns 2 and 6 and of 1 and 6, respectively.

To obtain the protection factors these data were divided into 500 mr/hr per mc/sq ft, which is the value of the free-field infinite-plane exposure rate, also taken from Rexroad.¹

Even though some of the data are presented in four figures, they are accurate to no more than three significant figures. These data have not been corrected for source anisotropy or detector orientation.

Each table contains all contributions necessary to determine protection factors. It was assumed that shielding the basement windows would not change the roof contributions. Therefore, the tables show identical values for roof contributions with and without shielded basement windows.

Operational problems prevented a 200-ft radius measurement from being made for Phase 1A. Therefore, the far-out ground contributions in Tables 4.1 and 4.2 are identical, assuming that shielding the basement windows would not significantly change this contribution. Measurements during Phase 2 confirmed this assumption.

REFERENCES

1. R. E. Rexroad and M. A. Schmoke, Scattered Radiation and Free-Field Dose Rates from Distributed Co⁶⁰ and Cs¹³⁷ Sources, Report NDL-TR-2, Nuclear Defense Laboratory, September 1960.
2. Capt. Clayton L. Schlemn et al., Scattered Gamma Radiation Measurements from a Co⁶⁰ Contaminated Field, Report AFSWC-TN-59-6, Air Force Special Weapons Center, Kirtland AFB, New Mexico, January 1959.

(Text continued on page 65)

TABLE 4.1 - PHASE 1, BARE BASEMENT WITH UNSHIELDED BASEMENT WINDOWS

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	7.55	19.71	3.19	4.41	8.48	16.07	35.79	23.63	13.97	21.16
2	3	7.80	16.45	3.19	4.08	7.93	15.20	31.66	23.01	15.79	21.73
3	3	7.23	14.53	2.25	3.05	6.01	11.31	25.83	18.54	19.36	26.97
4	3	7.75	16.75	3.04	4.25	7.85	15.14	31.89	22.86	15.68	21.85
5	3	7.18	16.60	3.86	4.19	8.06	16.11	32.71	23.29	15.28	21.46
6	3	7.85	18.82	3.94	5.06	9.60	18.61	37.43	26.46	13.36	18.90
7	3	8.16	17.79	3.94	4.74	9.24	17.91	35.70	26.07	14.01	19.18
8	3	7.91	16.60	3.66	4.19	8.06	15.91	32.51	23.81	15.38	21.00
9	3	8.37	18.38	3.98	4.74	9.06	17.78	36.16	26.15	13.83	19.12
10	3	8.58	19.57	3.70	4.95	9.42	18.08	37.64	26.66	13.28	18.76
11	3	8.53	19.57	4.50	5.45	10.46	20.40	39.97	28.93	12.51	17.29
12	3	8.68	22.53	4.56	6.04	11.63	22.23	44.76	30.92	11.17	16.17
13	3	8.53	20.75	4.45	5.61	11.04	21.10	41.85	29.63	11.95	16.88
14	3	7.70	20.60	4.22	5.61	10.82	20.65	41.25	28.35	12.12	17.64
15	1	6.87	16.01	2.81	3.81	7.48	14.11	30.11	20.98	16.60	23.83
15	2	7.34	17.19	3.21	4.36	8.38	15.95	33.14	23.28	15.09	21.47
15	3	7.70	18.38	3.34	4.74	9.12	17.20	35.58	24.90	14.05	20.08
15	4	8.27	19.86	4.14	5.34	10.20	19.68	39.54	27.95	12.65	17.89
16	3	7.96	17.05	3.66	4.41	8.38	16.45	33.50	24.41	14.93	20.48
17	3	7.34	14.97	2.48	3.32	6.46	12.25	27.22	19.59	18.37	25.52
19	3	8.01	17.19	3.36	4.36	8.63	16.34	33.54	24.35	14.91	20.53
20	1	6.72	13.78	1.78	2.78	5.30	9.86	23.64	16.58	21.15	30.17
20	3	7.49	14.97	2.47	3.38	6.23	12.07	27.04	19.57	18.49	25.55
21	1	6.67	13.04	1.56	2.61	5.06	9.23	22.28	15.90	22.44	31.45
21	2	7.89	14.38	1.88	2.94	5.95	10.36	24.74	18.16	20.21	27.53
21	3	7.60	14.97	2.16	3.16	5.98	11.29	26.26	18.89	19.04	26.47
21	5	8.41	16.19	3.42	4.68	8.30	16.41	32.59	24.82	15.34	20.15
22	1	8.16	14.97	2.19	3.27	6.11	11.57	26.54	19.73	18.84	25.34
22	2	7.70	15.42	2.22	3.59	6.68	12.50	27.91	20.20	17.91	24.75
22	3	7.96	16.45	2.91	4.03	7.47	14.41	30.86	22.37	16.20	22.36
23	3	8.27	16.45	4.03	5.17	9.84	19.04	35.50	27.31	14.09	18.31
24	3	8.16	17.94	3.94	4.74	9.07	17.75	35.68	25.91	14.01	19.30
25	3	7.60	15.56	2.77	3.70	6.98	13.45	29.01	21.04	17.23	23.76
26	1	7.92	16.72	3.19	4.57	8.96	16.72	33.44	24.64	14.95	20.30
26	3	8.89	21.34	4.34	5.61	10.86	20.81	42.16	29.70	11.86	16.83
26	5	10.17	23.60	9.06	7.41	14.04	30.50	54.10	40.67	9.24	12.29
27	1	7.70	17.79	3.43	4.68	9.12	17.24	35.02	24.94	14.28	20.05
27	3	8.89	20.75	4.71	5.88	11.40	21.98	42.74	30.87	11.70	16.20
27	5	9.71	23.95	6.43	7.51	14.35	28.30	52.25	38.01	9.57	13.15
28	1	7.23	17.49	3.75	4.90	9.39	18.04	35.53	25.27	14.07	19.78
28	3	8.37	20.31	4.82	5.94	11.09	21.84	42.15	30.22	11.86	16.55
28	5	9.40	24.25	6.56	7.95	14.72	29.23	53.48	38.64	9.35	12.94
29	1	7.19	17.70	3.71	5.23	10.25	19.19	36.89	26.38	13.55	18.95
29	3	8.53	22.38	4.41	6.10	12.00	22.51	44.89	31.03	11.14	16.11
29	5	9.36	25.55	5.53	7.73	14.55	27.82	53.37	37.18	8.37	13.45
30	1	7.26	16.90	3.75	3.92	7.09	14.76	31.66	22.02	15.79	22.71
30	3	8.12	18.79	3.00	4.63	8.95	16.58	35.37	24.70	14.14	20.24
30	5	9.36	22.29	3.75	5.77	10.87	20.39	42.68	29.75	11.72	16.81
31	1	7.52	18.74	3.88	5.23	9.94	19.05	37.79	26.57	13.23	18.81
31	3	8.54	21.67	4.40	6.32	12.18	22.89	44.56	31.43	11.22	15.91
31	5	9.71	26.47	6.38	8.06	15.13	29.56	56.04	39.28	8.92	12.73
33	1	6.24	12.42	2.34	2.83	5.53	10.71	23.13	16.95	21.62	29.49
33	3	6.70	13.52	2.86	3.38	6.41	12.64	26.16	19.34	19.11	25.86
33	5	7.75	15.12	4.86	4.79	8.65	18.30	33.42	26.05	14.96	19.19
34	1	6.51	13.52	2.63	3.20	7.63	13.45	26.97	19.96	18.54	25.05
34	5	8.39	19.27	11.91	5.05	10.78	27.74	47.01	36.13	10.44	13.84

Fig. 4.1 - Protection factors at 3 ft above the basement floor for Phase 1, bare basement with unshielded basement windows for a one-story and a two-story wood frame house.

TABLE 4.2 - PHASE 1, BARE BASEMENT WITH SHIELDED BASEMENT WINDOWS

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	7.55	19.71	2.51	4.42	8.48	15.40	35.11	22.96	14.24	21.78
2	3	7.80	16.45	2.38	4.14	7.93	14.46	30.91	22.26	16.17	22.46
3	3	7.23	14.53	1.83	3.14	6.01	10.98	25.50	18.21	19.60	27.45
4	3	7.75	16.75	2.49	4.15	7.85	14.49	31.24	22.24	16.00	22.48
5	3	7.18	16.60	2.43	4.26	8.06	14.75	31.36	21.94	15.95	22.79
6	3	7.85	18.82	3.03	5.13	9.60	17.77	36.59	25.62	13.66	19.51
7	3	8.16	17.79	2.93	4.88	9.24	17.05	34.84	25.21	14.35	19.83
8	3	7.91	16.60	2.64	4.37	8.06	15.07	31.67	22.97	15.79	21.76
9	3	8.37	18.38	2.94	4.88	9.06	16.88	35.26	25.25	14.18	19.80
10	3	8.58	19.57	2.93	5.00	9.42	17.35	36.92	25.93	13.54	19.28
11	3	8.53	19.57	3.29	5.49	10.46	19.24	38.80	27.77	12.88	18.01
12	3	8.63	22.53	3.58	6.12	11.63	21.33	43.86	30.01	11.40	16.66
13	3	8.53	20.75	3.39	5.74	11.04	20.17	40.92	28.69	12.22	17.43
14	3	7.70	20.60	3.38	5.68	10.82	19.89	40.49	27.59	12.35	18.13
15	1	6.87	16.01	2.18	3.96	7.48	13.62	29.62	20.49	16.88	24.40
15	2	7.34	17.19	2.51	4.41	8.38	15.30	32.50	22.64	15.39	22.08
15	3	7.70	18.38	2.85	4.84	9.12	16.80	35.18	24.50	14.21	20.40
15	4	8.27	19.86	3.32	5.47	10.20	18.99	38.86	27.26	12.87	18.34
16	3	7.96	17.05	2.67	4.51	8.38	15.56	32.60	23.52	15.34	21.26
17	3	7.34	14.97	2.04	3.48	6.46	11.99	26.96	19.32	18.55	25.88
19	3	8.01	17.19	2.51	4.56	8.63	15.70	32.90	23.71	15.20	21.08
20	1	6.72	13.78	1.48	2.92	5.30	9.70	23.48	16.42	21.29	30.46
20	3	7.49	14.97	1.88	3.35	6.23	11.46	26.43	18.95	18.92	26.38
21	1	6.67	13.04	1.42	2.62	5.06	9.10	22.15	15.77	22.58	31.71
21	2	7.80	14.38	1.57	2.90	5.55	10.02	24.40	17.82	20.49	28.05
21	3	7.60	14.97	1.77	3.13	5.98	10.88	25.85	18.48	19.34	27.06
21	5	8.41	16.19	3.32	4.40	8.30	16.01	32.20	24.43	15.53	20.47
22	1	8.16	14.97	1.74	3.20	6.11	11.05	26.02	19.21	19.22	26.02
22	2	7.70	15.42	1.91	3.55	6.68	12.14	27.56	19.84	18.14	25.20
22	3	7.96	16.45	2.25	3.97	7.47	13.69	30.14	21.65	16.59	23.10
23	3	8.27	16.45	3.10	5.25	9.84	18.20	34.65	26.46	14.43	18.89
24	3	8.16	17.94	2.90	4.66	9.07	16.63	34.57	24.79	14.47	20.17
25	3	7.60	15.56	2.22	3.68	6.98	12.88	28.44	20.48	17.58	24.42
26	1	7.92	16.72	2.52	4.40	8.96	15.88	32.60	23.79	15.34	21.02
26	3	8.89	21.34	3.29	5.58	10.86	19.74	41.08	28.63	12.17	17.47
26	5	10.17	23.60	4.54	7.03	14.04	25.62	49.22	35.79	10.16	13.97
27	1	7.70	17.79	2.76	4.53	9.12	16.41	34.20	24.11	14.62	20.74
27	3	8.89	20.75	3.65	5.78	11.40	20.83	41.58	29.72	12.03	16.83
27	5	9.71	23.95	4.98	7.25	14.35	26.58	50.54	36.30	9.89	13.77
28	1	7.23	17.49	2.97	4.84	9.39	17.19	34.68	24.43	14.42	20.47
28	3	8.37	20.31	3.85	5.77	11.09	20.71	41.01	29.08	12.19	17.20
28	5	9.40	24.25	5.47	7.69	14.72	27.88	52.13	37.28	9.59	13.41
29	1	7.19	17.70	3.00	5.06	10.25	18.30	36.00	25.50	13.89	19.61
29	3	8.53	22.38	3.61	6.09	12.00	21.70	44.08	30.23	11.34	16.54
29	5	9.36	25.55	4.47	7.25	14.55	26.27	51.83	35.64	9.65	14.03
30	1	7.26	16.90	2.07	4.13	7.09	13.29	30.19	20.55	16.56	24.33
30	3	8.12	18.79	2.49	4.52	8.95	15.95	34.75	24.08	14.39	20.77
30	5	9.36	22.29	3.15	5.49	10.87	19.51	41.80	28.87	11.96	17.32
31	1	7.52	18.74	3.10	5.06	9.94	18.10	36.84	25.63	13.87	19.51
31	3	8.54	21.67	3.95	6.13	12.18	22.26	43.93	30.80	11.38	16.23
31	5	9.71	26.47	5.24	7.69	15.13	28.06	54.53	37.78	9.17	13.24
33	1	6.24	12.42	2.16	2.75	5.53	10.44	22.86	16.88	21.87	29.97
33	3	6.70	13.52	2.66	3.35	6.41	12.42	25.94	19.12	19.27	26.15
33	5	7.75	15.12	4.18	4.66	8.65	17.49	32.61	25.24	15.33	19.81
34	1	6.51	13.52	2.20	3.96	7.63	13.78	27.30	20.29	18.32	24.64
34	5	8.39	19.27	3.86	5.49	10.78	20.14	39.41	28.53	12.69	17.52

Fig. 4.2 - Protection factors at 3 ft above the basement floor for Phase 1, bare basement with shielded basement windows for a one-story and a two-story wood frame house.

TABLE 4.3 - PHASE 2A, 12 x 12-FT OVERHEAD BARRIER WITH STANDARD
CROSS BRACING BETWEEN JOISTS, AND PHASE 2B, 12 x 12-FT OVERHEAD BARRIER
WITH SIMULATED DUCT BETWEEN TWO JOISTS

PHASE 2A

POS	HT.	STORY 2	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 2	P.F. 2
1	3	3.75	2.38	2.92	5.39	10.69	14.44	34.64
2	3	1.83	2.04	2.19	3.78	8.01	9.84	50.83
3	3	1.57	1.58	1.54	2.54	5.65	7.22	69.26
4	3	2.05	2.11	2.15	3.68	7.94	9.98	50.09
5	1	3.01	1.82	2.30	4.38	8.51	11.51	43.42
5	3	3.41	2.17	2.60	4.93	9.70	13.12	38.12
5	5	3.38	2.74	2.91	5.15	10.80	14.17	35.28
6	3	2.72	2.64	3.05	5.37	11.07	13.79	36.26
7	3	2.12	2.45	2.60	4.47	9.53	11.65	42.93
8	3	2.09	1.87	2.14	3.73	7.74	9.83	50.86
9	3	2.33	2.45	2.53	4.44	9.42	11.75	42.54
10	3	2.65	2.50	2.78	5.17	10.45	13.10	38.18
11	3	2.47	2.79	2.96	5.27	11.02	13.50	37.04
12	3	3.49	3.19	3.93	7.21	14.33	17.82	28.05

PHASE 2B

POS	HT.	STORY 2	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 2	P.F. 2
1	3	3.95	2.72	2.93	5.51	11.16	15.11	33.10
2	3	3.53	2.38	2.40	4.29	9.08	12.61	39.67
3	3	2.28	1.84	1.69	2.93	6.46	8.74	57.20
4	3	2.82	2.48	2.35	4.07	8.89	11.72	42.68
5	1	4.12	2.09	2.31	4.72	9.12	13.24	37.76
5	3	4.07	2.48	2.78	5.19	10.45	14.52	34.43
5	5	3.30	3.17	3.03	5.30	11.51	14.80	33.77
6	3	2.97	3.03	3.18	5.73	11.94	14.92	33.52
7	3	4.01	2.86	2.82	5.15	10.83	14.84	33.70
8	3	3.34	2.52	2.40	4.21	9.13	12.47	40.09
9	3	3.68	2.89	2.77	4.97	10.63	14.31	34.94
10	3	3.96	2.94	3.02	5.73	11.69	15.65	31.95
11	3	4.34	3.25	3.30	5.85	12.39	16.73	29.88
12	3	3.69	3.39	3.98	7.53	14.91	18.60	26.89

Fig. 4.3 - Protection factors at 3 ft above basement floor for Phase 2 (A and B), 12 x 12-ft overhead barrier with standard cross bracing between joists and for a simulated duct between two joists for a two-story wood frame house.

TABLE 4.4 - PHASE 2CD, 12 x 12-FT SOLID OVERHEAD BARRIER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	3.92	9.62	2.37	2.93	5.34	10.64	20.26	14.56	24.68	34.35
2	3	2.00	4.65	2.09	2.17	3.68	7.95	12.59	9.95	39.71	50.26
3	3	1.65	2.88	1.59	1.54	2.46	5.60	8.47	7.24	59.00	69.04
4	3	2.12	4.29	2.12	2.11	3.52	7.76	12.05	9.88	41.51	50.60
5	1	3.64	8.43	1.89	2.35	4.38	8.62	17.04	12.25	29.33	40.80
5	3	3.64	8.59	2.24	2.62	4.94	9.80	18.40	13.44	27.18	37.20
5	5	3.20	8.31	2.84	2.92	5.13	10.90	19.20	14.09	26.04	35.47
6	3	2.94	7.95	2.74	3.06	5.35	11.15	19.10	14.08	26.18	35.50
7	3	2.27	5.36	2.53	2.59	4.43	9.55	14.91	11.82	33.53	42.29
8	3	2.16	3.91	2.21	2.19	3.59	7.98	11.89	10.14	42.06	49.33
9	3	2.38	4.91	2.56	2.54	4.34	9.43	14.34	11.81	34.87	42.33
10	3	2.77	7.11	2.60	2.86	5.03	10.49	17.60	13.26	28.40	37.71
11	3	2.63	6.36	2.88	2.99	5.11	10.98	17.34	13.62	28.83	36.72
12	3	3.70	11.57	3.25	3.88	7.18	14.32	25.88	18.02	19.32	27.75
23	3	3.13	8.77	2.91	3.17	5.76	11.85	20.62	14.98	24.25	33.37
24	3	2.26	5.30	2.62	2.56	4.46	9.64	14.04	11.89	33.46	42.04
25	3	1.96	3.62	1.94	1.88	3.07	6.88	10.50	8.84	47.63	56.53
15	1	3.39	8.72	2.11	2.62	5.06	9.79	18.50	13.18	27.02	37.95
15	2	2.92	9.02	2.42	2.87	5.42	10.72	19.73	13.64	25.34	36.67
15	3	3.20	8.88	2.71	3.05	5.53	11.28	20.16	14.48	24.80	34.53
15	4	3.02	8.54	3.10	3.29	5.81	12.20	20.74	15.22	24.11	32.86
16	3	1.93	4.71	2.29	2.25	4.00	8.54	13.25	10.46	37.73	47.78
17	3	1.72	3.34	1.84	1.72	2.80	6.36	9.70	8.08	51.53	61.89
13	3	2.89	8.00	3.13	3.34	6.09	12.56	20.57	15.46	24.31	32.35
14	3	4.47	11.85	3.23	3.95	7.49	14.66	26.51	19.13	18.86	26.14
26	1	7.91	16.67	2.53	3.76	7.57	13.86	30.52	21.77	16.38	22.97
26	3	8.79	19.79	3.40	4.70	9.35	17.45	37.24	26.24	13.43	19.05
26	5	10.07	23.59	4.73	6.15	12.57	23.45	47.04	33.52	10.63	14.91
27	1	7.68	17.72	2.98	4.36	8.79	16.13	33.85	23.81	14.77	21.00
27	3	8.76	20.31	4.17	5.55	10.96	20.68	40.99	29.44	12.20	16.99
27	5	9.72	23.89	6.03	7.05	14.00	27.89	50.88	36.80	9.81	13.59
28	1	7.22	17.49	3.21	4.36	8.81	16.38	33.87	23.59	14.76	21.19
28	3	8.06	19.80	4.31	5.36	10.68	20.35	40.16	28.42	12.45	17.60
28	5	9.40	24.26	6.38	7.25	14.02	27.65	51.91	37.05	9.63	13.50
29	1	7.17	17.69	3.15	4.46	9.02	16.63	34.32	23.80	14.57	21.01
29	3	8.28	20.42	3.87	5.36	10.57	19.80	40.23	28.09	12.43	17.80
29	5	9.35	25.59	4.88	6.58	13.22	24.68	50.27	34.03	9.95	14.69
21	1	6.66	12.69	1.37	2.16	4.31	7.84	20.53	14.50	24.35	34.47
21	2	7.14	13.57	1.55	2.42	4.85	8.82	22.39	15.96	22.33	31.32
21	3	7.58	14.42	1.80	2.73	5.41	9.94	24.36	17.53	20.52	28.53
21	5	8.40	16.20	3.42	4.05	7.59	15.06	31.26	23.46	16.00	21.32
22	1	7.05	14.29	1.70	2.78	5.31	9.79	24.08	16.84	20.76	29.70
22	2	7.54	14.82	1.97	3.00	5.93	10.90	25.71	18.44	19.45	27.12
22	3	8.09	15.98	2.32	3.48	6.72	12.52	28.50	20.61	17.55	24.26
30	1	7.25	16.90	2.10	3.55	7.08	12.73	29.63	19.98	16.88	25.03
30	3	8.11	18.79	2.65	4.21	8.43	15.29	34.08	23.40	14.67	21.37
30	5	9.35	22.31	3.39	5.20	10.50	19.09	41.40	28.44	12.08	17.58
31	1	7.51	18.73	3.36	4.64	9.35	17.35	36.09	24.87	13.86	20.11
31	3	8.53	21.70	4.36	5.77	11.57	21.71	43.40	30.23	11.52	16.54
31	5	9.69	26.48	6.01	7.42	14.69	28.12	54.59	37.81	9.16	13.23
33	1	6.24	12.40	2.15	2.61	5.07	9.83	22.24	16.08	22.49	31.10
33	3	6.69	13.50	2.75	3.10	6.17	12.03	25.53	18.71	19.59	26.72
33	5	7.73	15.14	4.60	4.38	8.37	17.34	32.49	25.07	15.39	19.94
34	1	6.50	13.50	2.30	3.20	6.55	12.05	25.55	18.55	19.57	26.96
34	3	7.33	15.79	2.85	3.82	7.53	14.19	29.98	21.53	16.68	23.23
34	5	8.39	20.42	4.13	5.05	9.79	18.97	39.39	27.36	12.69	18.27

Fig. 4.4 - Protection factors at 3 ft above the basement floor for Phase 2CD, 12 x 12-ft solid overhead barrier for a one-story and a two-story house.

TABLE 4.5 - PHASE 2E, 12 x 12-FT SOLID OVERHEAD BARRIER, ALL WINDOWS SHIELDED

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	3.92	9.62	2.12	2.92	5.51	10.56	20.18	14.47	24.78	34.54
2	3	2.00	4.65	1.78	2.10	3.46	7.34	11.99	9.34	41.71	53.52
3	3	1.65	2.88	1.33	1.53	2.44	5.30	8.18	6.95	61.14	71.98
4	3	2.12	4.29	1.76	2.08	3.50	7.34	11.63	9.46	42.99	52.83
5	1	3.64	8.43	1.65	2.17	4.37	8.40	16.82	12.03	29.72	41.55
5	3	3.64	8.59	1.96	2.60	4.79	9.34	17.94	12.98	27.88	38.52
5	5	3.20	8.31	2.30	2.86	4.96	10.12	18.42	13.31	27.14	37.55
6	3	2.94	7.95	2.40	3.05	5.30	10.75	18.70	13.69	26.74	36.53
7	3	2.27	5.36	2.21	2.58	4.27	9.05	14.41	11.33	34.69	44.15
8	3	2.16	3.91	1.89	2.15	3.47	7.52	11.42	9.67	43.77	51.69
9	3	2.38	4.91	2.15	2.53	4.25	8.92	13.83	11.30	36.15	44.24
10	3	2.77	7.11	2.18	2.82	4.95	9.95	17.07	12.72	29.30	39.31
11	3	2.63	6.36	2.47	2.96	5.08	10.51	16.87	13.15	29.64	38.03
12	3	3.70	11.57	2.80	3.89	7.11	13.81	25.38	17.51	19.70	28.55
23	3	3.13	8.77	2.46	3.55	5.56	11.07	19.84	14.20	25.20	35.21
24	3	2.26	5.30	2.13	2.47	4.21	8.81	14.11	11.06	35.43	45.19
25	3	1.96	3.62	1.61	1.77	3.05	6.42	10.04	8.38	49.82	59.64
15	1	3.39	8.72	1.86	2.54	4.94	9.34	18.06	12.73	27.69	39.28
15	2	2.92	9.02	2.11	2.78	5.30	10.19	19.21	13.11	26.03	38.13
15	3	3.20	8.88	2.29	2.92	5.49	10.71	19.59	13.91	25.52	35.96
15	4	3.02	8.54	2.67	3.16	5.59	11.43	19.97	14.44	25.04	34.62
16	3	1.93	4.71	1.87	2.17	3.71	7.75	12.46	9.68	40.12	51.68
17	3	1.72	3.34	1.51	1.63	2.87	6.01	9.35	7.73	53.47	64.71
13	3	2.89	8.00	2.60	3.22	5.84	11.66	19.66	14.55	25.43	34.35
14	3	4.47	11.85	2.77	3.84	7.29	13.90	25.75	18.37	19.41	27.22
26	1	7.91	16.67	2.27	3.70	7.40	13.37	30.03	21.28	16.65	23.50
26	3	8.79	19.79	2.89	4.63	9.21	16.73	36.52	25.53	13.69	19.59
26	5	10.07	23.59	4.05	5.91	12.20	22.15	45.74	32.23	10.93	15.52
27	1	7.68	17.72	2.69	4.25	8.70	15.64	33.36	23.33	14.99	21.43
27	3	8.76	20.31	3.51	5.33	10.81	19.65	39.96	28.41	12.51	17.60
27	5	9.72	23.89	5.08	6.96	13.81	25.85	49.74	35.57	10.05	14.06
28	1	7.22	17.49	2.85	4.25	8.66	15.76	33.25	22.98	15.04	21.76
28	3	8.06	19.80	3.74	5.29	10.64	19.67	39.47	27.73	12.67	18.03
28	5	9.40	24.26	5.59	7.86	13.73	26.37	50.63	35.77	9.88	13.98
29	1	7.17	17.69	2.80	4.37	8.80	15.98	33.67	23.15	14.85	21.60
29	3	8.28	20.42	3.39	5.15	10.44	18.99	39.41	27.27	12.69	18.33
29	5	9.35	25.59	4.15	6.35	12.84	23.34	48.92	32.69	10.22	15.30
21	1	6.66	12.69	1.21	2.11	4.22	7.54	20.24	14.21	24.71	35.19
21	2	7.14	13.57	1.43	2.31	4.81	8.55	22.12	15.69	22.61	31.87
21	3	7.58	14.42	1.62	2.62	5.26	9.51	23.92	17.09	20.90	29.24
21	5	8.40	16.20	3.06	3.88	7.47	14.40	30.60	22.80	16.34	21.93
22	1	7.05	14.29	1.54	2.68	5.36	9.58	23.88	16.63	20.94	30.06
22	2	7.54	14.82	1.74	2.84	5.83	10.41	25.22	17.95	19.82	27.86
22	3	8.09	15.98	2.09	3.37	6.75	12.20	28.18	20.30	17.74	24.64
30	1	7.25	16.90	1.91	3.44	6.93	12.28	29.18	19.53	17.14	25.60
30	3	8.11	18.79	2.37	4.09	8.24	14.71	33.50	22.82	14.92	21.91
30	5	9.35	22.31	3.02	5.01	10.21	18.24	40.55	27.59	12.33	18.12
31	1	7.51	18.73	3.02	4.60	9.26	16.87	35.61	24.39	14.04	20.50
31	3	8.53	21.70	3.85	5.71	11.40	20.96	42.66	29.49	11.72	16.95
31	5	9.69	26.48	5.25	7.24	14.34	26.84	53.31	36.53	9.38	13.69
33	1	6.24	12.40	2.04	2.47	5.15	9.65	22.06	15.90	22.67	31.45
33	3	6.69	13.50	2.59	3.07	6.06	11.72	25.22	18.40	19.83	27.17
33	5	7.73	15.14	4.19	4.32	8.25	16.77	31.91	24.49	15.67	20.41
34	1	6.50	13.50	2.09	3.12	6.46	11.67	25.17	18.17	19.86	27.51
34	3	7.33	15.79	2.60	3.70	7.40	13.69	29.48	21.03	16.96	23.78
34	5	8.39	20.42	3.74	4.85	9.48	18.07	38.49	26.46	12.99	18.90

Fig. 4.5 - Protection factors at 3 ft above the basement floor for Phase 2E, 12 x 12-ft solid overhead barrier with all basement windows shielded for a one-story and a two-story house.

TABLE 4.6 - PHASE 2F, 12 x 16-FT SOLID OVERHEAD BARRIER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	2.24	5.59	2.40	2.43	4.27	9.09	14.68	11.34	34.05	44.10
2	3	1.88	3.55	2.14	1.98	3.18	7.30	10.86	9.18	46.05	54.46
3	3	1.66	2.77	1.66	1.52	2.32	5.50	8.27	7.15	60.46	69.89
4	3	2.08	4.20	2.19	2.03	3.31	7.53	11.72	9.60	42.66	52.07
5	3	3.53	8.56	2.28	2.55	4.53	9.36	17.92	12.90	27.90	38.77
6	3	2.39	5.19	2.70	2.57	4.39	9.66	14.85	12.05	33.68	41.51
7	3	2.19	4.54	2.63	2.39	3.88	8.89	13.44	11.08	37.21	45.12
8	3	2.08	3.71	2.35	2.14	3.39	7.88	11.59	9.97	43.13	50.16
9	3	2.29	4.63	2.64	2.44	4.07	9.15	13.78	11.44	36.30	43.71
10	3	2.63	6.91	2.64	2.74	4.74	10.12	17.03	12.75	29.36	39.23
11	3	2.50	5.60	2.98	2.72	4.60	10.31	15.91	12.80	31.43	39.06
12	3	3.08	8.98	3.23	3.54	6.32	13.08	22.06	16.16	22.46	30.94
5	1	3.51	8.20	1.91	2.25	4.18	8.35	16.55	11.86	30.22	42.18
5	5	3.08	8.25	2.86	2.88	5.00	10.74	18.99	13.82	26.33	36.19
23	3	2.34	5.35	2.74	2.64	4.48	9.85	15.20	12.20	32.89	41.00
24	3	2.16	4.36	2.58	2.30	3.77	8.64	13.01	10.81	38.44	46.27
25	3	1.85	3.30	1.98	1.76	2.78	6.52	9.82	8.37	50.90	59.77
15	1	2.08	5.81	2.01	2.23	4.16	8.40	14.22	10.48	35.17	47.70
15	2	2.19	5.80	2.30	2.45	4.26	9.01	14.81	11.19	33.77	44.66
15	3	2.11	5.35	2.53	2.54	4.31	9.38	14.73	11.49	33.94	43.52
15	4	2.17	5.07	2.96	2.70	4.35	10.01	15.09	12.18	33.14	41.04
16	3	1.87	3.72	2.31	2.11	3.35	7.77	11.49	9.64	43.52	51.86
17	3	1.70	3.14	1.84	1.66	2.57	6.07	9.21	7.78	54.28	64.30
29	1	6.04	15.64	3.09	4.18	8.12	15.40	31.04	21.43	16.11	23.33
29	3	6.86	17.72	3.73	4.88	9.48	18.10	35.81	24.96	13.96	20.03
29	5	7.73	21.58	4.76	5.96	11.53	22.24	43.82	29.97	11.41	16.68
34	1	4.42	10.23	2.16	2.73	5.27	10.15	20.39	14.57	24.53	34.31
34	3	4.80	11.17	2.67	3.18	5.87	11.73	22.89	16.53	21.84	30.26
34	5	5.34	13.03	3.86	4.05	7.17	15.07	28.11	20.41	17.79	24.50
13	3	2.62	5.88	3.07	2.94	5.00	11.01	16.89	13.62	29.61	36.71
14	3	2.69	7.93	3.07	3.64	5.84	12.55	20.48	15.24	24.41	32.81

TABLE 4.7 - PHASE 2G, 12 x 16-FT SOLID OVERHEAD BARRIER, ALL WINDOWS SHIELDED

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	2.24	5.59	1.96	2.34	4.12	8.42	14.01	10.67	35.68	46.86
2	3	1.88	3.55	1.72	1.85	2.97	6.54	10.09	8.42	49.54	59.40
3	3	1.66	2.77	1.34	1.39	2.24	4.06	7.74	6.62	64.62	75.50
4	3	2.08	4.20	1.73	1.96	3.20	6.88	11.08	8.96	45.13	55.79
5	3	3.53	8.56	1.87	2.46	4.60	8.93	17.49	12.46	28.59	40.13
6	3	2.39	5.19	2.24	2.47	4.18	8.90	14.09	11.29	35.49	44.29
7	3	2.19	4.54	2.11	2.26	3.68	8.05	12.60	10.24	39.69	48.83
8	3	2.08	3.71	1.89	1.96	3.24	7.09	10.80	9.18	46.29	54.49
9	3	2.29	4.63	2.04	2.32	3.89	8.26	12.88	10.55	38.81	47.40
10	3	2.63	6.91	2.11	2.61	4.69	9.40	16.32	12.03	30.64	41.56
11	3	2.50	5.60	2.29	2.65	4.44	9.37	14.98	11.87	33.38	42.12
12	3	3.08	8.98	2.65	3.38	6.17	12.20	21.18	15.28	23.61	32.73
5	1	3.51	8.20	1.58	2.16	4.16	7.90	16.10	11.41	31.05	43.82
5	5	3.08	8.25	2.21	2.73	4.83	9.78	18.03	12.85	27.73	38.90
23	3	2.34	5.35	2.28	2.53	4.24	9.05	14.40	11.39	34.72	43.89
24	3	2.16	4.36	2.04	2.21	3.62	7.87	12.23	10.03	40.87	49.84
25	3	1.85	3.30	1.60	1.68	2.70	5.97	9.27	7.82	53.91	63.95
15	1	2.08	5.81	1.70	2.15	3.97	7.82	13.63	9.90	36.67	50.51
15	2	2.19	5.80	1.91	2.34	4.20	8.45	14.25	10.64	35.09	47.01
15	3	2.11	5.35	2.10	2.42	4.15	8.68	14.03	10.79	35.64	46.35
15	4	2.17	5.07	2.42	2.51	4.18	9.12	14.20	11.29	35.22	44.28
16	3	1.87	3.72	1.84	1.99	3.16	6.98	10.70	8.86	46.71	56.46
17	3	1.70	3.14	1.47	1.52	2.45	5.44	8.57	7.14	58.32	70.05
29	1	6.04	15.64	2.58	4.05	8.01	14.64	30.28	20.68	16.51	24.17
29	3	6.86	17.72	3.18	4.76	9.39	17.34	35.06	24.20	14.26	20.66
29	5	7.73	21.58	3.92	5.67	11.25	20.84	42.42	28.57	11.79	17.50
34	1	4.42	10.23	1.88	2.67	5.16	9.71	19.95	14.13	25.07	35.39
34	3	4.80	11.17	3.07	3.10	5.77	11.94	23.11	16.74	21.64	29.87
34	5	5.34	13.03	3.39	3.85	6.97	14.21	27.24	19.54	18.36	25.58
13	3	2.62	5.88	2.46	2.80	4.90	10.16	16.84	12.77	31.17	39.14
14	3	2.69	7.93	2.51	3.14	5.67	11.33	19.26	14.02	25.96	35.67

Fig. 4.6 - Protection factors at 3 ft above the basement floor for Phase 2F, 12 x 16-ft solid overhead barrier for a one-story and a two-story house.

N ←

ONE-STORY WOOD FRAME HOUSE

N ←

TWO-STORY WOOD FRAME HOUSE

Fig. 4.7 - Protection factors at 3 ft above the basement floor for Phase 2G, 12 x 16-ft solid overhead barrier, all basement windows shielded for a one-story and a two-story house.

TABLE 4.8 - PHASE 3, SIT-DOWN SHELTER, LEAN-TO SHELTER, AND WORKBENCH SHELTER COVERED WITH MAGAZINES AND BOOKS

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
15	1	.66	1.60	.19	.18	.39	.76	2.36	1.43	211.67	350.05
15	2	.78	1.86	.24	.21	.44	.89	2.75	1.67	181.63	298.79
15	3	.88	2.16	.26	.23	.48	.97	3.13	1.84	159.88	271.26
15	4	1.06	2.46	.30	.26	.54	1.11	3.56	2.17	140.33	230.85
16	3	1.19	2.51	.31	.25	.52	1.08	3.59	2.27	139.29	220.21
17	3	1.06	2.13	.31	.26	.54	1.12	3.25	2.17	153.94	230.00
18	3	1.06	2.50	.28	.26	.52	1.06	3.56	2.12	140.37	235.38
19	3	1.47	3.38	.31	.36	.74	1.41	4.79	2.88	104.35	173.86
20	1	1.06	2.29	.15	.20	.41	.77	3.06	1.83	163.32	273.08
20	3	1.19	2.49	.18	.22	.45	.85	3.34	2.04	149.63	244.75
35	3	2.10	4.80	.47	.58	1.20	2.25	7.06	4.36	70.86	114.80
21	1	4.36	6.50	.89	1.24	2.54	4.67	11.18	9.03	44.74	55.36
21	2	4.93	5.79	.68	.97	1.96	3.62	9.40	8.55	53.18	58.51
22	1	3.69	7.99	1.09	1.67	3.36	6.12	14.10	9.80	35.45	51.00

TABLE 4.9 - PHASE 4A, TILT-UP UNIT SHELTER, WITH DOORWAY AND WORKBENCH SHELTER WITH CONCRETE ON SIDES AND TOP

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
23	3	1.69	3.48	.58	.62	1.29	2.49	5.97	4.18	83.77	119.56
24	3	2.04	3.78	.41	.41	.83	1.65	5.43	3.69	92.11	135.48
25	3	1.66	2.89	.31	.29	.56	1.16	4.05	2.82	123.41	177.49
21	1	1.21	3.30	.29	.55	1.12	1.96	5.26	3.17	95.09	157.71
21	2	1.16	2.00	.30	.45	.82	1.57	3.57	2.72	140.05	183.49
22	1	1.27	3.55	.19	.39	.82	1.41	4.95	2.68	100.93	186.73
22	2	1.28	2.34	.40	.50	.92	1.82	4.16	3.10	120.22	161.22

TABLE 4.10 - PHASE 4B, TILT-UP UNIT SHELTER WITH DOORWAY CLOSED

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
23	3	1.52	3.08	.25	.27	.53	1.06	4.14	2.58	120.91	193.84
24	3	1.96	3.81	.37	.36	.69	1.42	5.24	3.39	95.44	147.66
25	3	1.65	2.88	.31	.27	.54	1.13	4.01	2.78	124.65	179.73

TABLE 4.11 - PHASE 5, 12 x 12-FT ALTERNATE SOLID OVERHEAD BARRIER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	3.41	8.65	2.24	2.62	4.74	9.60	18.25	13.01	27.40	38.43
2	3	1.93	4.16	2.06	2.12	3.37	7.56	11.72	9.46	42.66	52.85
3	3	1.45	2.93	1.55	1.46	2.25	5.27	8.20	6.72	60.99	74.37
4	3	2.11	4.06	1.97	1.92	3.16	7.05	11.11	9.15	45.02	54.62
5	3	3.49	7.84	2.10	2.43	4.44	8.97	16.81	12.46	29.75	40.14
6	3	2.64	7.16	2.53	2.80	4.79	10.12	17.28	12.75	28.93	39.20
7	3	2.17	4.68	2.46	2.37	3.97	8.80	13.48	10.97	37.10	45.59
8	3	1.92	3.52	2.12	2.80	3.26	7.38	10.90	9.30	45.86	53.75
9	3	2.19	4.66	2.32	2.27	3.78	8.36	13.02	10.55	38.39	47.40
10	3	2.51	6.41	2.43	2.60	4.65	9.68	16.09	12.19	31.08	41.02
11	3	2.43	5.57	2.71	2.67	4.65	10.02	15.59	12.45	32.07	40.16
12	3	3.24	10.17	3.08	3.62	6.70	13.40	23.57	16.63	21.22	30.06
5	1	3.37	7.49	1.73	2.18	3.95	7.86	15.36	11.23	32.56	44.52
5	5	3.63	8.62	2.54	2.72	4.93	10.19	18.81	13.82	26.58	36.18
23	3	2.84	7.79	2.60	2.88	5.03	10.51	18.30	13.35	27.33	37.46
24	3	2.13	4.45	2.32	2.41	3.87	8.59	13.04	10.72	38.35	46.65
25	3	1.76	3.22	1.80	1.77	2.64	6.21	9.43	7.98	53.02	62.68
15	1	3.01	7.67	1.92	2.49	4.51	8.92	16.58	11.93	30.15	41.90
15	2	2.97	7.57	2.11	2.56	4.64	9.30	16.87	12.28	29.64	40.73
15	3	2.72	7.49	2.35	2.72	4.74	9.81	17.30	12.53	28.90	39.91
15	4	2.63	7.58	2.69	2.93	5.08	10.70	18.28	13.34	27.35	37.49
16	3	1.87	4.07	2.20	2.17	3.56	7.93	12.00	9.79	41.67	51.06
17	3	1.53	2.97	1.71	1.63	2.38	5.72	8.69	7.25	57.57	68.99
18	3	2.47	6.86	2.38	2.65	4.56	9.58	16.44	12.05	30.41	41.48
13	3	2.65	7.36	2.84	3.66	5.37	11.27	18.63	13.92	26.83	35.91
14	3	4.10	10.93	3.08	3.73	6.76	13.57	24.50	17.67	20.41	28.29

Fig. 4.8 - Protection factors at 3 ft above the basement floor for Phase 3, sit-down shelter, lean-to shelter, and workbench shelter with top covered with magazines, newspapers, and books for a one-story and a two-story house.

Fig. 4.9 - Protection factors for Phase 4A, tilt-up unit shelter with entrance-way unshielded and workbench shelter with concrete blocks on sides and top for a one-story and a two-story house.

Fig. 4.10 - Protection factors at 3 ft above the basement floor for Phase 4B, tilt-up unit shelter with entranceway shielded for a one-story and a two-story house.

ONE-STORY WOOD FRAME HOUSE

TWO-STORY WOOD FRAME HOUSE

Fig. 4.11 - Protection factors at 3 ft above the basement floor for Phase 5, 12 x 12-ft alternate solid overhead barrier for a one-story and a two-story house.

TABLE 4.12 - PHASE 6A, 12 x 12-FT BY 2.25-IN. -THICK CONCRETE OVERHEAD BARRIER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	5.43	13.48	2.87	3.56	6.06	12.49	25.97	17.92	19.25	27.90
2	3	4.21	9.37	2.70	2.99	5.01	10.70	20.07	14.91	24.01	33.53
3	3	3.78	7.51	2.12	2.22	3.46	7.80	15.31	11.58	32.66	43.16
4	3	4.44	9.44	2.75	3.08	4.99	10.82	20.25	15.25	24.49	32.78
5	3	5.17	12.20	2.66	4.61	5.68	12.95	25.14	18.12	19.89	27.60
6	3	5.24	12.84	3.35	4.32	6.73	14.39	27.23	19.64	18.36	25.46
7	3	4.53	10.59	3.14	3.59	5.88	12.61	23.20	17.14	21.55	29.16
8	3	4.44	9.44	2.78	3.08	5.03	10.90	20.33	15.33	24.99	32.61
9	3	4.63	10.78	3.09	3.52	5.83	12.44	23.22	17.06	21.93	29.30
10	3	5.24	12.84	3.19	3.94	6.50	13.64	26.47	18.88	18.89	26.48
11	3	4.87	12.26	3.53	4.16	6.97	14.66	26.92	19.53	18.97	25.61
12	3	5.99	16.30	3.80	4.90	8.44	17.14	33.45	23.14	14.95	21.61
13	3	5.26	14.12	3.77	4.58	7.62	15.96	30.09	21.23	16.42	23.56
14	3	5.84	15.73	3.84	4.90	8.16	16.90	32.63	22.74	15.33	21.99
15	3	5.32	13.03	3.14	3.97	6.44	13.55	26.58	18.87	18.81	26.50
16	3	4.34	10.08	2.96	3.31	5.31	11.59	21.67	15.93	23.08	31.38
17	3	4.04	7.96	2.30	2.52	3.92	8.74	16.70	12.78	29.95	39.12
23	3	5.24	13.48	3.33	4.01	6.85	14.20	27.68	19.44	18.07	25.72
24	3	4.49	10.33	3.10	3.48	5.80	12.38	22.71	16.87	22.02	29.64
25	3	4.16	7.90	2.43	2.59	4.24	9.26	17.16	13.42	29.14	37.26

TABLE 4.13 - PHASE 6B, 12 x 12-FT BY 4.50-IN. -THICK CONCRETE OVERHEAD BARRIER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	4.27	10.57	2.59	3.21	5.71	11.51	22.08	15.78	22.44	31.69
2	3	2.69	6.25	2.50	2.68	4.59	9.77	16.02	12.46	31.20	40.13
3	3	2.27	4.18	1.91	1.94	3.03	6.88	11.06	9.15	45.21	54.66
4	3	2.71	5.79	2.54	2.67	4.68	9.89	15.68	12.60	31.90	39.68
5	3	4.14	9.29	2.47	3.05	5.57	11.09	20.37	15.23	24.54	32.83
6	3	3.77	9.44	3.10	3.63	6.28	13.01	22.45	16.78	22.27	29.80
7	3	2.91	7.24	2.93	3.16	5.49	11.57	18.82	14.49	26.57	34.52
8	3	2.75	5.73	2.58	2.69	4.62	9.89	15.62	12.65	32.01	39.53
9	3	3.03	7.03	2.88	3.12	5.47	11.46	18.49	14.49	27.04	34.50
10	3	3.64	9.39	2.95	3.46	6.11	12.52	21.92	16.17	22.81	30.93
11	3	3.89	8.59	3.29	3.70	6.48	13.47	22.06	17.36	22.67	28.79
12	3	4.57	13.31	3.49	4.47	8.06	16.02	29.33	20.59	17.05	24.28
13	3	3.68	10.29	3.40	4.00	7.16	14.56	24.85	18.24	20.12	27.41
14	3	4.77	12.44	3.53	4.58	8.06	16.18	28.62	20.95	17.47	23.87
15	3	3.94	9.98	2.92	3.47	6.05	12.44	22.42	16.38	22.70	30.53
16	3	2.75	6.50	2.68	2.82	4.90	10.41	16.91	13.15	29.57	38.01
17	3	2.44	4.63	2.12	2.18	3.55	7.86	12.49	10.29	40.05	48.57
23	3	3.76	10.08	3.08	3.43	6.41	13.12	23.20	16.88	21.55	29.62
24	3	2.98	6.76	2.89	3.10	5.32	11.31	18.07	14.21	27.67	35.20
25	3	2.47	4.98	2.29	2.29	3.82	8.40	13.39	10.87	37.35	45.98

TABLE 4.14 - PHASE 6C, 12 x 12-FT BY 6.75-IN. -THICK CONCRETE OVERHEAD BARRIER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	3.76	9.19	2.65	3.02	5.50	11.17	20.36	14.94	24.56	33.48
2	3	1.77	4.69	2.49	2.50	4.35	9.34	14.03	11.10	35.65	45.04
3	3	1.40	2.77	1.86	1.65	3.15	6.66	9.43	8.06	53.02	62.04
4	3	1.80	4.25	2.51	2.51	4.37	9.39	13.63	11.19	36.68	44.68
5	3	3.73	8.23	2.47	2.95	5.32	10.74	18.97	14.47	26.35	34.56
6	3	2.91	7.87	3.09	3.45	6.07	12.61	20.47	15.52	24.42	32.21
7	3	2.02	5.19	2.92	2.94	5.16	11.01	16.20	13.03	30.87	38.39
8	3	1.79	3.93	2.59	2.53	4.35	9.46	13.39	11.25	37.34	44.45
9	3	2.03	5.06	2.92	2.95	5.09	10.96	16.02	12.99	31.21	38.48
10	3	2.77	7.84	2.93	3.26	5.80	11.99	19.83	14.77	25.21	33.86
11	3	2.28	6.52	3.31	3.52	6.05	12.88	19.40	15.16	25.77	32.98
12	3	3.86	11.62	3.52	4.27	7.82	15.61	27.22	19.47	18.37	25.68
13	3	2.80	8.36	3.43	3.85	6.76	14.04	22.40	16.83	22.32	29.70
14	3	4.27	11.12	3.54	4.46	7.99	15.99	27.11	20.26	18.44	24.68
15	3	3.27	8.38	2.92	3.33	5.72	11.97	20.34	15.24	24.58	32.81
16	3	1.83	4.70	2.69	2.66	4.64	9.98	14.68	11.81	34.05	42.34
17	3	1.52	3.01	2.10	1.97	3.24	7.22	10.32	8.84	48.43	56.55
23	3	3.07	8.45	3.07	3.44	6.05	12.56	21.01	15.63	23.80	32.00
24	3	1.94	4.83	2.92	2.91	4.95	10.77	15.61	12.71	32.04	39.32
25	3	1.57	3.07	2.26	2.11	3.63	8.00	11.07	9.57	45.17	52.26

Fig. 4.12 - Protection factors at 3 ft above the basement floor for Phase 6A, 12 x 12-ft by 2.25-in. thick concrete overhead barrier for a one-story and a two-story house.

ONE-STORY WOOD FRAME HOUSE

TWO-STORY WOOD FRAME HOUSE

Fig. 4.13 - Protection factors at 3 ft above the basement floor for Phase 6B, 12 x 12-ft by 4.50-in. -thick concrete overhead barrier for a one-story and a two-story house.

Fig. 4.14 - Protection factors at 3 ft above the basement floor for Phase 6C, 12 x 12-ft by 6.75-in. -thick concrete overhead barrier for a one-story and a two-story house.

TABLE 4.15 - PHASE 6D, SIMULATED BRICK VENEER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
3	1	6.28	12.22	1.68	2.45	4.26	8.39	20.61	14.67	24.26	34.08
3	3	6.83	13.30	2.03	3.09	4.96	10.08	23.38	16.92	21.38	29.56
3	5	7.59	14.99	3.63	4.04	6.59	14.26	29.26	21.86	17.09	22.87
5	1	6.95	14.53	2.29	3.54	6.20	12.04	26.57	18.99	18.82	26.33
5	3	7.17	15.40	2.73	4.29	7.07	14.10	29.50	21.27	16.95	23.51
5	5	7.26	17.71	3.47	4.84	8.50	16.80	34.52	24.06	14.49	20.78
13	1	7.20	17.00	2.98	4.54	8.01	15.54	32.53	22.73	15.37	21.99
13	3	8.14	19.31	3.96	5.68	9.73	19.37	38.67	27.51	12.93	18.18
13	5	9.61	22.80	5.51	7.31	12.26	25.08	47.88	34.69	10.44	14.41
8	3	7.44	15.35	2.89	4.02	6.91	13.82	29.18	21.27	17.14	23.51
21	3	7.64	14.33	2.03	3.16	5.26	10.44	24.76	18.08	20.19	27.65
26	3	8.82	20.49	3.74	5.75	9.80	19.28	39.77	28.10	12.57	17.80
27	1	7.47	17.92	2.96	4.68	8.13	15.77	33.69	23.24	14.84	21.51
27	3	8.72	20.18	4.15	5.93	10.19	20.26	40.44	28.98	12.36	17.25
27	5	9.94	24.49	7.12	8.93	13.93	29.08	53.57	39.02	9.33	12.81
28	3	8.14	19.64	4.51	5.77	10.04	20.33	39.97	28.47	12.51	17.56
29	1	7.35	19.10	3.41	5.27	9.25	17.93	37.03	25.28	13.50	19.78
29	3	8.27	21.26	4.25	6.22	10.88	21.35	42.61	29.62	11.73	16.88
29	5	9.36	25.47	5.27	7.27	12.77	25.31	50.77	34.67	9.85	14.42
31	3	8.39	21.87	4.98	6.41	11.24	22.63	44.50	31.02	11.24	16.12
32	1	6.65	15.33	2.31	3.66	6.26	12.23	27.56	18.88	18.15	26.49
32	3	7.37	17.20	3.11	4.34	7.61	15.06	32.26	22.42	15.50	22.30
32	5	7.96	19.46	4.77	5.63	9.41	19.81	39.27	27.77	12.73	18.00
33	3	6.68	13.86	2.80	3.16	5.44	11.40	25.26	18.08	19.80	27.66
34	1	6.65	15.45	2.53	3.77	6.73	13.03	28.49	19.68	17.55	25.40
34	3	7.17	17.15	3.09	4.38	7.62	15.10	32.25	22.27	15.50	22.45
34	5	8.19	20.18	4.37	5.41	9.33	19.11	39.28	27.30	12.73	18.32

TABLE 4.16 - PHASE 6E, TYPICAL FIRST-FLOOR FURNITURE

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	6.99	17.18	3.01	4.17	7.71	14.89	32.07	21.88	15.59	22.85
2	3	7.01	15.35	2.86	4.01	7.40	14.27	29.62	21.28	16.88	23.50
3	3	6.31	13.09	2.14	2.88	5.52	10.54	23.62	16.84	21.16	29.68
4	3	7.33	15.38	2.94	4.00	7.21	14.15	29.53	21.48	16.93	23.28
5	3	6.96	15.46	2.88	4.37	7.46	14.71	30.17	21.67	16.97	23.07
6	3	7.60	17.94	3.55	5.12	9.17	17.84	35.77	25.44	13.98	19.65
7	3	7.39	16.48	3.34	4.69	8.47	16.51	32.99	23.90	15.15	20.92
8	3	7.30	15.24	3.10	4.11	7.58	14.79	30.03	22.10	16.65	22.63
9	3	7.95	17.02	3.40	4.59	8.53	16.52	33.54	24.46	14.91	20.44
10	3	8.38	18.29	3.44	4.86	8.87	17.16	35.45	25.54	14.10	19.58
11	3	8.07	18.85	3.90	5.44	9.80	19.14	37.99	27.21	13.16	18.38
12	3	8.46	21.44	4.17	5.95	10.88	21.01	42.45	29.47	11.78	16.97
23	3	7.48	17.86	3.53	5.04	8.99	17.56	35.41	25.04	14.12	19.97
24	3	7.48	16.37	3.29	4.63	8.25	16.16	32.54	23.64	15.37	21.15
25	3	7.01	14.11	2.64	3.57	6.44	12.64	26.75	19.65	18.69	25.45
15	3	7.27	16.91	3.30	4.61	8.49	16.40	33.31	23.67	15.01	21.12
16	3	7.34	15.59	3.10	4.24	7.93	15.27	30.86	22.60	16.20	22.12
17	3	6.68	13.90	2.46	3.30	5.96	11.71	25.61	18.40	19.52	27.18
13	3	7.95	19.09	3.99	5.53	10.19	19.71	38.81	27.66	12.88	18.08
14	3	7.38	18.96	3.96	5.63	10.13	19.72	38.68	27.10	12.93	18.45
26	3	8.56	20.44	4.06	5.67	10.22	19.95	40.39	28.51	12.38	17.54
27	3	8.21	19.44	4.67	5.73	10.79	21.18	40.63	29.40	12.31	17.01
28	3	7.89	19.28	4.61	5.57	10.37	20.55	39.84	28.45	12.55	17.58
29	3	8.11	20.84	4.33	6.04	11.18	21.55	42.40	29.66	11.79	16.86
30	3	8.08	18.74	2.95	4.57	8.46	15.98	34.73	24.06	14.40	20.78
31	3	8.38	21.06	4.78	6.06	11.32	22.17	43.23	30.54	11.57	16.37
32	3	7.25	16.37	3.12	4.29	7.90	15.31	31.68	22.56	15.78	22.17
33	3	6.24	12.98	2.94	3.19	5.89	12.02	25.01	18.27	20.00	27.37
34	3	7.04	16.37	3.14	4.39	8.06	15.59	31.97	22.63	15.64	22.09
20	3	6.67	13.90	2.17	3.32	5.81	11.30	25.20	17.98	19.84	27.81
21	3	6.97	13.47	2.07	3.08	5.56	10.71	24.18	17.68	20.68	28.28

Fig. 4.15 - Protection factors at 3 ft above the basement floor for Phase 6D, simulated brick veneer for a one-story and a two-story house.

Fig. 4.16 - Protection factors at 3 ft above the basement floor for Phase 6E, typical first-floor furniture distributed realistically for a one-story and a two-story house.

TABLE 4.17 - PHASE 6F, FURNITURE STACKED IN ONE CORNER

POS	HT.	STORY 2	STORY 1	GROUND 1	GROUND 2	GROUND FO	TOTAL GRD	TOTAL 1	TOTAL 2	P.F. 1	P.F. 2
1	3	6.75	15.90	3.06	4.44	7.86	15.36	31.26	22.11	15.99	22.61
2	3	6.26	14.24	2.92	4.13	7.39	14.43	28.67	20.69	17.44	24.16
3	3	5.44	11.43	2.21	3.03	5.32	10.57	22.00	16.00	22.73	31.25
4	3	6.32	13.72	3.00	4.10	7.09	14.19	27.91	20.51	17.92	24.38
5	3	6.52	15.35	3.02	4.43	7.46	14.91	30.26	21.43	16.52	23.33
6	3	7.10	16.42	3.65	5.17	9.13	17.95	34.37	25.05	14.55	19.96
7	3	6.72	14.86	3.41	4.76	8.38	16.55	31.41	23.26	15.92	21.49
8	3	6.63	13.61	3.18	4.31	7.38	14.87	28.48	21.49	17.56	23.26
9	3	6.99	15.33	3.47	4.67	8.38	16.52	31.84	23.51	15.70	21.27
10	3	7.47	17.09	3.51	4.97	8.71	17.18	34.27	24.65	14.59	20.29
11	3	7.39	17.56	3.96	5.54	9.69	19.19	36.76	26.59	13.60	18.81
12	3	8.03	20.68	4.26	6.05	10.87	21.17	41.85	29.21	11.95	17.12
23	3	7.19	16.42	3.63	5.24	9.06	17.93	34.35	25.12	14.56	19.90
24	3	6.81	14.57	3.33	4.63	8.22	16.18	30.76	22.99	16.26	21.75
25	3	5.99	12.31	2.68	3.70	6.29	12.67	24.99	18.66	20.01	26.80
15	3	7.02	15.93	3.39	4.77	8.48	16.64	32.57	23.67	15.35	21.13
16	3	6.57	14.44	3.14	4.40	7.83	15.37	29.81	21.93	16.77	22.79
17	3	5.93	11.90	2.52	3.44	5.88	11.83	23.73	17.76	21.07	28.16
13	3	7.47	17.82	4.09	5.74	10.09	19.93	37.75	27.39	13.25	18.25
14	3	7.15	18.34	4.04	5.82	10.28	20.14	38.49	27.29	12.99	18.32
26	3	8.63	20.34	4.23	5.79	10.25	20.26	40.61	28.89	12.31	17.31
27	3	8.52	20.26	4.66	5.88	10.73	21.28	41.54	29.80	12.04	16.78
28	3	7.80	19.22	4.68	5.72	10.42	20.82	40.05	28.63	12.48	17.47
29	3	8.09	20.68	4.42	6.13	11.12	21.67	42.35	29.77	11.81	16.80
30	3	8.02	18.97	2.95	4.67	8.48	16.10	35.07	24.12	14.26	20.73
31	3	8.28	21.30	4.85	6.20	11.33	22.37	43.68	30.65	11.45	16.31
32	3	7.36	17.04	3.17	4.50	7.92	15.59	32.63	22.95	15.32	21.79
33	3	6.41	13.20	2.96	3.26	5.96	12.18	25.38	18.60	19.70	26.89
34	3	6.93	16.11	3.20	4.43	8.06	15.69	31.80	22.63	15.72	22.10
20	3	7.22	14.78	2.16	3.40	5.79	11.35	26.13	18.57	19.13	26.92
21	3	7.45	14.24	2.09	3.20	5.64	10.93	25.16	18.38	19.87	27.20

Fig. 4.17 - Protection factors at 3 ft above the basement floor for Phase 6F, typical first-floor furniture stacked in one corner of the first floor for a one-story and two-story house.

TABLE 4.18 — INFORMATION USED IN CORRECTING & NORMALIZING DATA

Data in Table No.	Phase	Type of run	Exposure time, hrs	Average temp, °C	Average press, mm Hg	Area, sq ft	Source activity, curies
4.1	1	Roof 2nd	0.891	12.6	658	865	0.530
"	1	Roof 1st	0.2345	13.3	656	649	0.530
"	1	Ground 1	1.772	14.2	661	1558	0.530
"	1	Ground 2	1.105	16.0	622	18640	8.80
"	1	Ground FO	0.405	17.0	650	1256*	821
4.2	1	Roof 2nd	0.891	12.6	658	865	0.530
"	1	Roof 1st	0.2345	13.3	656	649	0.530
"	1	Ground 1	0.2665	16.4	660	1558	8.80
"	1	Ground 2	1.092	16.0	662	18640	8.80
"	1	Ground FO	0.405	17.0	650	1256*	821
4.3	2A	Roof 2nd	0.190	15.8	667	865	8.78
"	2A	Ground 1	0.570	15.4	667	1558	8.78
"	2A	Ground 2	3.247	15.5	662	18640	8.78
"	2A	Ground FO	0.402	15.9	662	1256*	821
"	2B	Roof 2nd	0.191	17.1	662	865	8.78
"	2B	Ground 1	0.1378	17.5	662	1558	8.78
"	2B	Ground 2	3.254	17.3	663	18640	8.78
"	2B	Ground FO	0.403	17.0	663	1256*	819
4.4	2CD	Roof 2nd	1.744	15.0	666	865	0.525
"	"	Roof 1st	0.507	18.0	664	649	0.525
"	"	Ground 1	0.2664	17.1	664	1558	8.77
"	"	Ground 2	2.1575	19.4	663	18640	8.77
"	"	Ground FO	0.405	18.1	660	1256*	819
4.5	2E	Roof 2nd	1.744	15.0	666	865	0.525
"	"	Roof 1st	0.507	18.0	664	649	0.525
"	"	Ground 1	0.273	19.9	658	1558	8.77
"	"	Ground 2	3.204	19.0	661	18640	8.77
"	"	Ground FO	0.399	16.0	657	1256*	819
4.6	2F	Roof 2nd	1.784	14.0	661	865	0.523
"	"	Roof 1st	0.504	15.0	661	649	0.523
"	"	Ground 1	0.283	13.8	660	1558	8.75
"	"	Ground 2	2.207	13.5	661	19640	8.75
"	"	Ground FO	0.388	10.4	660	1256*	810
4.7	2G	Roof 2nd	1.784	14.0	661	865	0.523
"	"	Roof 1st	0.504	15.0	661	649	0.523
"	"	Ground 1	0.268	15.1	661	1558	8.75
"	"	Ground 2	2.155	13.1	663	18640	8.75
"	"	Ground FO	0.388	10.0	661	1256*	810
4.8	3	Roof 2nd	0.490	6.0	664	865	8.63
"	"	Roof 1st	0.0958	6.6	664	649	8.63
"	"	Ground 1	1.072	7.4	663	1558	8.63
"	"	Ground 2	1.100	7.0	667	18640	143
"	"	Ground FO	1.760	7.0	668	1256*	802
4.9	4A	Roof 2nd	0.499	3.4	653	865	8.58
"	"	Roof 1st	0.142	3.4	653	649	8.58
"	"	Ground 1	0.1267	1.6	661	1558	142
"	"	Ground 2	1.069	1.9	660	18640	142
"	"	Ground FO	2.172	5.0	654	1256*	801

*Circumference of a circle of radius 200 ft = 1256 ft

TABLE 4.18 - INFORMATION USED IN CORRECTING & NORMALIZING DATA (Continued)

Data in Table No.	Phase	Type of run	Exposure time, hrs	Average temp, °C	Average press, mm Hg	Area, sq ft	Source activity, curies
4.10	4B	Roof 2nd	0.439	3.3	654	865	8.58
"	"	Roof 1st	0.187	3.4	653	649	8.58
"	"	Ground 1	0.1319	1.5	661	1558	142
"	"	Ground 2	1.047	2.0	660	18640	142
"	"	Ground FO	2.348	5.0	653	1256*	801
4.11	5	Roof 2nd	0.190	0.0	663	865	8.50
"	"	Roof 1st	0.542	0.2	662	649	0.510
"	"	Ground 1	0.534	0.9	661	1558	8.50
"	"	Ground 2	3.187	0.8	662	18640	8.50
"	"	Ground FO	0.400	0.3	666	1256*	795
4.12	6A	Roof 2nd	0.992	5.0	659	865	0.508
"	"	Roof 1st	0.218	5.0	661	649	0.508
"	"	Ground 1	0.127	2.5	663	1558	8.50
"	"	Ground 2	1.024	5.0	660	18640	8.50
"	"	Ground FO	0.384	3.5	656	1256*	795
4.13	6B	Roof 2nd	1.370	3.3	657	865	0.508
"	"	Roof 1st	0.444	0.5	661	649	0.508
"	"	Ground 1	0.258	0.0	661	1558	8.50
"	"	Ground 2	2.100	2.3	658	18640	8.50
"	"	Ground FO	0.384	0.0	659	1256*	795
4.14	6C	Roof 2nd	0.179	1.0	660	865	8.50
"	"	Roof 1st	0.529	1.5	660	649	0.508
"	"	Ground 1	0.257	1.1	660	1558	8.50
"	"	Ground 2	1.61	1.4	661	18640	8.50
"	"	Ground FO	0.387	0.9	660	1256*	793
4.15	6D	Roof 2nd	0.600	2.1	665	865	0.508
"	"	Roof 1st	0.269	3.0	664	649	0.508
"	"	Ground 1	0.259	3.0	664	1558	8.50
"	"	Ground 2	1.034	1.2	665	18640	8.50
"	"	Ground FO	0.389	-0.8	663	1256*	792
4.16	6E	Roof 2nd	0.839	0.6	661	865	0.501
"	"	Roof 1st	0.260	1.4	660	649	0.501
"	"	Ground 1	0.262	1.8	658	1558	8.45
"	"	Ground 2	1.058	0.6	665	18640	8.45
"	"	Ground FO	0.381	1.5	658	1256*	787
4.17	6F	Roof 2nd	0.605	1.4	667	865	0.501
"	"	Roof 1st	0.268	2.4	667	649	0.501
"	"	Ground 1	0.258	3.4	665	1558	8.45
"	"	Ground 2	1.054	3.0	663	18640	8.45
"	"	Ground FO	0.391	2.0	665	1256*	787

*Circumference of a circle of radius 200 ft = 1256 ft

Chapter 5

RESULTS

5.1 INTRODUCTION

Several thousand data points were taken during the project. For this report the data and a brief analysis are presented. A few engineering calculations were done for the bare basement case and are presented for comparison.

5.2 PROTECTION FACTOR CALCULATIONS

To evaluate the protective qualities of a structure and to give the protection quantitative expression, the term protection factor (PF) is used. This is a number indicating the protective value of a structure and it provides a measure of how much less the radiation level would be at a given point inside the structure than outside in an unprotected area. In technical terms it is the ratio of the dose rate 3 ft above a smooth infinite plane uniformly contaminated with radioactive material to the dose rate at a specific point in question, assuming the same source distribution. Accordingly,

$$PF = \frac{D_{\infty}}{D}$$

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

To accurately determine a protection factor, it is necessary to simulate fallout radiation on the structure and on the ground surrounding the structure out to an infinite distance. Since this is impractical, simulation in these experiments was limited to the immediate vicinity of the structures, where results would be helpful in estimating protection factors. The contribution from those areas not simulated was analytically estimated by using experimental data as guide lines.

5.3 PHASE 1, BARE BASEMENT

As shown in Fig. 4.1 the protection factors in the bare basement varied from 11 to 19 and from 16 to 27 for the simulated one-story and actual two-story houses, respectively, at 3 ft above the basement floor. For the simulated one-story house, the roof contribution nearly equaled the total

ground contribution. However, for the two-story house, the ratio of the roof-to-ground contributions was about 0.4 for center positions and about 0.6 for the corner; i.e., for the two-story house the ground contribution is about twice as great as the roof contribution.

Shielding the basement windows had very little effect on the already inherent protection in the basement, as can be seen in Figs. 4.1 and 4.2.

The second-story roof contributions agreed with results obtained in the same house from previous experiments ^{1,2} to within $\pm 10\%$. Although some shelters were in the basement during these other experiments, positions which would be least influenced were chosen for the roof contribution comparison.

Engineering calculations are presented in Appendix D. Mass thicknesses used are given in Appendix C. These calculated results along with experimental data for the center of the basement are tabulated in Table 5.1. These experimental data have been corrected for source anisotropy and detector orientation, as discussed in Appendix B. The probable spread of data due to errors is also indicated.

TABLE 5.1 - RADIATION CONTRIBUTIONS AND PROTECTION FACTORS
3 FT ABOVE THE CENTER (POSITION 29) OF THE BASEMENT FLOOR
(UNSHIELDED WINDOWS)

	Radiation contribution, mr/hr per mc/sq ft					Protection factor	
	1st story	2nd story	Total Ground	Total 1	Total 2	PF1	PF2
Corrected experimental data	24.6 $\pm$ 1.7	9.2 $\pm$ 0.64	24.1 $\pm$ 1.5	48.7 $\pm$ 2.4	33.3 $\pm$ 1.7	10.3 $\pm$ 0.8	15.0 $\pm$ 1.2
Engineering Manual, hand calculated	33	13.3	15 to 17	47	30	11	17
CAPS-2	34	14	21	55	35	9	14
Calc. from Spencer - ⁶⁰ Co	22.7 to 31.5	10.1 to 12.1					

Calculations from NBS-42 (Spencer) for ⁶⁰Co agree with corrected experimental data. Exposure rates for roof sources using the Engineering Manual³ for hand calculations and using the CAPS-2 computer program are about 30% higher than the corrected experimental data. Factors possibly contributing to the differences are: (1) Calculations are for fallout (1-hr fission products); data are for ⁶⁰Co; (2) Calculations assume the mass is uniformly distributed as a horizontal barrier; more than half of the overhead mass was actually due to beams, joists, stairways and partitions. The stairway existed near the center of the house. Diagonal traverse data plotted in Fig. 5.1 indicate this possible influence on the experimental data; (3) The calculations also include a skyshine contribution from ground sources coming through the roof. Separate calculations, however, indicate this contribution is probably small.

Calculations of ground contributions are as much as 50% lower than experimental data. This difference is probably due to the inaccuracy of the Engineering Manual in handling "in-and-down" scattered radiation. Experimental data of other experiments* have shown that the manual method produces results as much as a factor of 3 lower than experimental results in certain in-and-down situations and in handling attenuation by horizontal barriers. Diagonal traverse data from ground sources are presented in Fig. 5.2.

The protection factors in Table 5.1 as determined by calculations and by experimental data agree quite well. This, however, does not indicate proof testing or confirming the engineering calculations. Since the Engineering Manual overestimates some effects and underestimates others, the overall good agreement must be regarded as fortuitous.

5.4 PHASE 2, OVERHEAD BARRIER, PLAN A

The homeowner may encounter various problems when building Plan A shelters, such as existing cross bracing between the basement ceiling floor joists or a heating duct between the joists in the corner where he chooses to build the shelter. Therefore, the protection afforded by the 12 x 12-ft overhead barrier (Plan A) was determined for each of these problem areas (Table 4.3) as well as for a solid 12 x 12-ft overhead barrier with and without shielded basement windows (Tables 4.4 and 4.5). Again the shielded basement windows had very little effect on the protection factors.

Protection factors and effective floor area** with the $PF > 40$ for four positions for all variations in Phase 2 are listed in Table 5.2. Comparisons are made in Table 5.3, based upon data presented in Table 5.2.

Positions tabulated are located in the basement on a line that bisects the corner directly under the overhead barrier. Position 3, 8, 11, and 12 are 1, 3, 6 and 9 ft from both corner walls, respectively. Negligible differences are noted both in effective area and protection factors between variation A and CD. The duct (B) caused a 40% reduction in protected area compared with variation A, with only about an 18% reduction in protection.

Shielding the basement windows caused an increase in protection factors of approximately 2 to 5% for both the one-story and two-story house, but increased the overall effective area where the $PF > 40$ by 29% and 13%, respectively.

Increasing the area of the overhead barrier to 12 x 16 ft (CD to F) caused a 63 and 59% increase in effective area ($PF > 40$) for the one-story and two-story house, respectively, and a PF increase range of 2 to 18% and 1 to 12%, respectively. Increasing the area of the overhead barrier with shielded

*See for instance (1) A. L. Kaplan et al., Final Report - Phase 1, Structure Shielding From Simulated Fallout Gamma Radiation, Report No. TO-B-65-27, Technical Operations Research, November 1965.

(2) Z. G. Burson and R. L. Summers, Barrier Attenuation of Air-Scattered Gamma Radiation, Report CEX-63.3, June 1965.

**Effective floor area was estimated from the data plotted on the floor plans as presented in previous chapter.

TABLE 5.2 - PROTECTION FACTORS AT 3 FT FOR PHASE 2*

Phase variation	Area, **		Positions							
	sq ft 1st story PF>40	sq ft 2nd story PF>40	3		8		11		12	
			PF 1	PF 2	PF 1	PF 2	PF 1	PF 2	PF 1	PF 2
(A) 12 x 12 ft, cross bracing		47		69		51		37		28
(B) 12 x 12 ft, duct		28		57		40		30		26
(CD) 12 x 12 ft, solid	22	47	59	69	42	49	29	37	19	28
(E) 12 x 12 ft, solid; basement, shielded windows	28	54	62	72	44	52	30	38	20	29
(F) 12 x 16 ft, solid	36	75	60	70	43	50	31	39	23	31
(G) 12 x 16 ft, solid; base- ment shielded windows	37	91	65	76	46	54	33	42	24	33

*Taken directly from Tables and Figs. 4.3 through 4.7.

**Estimated by examining Figs. 4.3 through 4.7.

TABLE 5.3 - RESULTS OF TABLE 5.2

Phase compar- ison	Area % change		Percent change in protection factors							
	1-story	2-story	Position							
			3		8		11		12	
			1-story	2-story	1-story	2-story	1-story	2-story	1-story	2-story
A to B		42		17		21		19		7
A to CD		Negli- gible		<1						
B to CD		73		20		23		23		6
CD to E	29	13	4	5	4	5	3	5	2	3
CD to F	63	6	2	1	2	2	9	7	18	10
E to G	31	70	5	5	6	5	13	11	20	22
F to G	4	21	7	8	7	8	6	8	4	6

Fig. 5.1 - Diagonal traverse of exposure rate at 3 ft above the basement floor, roof contribution in bare basement, Phase 1.

Fig. 5.2 - Diagonal traverse of exposure rates 3 ft above the basement floor, ground contributions, bare basement, Phase 1.

basement windows to 12 x 16-ft (E to G) caused a 31 and 10% increase in effective area ($PF > 40$), respectively, for a one-story and two-story house and a PF increase range of about 5 to 20% for both the one-story and two-story house.

A 4 and 21% increase in effective area ($PF > 40$) was caused when the 12 x 16-ft solid overhead barrier (variation F) had the exposed basement windows shielded (variation G) for the one-story and two-story house respectively, and a PF increase range of 4 to 7% for the one-story house and 6 to 8% increase for the two-story house.

Observations drawn from Tables 5.2 and 5.3 are (1) a duct greatly reduces the protection and effective floor area; (2) cross bracing between joists of the shelter does not affect the overall protection of the shelter; (3) shielding the basement windows and/or increasing the shelter size from 12 x 12 to 12 x 16 ft caused an appreciable increase in the effective floor area where $PF > 40$, but only a small increase in PF values.

These observations are based upon these shelters built in this house, which has approximately 20% apertures, and may not apply in another house.

As noted in Appendix D, the roof contributions were calculated in the shelter corner, using the Engineering Manual and NBS-42. Calculations from the manual gave values of 4.50 and 2.62 mr/hr per mc/sq ft for the first-story and second-story roof contributions, respectively, and those from NBS-42 gave 3.00 and 1.70, respectively. Experimental data, extrapolated to the corners and corrected (Appendix B), were 2.60 ± 0.18 and 1.54 ± 0.11 mr/hr per mc/sq ft for the first-story and second-story roof contributions, respectively.

5.5 PHASE 3, SMALL SHELTERS

5.5.1 Sit-down Shelter

Blocking up the entranceway would greatly hinder retrieving the detectors; therefore, the entranceway was modified by placing a wall 15 in. away from the entrance, at a height of the overall height of the shelter and the same width as the entrance. The protection factors ranged from 220 to 270 for the two-story house and 140 to 154 for the one-story house.

5.5.2 Lean-to Shelter

The entranceway was handled in the same manner as described above. The protection factors ranged from 150 to 245 for the two-story house and 70 to 150 for the one-story house.

5.5.3 Workbench Shelter, Variation A

The workbench shelter, which has an area of 17.5 sq ft, was stacked with books, magazines, and newspapers. The total mass was 610 lb or 34.8 lb/sq ft mass thickness. The protection factors ranged from 35 to 59 for both the one-story and two-story house. No shielding was provided on the sides of this shelter.

5.6 PHASE 4, TILT-UP SHELTER AND WORKBENCH VARIATIONS

5.6.1 Tilt-up Shelter

The entranceway to this shelter was unlike the sit-down shelter, for its entranceway was located away from the corner of the basement. This shelter was therefore tested with the entranceway both shielded and unshielded to evaluate the maximum variation in protection factors.

The protection factors ranged from 120 to 177 unshielded and 148 to 194 shielded for the two-story house and 84 to 123 unshielded and 95 to 125 shielded for the one-story house. An average increase of only about 20% was noted by blocking the entrance. In both cases the entranceway's width was perpendicular to the width of the house. If the entranceway's width were parallel to the width of the house, there would be a higher roof contribution, thus a lower PF. If the entrance were next to the corner basement wall, an even smaller difference would be observed, probably not enough to require shielding the entrance.

5.6.2 Workbench Shelter

This shelter was tested with concrete blocks on the top and exposed sides. The mass thickness on the top was 104.2 lb/sq ft and on the sides, 74.6 lb/sq ft. The protection factors ranged from 158 to 187 for the two-story house and from 95 to 140 for the one-story house.

5.7 PHASE 5, 12 x 12-FT ALTERNATE SOLID OVERHEAD BARRIER, PLAN B

This shelter was tested structurally and to determine the protection it afforded. Due to the unique construction of the house for sustaining blast from nuclear testing, this shelter design needed to be modified. The 2 x 12-in. joists were cut for bearing in the usual manner but instead of bearing on the actual house beam it was nailed to the existing 2 x 10-in. floor joists; therefore, the load of the overhead mass was partially on the floor joists and partially on the house foundation. A screw-jack column was installed for the testing phase and then removed for the weekend. No deformation occurred during the period.

The protection factors under the shelter area ranged from 28 to 74 for the two-story house and 20 to 60 for the one-story house.

The 54% increase in the overhead mass thickness caused a 47% increase in the effective area ($PF > 40$) for both the one-story and the two-story house, but only a 7 to 10% increase in protection for the two-story house and a 9 to 20% increase for the one-story house was obtained (see Table 5.4).

5.8 PHASE 6, SUPPLEMENTAL INVESTIGATIONS

5.8.1 Incremental Overhead Mass Layers

Three separate layers of concrete blocks, mass thicknesses of 24.75, 49.50 and 74.25 lb/sq ft, were placed on top of the floor of the first floor in a 12 x 12-ft corner area to determine how much "added weight" would be needed to raise the protection in this area to a PF of 40. All five radiation contributions were measured for each layer. Figure 5.3 shows the influence

TABLE 5.4 - PROTECTION FACTORS AND
EFFECTIVE AREA, PF>40, FOR PHASE 2CD AND PHASE 5

Phase variation	Area, sq ft, 1-story PF>40	Area, sq ft, 2-story PF>40	Protection factors							
			Position							
			3		8		11		12	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd
Phase 2CD 12 x 12' solid overhead barrier, Plan A	22	47	59	69	42	49	29	37	19	28
Phase 5, 12 x 12' solid overhead barrier, Plan B	32	69	71	74	46	54	32	40	21	30

of these layers on the first-story roof contributions for four detector positions. Also shown are data from Phase 1 (bare basement), Phase 2CD (12 x 12-ft solid overhead barrier, Plan A), Phase 6F (stacked furniture) and Phase 5 (12 x 12-ft alternate overhead barrier) superimposed on the curves to show the effect of the height of the barrier. Figure 5.4 shows similar curves for the total ground contribution. The position of the barrier influences the ground contribution much more than the roof contributions. In both cases, however, its position greatly influences the resulting protection factor.

Data in Fig. 5.4 suggest that adding more than about 50 lb/sq ft on top of the floor would reduce the ground contribution very little. Because of this, a protection factor of 40 cannot be attained in the simulated first-story house beyond the immediate vicinity of the corner by this type of technique and size (12 x 12) of barrier. For the two-story house, a PF of 40 at Position 8 was attained with about 70 lb/sq ft added (corrected for source anisotropy and detector orientation, Appendix B). This would provide a PF of 40 for about a 20-sq-ft area.

5.8.2 Simulated Brick Veneer, 6D

A brick veneer was simulated by placing concrete blocks on the inside of the outside walls of the house to a height of 4 ft. All five contributions were measured and protection factors were determined.

The roof contributions were measured although they were not expected to differ greatly from the bare basement data. Table 5.5 was prepared, containing the percent deviation of data (at 3 ft) from several phases at several locations assumed to be least affected by the construction, using the bare basement data as a standard. Although the results are well within the standard deviation expected, they do show the Phase 6D (brick veneer) data to be consistently lower than bare basement data, especially in the southeast quarter of the basement. The reason for this is not known.

Figure 5.5 shows the total ground contribution and the total contribution for Phase 6D, compared with those for Phase 1. Adding the brick veneer decreased the ground contribution and the total contribution (increased the protection) from about 5 to 10% for both the one-story and the two-story houses.

Fig. 5.3 - First-story roof contribution for several phases as a function of added overhead mass thickness.

Fig. 5.4 - Total ground contributions for several phases as a function of added overhead mass thickness.

TABLE 5.5 - PERCENT DEVIATION OF DATA FROM BARE BASEMENT DATA

Position	First-story roof			Second-story roof		
	Phase 2CD	Phase 6D	Phase 6F	Phase 2CD	Phase 6D	Phase 6F
3		-8		6	-6	
8		-8			-6	
13		-7			-5	
21	-3	-4	-5	0	1	-2
26		-4		-1	0	-4
27	-2	-3	-2	-1	-2	-4
28	-3	-3	-5	-4	-3	-7
29		-5			-3	
30	0	1		0		-1
31	0	+1	-2	0	-2	-3
33	0	+3	-2	0	0	-4

5.8.3 Household Furniture, 6E and F

The effect of household furniture on the overall protection afforded in the basement of a two-story and simulated one-story house was determined. Total contributions of the one-story and two-story houses with the furniture realistically distributed are plotted and compared with the total contribution in the bare basement case for five detector locations spanning a diagonal line from the southeast corner to the northwest corner. This same contribution is again compared when all the furniture is stacked in the southeast corner of the first floor. These contributions are shown in Fig. 5.6. Placing furniture in the empty house increases the protection in the basement by 10% in the corner and diminishes to 5% in the center of the basement.

The very small increase in protection gained by moving the furniture into one corner compared to having the furniture normally placed can readily be seen as itemized in Table 5.6.

TABLE 5.6 - RATIO OF 6E/6F

Position	Ht	2-story	1-story	Ground T	Total 1	Total 2
3	3	1.160	1.142	0.998	1.072	1.052
8	3	1.101	1.119	1.000	1.054	1.028
13	3	1.061	1.070	0.989	1.029	1.010
29	3	1.001	1.009	0.995	1.001	0.998
27	3	0.963	0.960	1.000	0.978	0.986

REFERENCES

1. J. A. Auxier et al., Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, Report CEX-58.1, January 1959.
2. Z. G. Burson, Experimental Radiation Measurements in Conventional Structures, Report CEX-59. 7B, Part I, July 1966.
3. Design and Review of Structures for Protection from Fallout Gamma Radiation, Dept. of Defense, Office of Civil Defense, PM-100-1.

Fig. 5.5 - Diagonal traverse of exposure rate at 3 ft above the basement floor for ground and total contributions, Phases 1 and 6D.

Fig. 5.6 - Diagonal traverse of exposure rate at 3 ft above the basement floor, total contributions, Phases 1, 6E and 6F.

Chapter 6

SHELTER APPRAISAL

The radiation protection each shelter provides has been discussed in previous chapters. In this chapter an effort is made to estimate the time required for the homeowner to construct these shelters. In most cases skilled workmen were not used; some carpenters were used but most of the work was done by laborers. These estimates are based on a two-man unskilled work crew.

6.1 PLAN A, 12 x 12 AND 12 x 16-FT SOLID OVERHEAD BARRIER

These shelters can be built in 16 and 24 hr respectively, provided all plywood sheets are precut and all concrete blocks are located near the planned shelter area. These shelters are relatively easy to build, requiring few construction skills. The major problem is the handling and placement of 2000 to 2700 concrete blocks. This shelter is uneconomical, based on the cost and effort required to produce minimum* radiation protection. Its advantage is that it produces the minimum protection and still saves all the basement floor space for other uses.

6.2 PLAN B, 12 x 12-FT SOLID OVERHEAD BARRIER

This shelter can be built in 32 hr. It requires two men and is relatively hard to build without skilled help. Major problems are handling and placing 2 x 12 joists and more than 2000 concrete blocks. This shelter is even more uneconomical (effort vs protection) than Plan A, but does not require a screw-jack column.

6.3 PLAN C, CONCRETE BLOCK SIT-DOWN SHELTER

This shelter can be built in 16 hr. One man can easily build this shelter, needing very few special talents. For the 600 concrete blocks that go into this shelter it provides excellent radiation protection but sacrifices 51 sq ft of basement floor space.

*Minimum refers to OCD's present criteria, establishing a PF of 40 as adequate radiation protection.

6.4 PLAN F, LEAN-TO SHELTER

This shelter can be built in 40 hr. It is extremely difficult to build and unless qualified carpenters are used, the homeowner would be at a disadvantage. The problem areas are many angular cuts to be made, heavy sections to handle, and transporting these sections into the basement if they were not built there. Another problem is that if the lumber is warped, placing the concrete blocks in the cases will be difficult, especially if the warped ends are on the high side of the shelter. This shelter will cost almost twice as much and have only half the protection of Plan C for approximately the same floor area.

6.5 PLAN E, TILT-UP SHELTER

This shelter can be built in 40 hr. It is difficult to build unless qualified carpenters are used for fabricating and installing the cases. If the cases are not level, they will not swing up to their horizontal position. If too much separation is made between the cases for clearance because of badly hung cases, the protection afforded will be less. This shelter has about the same floor area as Plan C but probably has greater utility.

6.6 PLAN W, WORKBENCH SHELTER

This shelter can be built in 4 hr. It is easily built and no special skills are required. It provides shelter for one man. If two of those benches were placed together with concrete blocks on the top and sides, at least a two-man shelter would be available. Although this shelter is suitable for the prone position, it could probably be endured for 24 hr without too much discomfort, at which time the bare basement may be adequate protection.

Table 6.1 is a summary of all quantities that were considered in this shelter appraisal.

TABLE 6.1 - SUMMARY OF SHELTER APPRAISALS

Shelter description	*Construction time, hr	Skills req'd	Second Story Area of min. PF	PF range	Total area of shelter, sq ft	Sacrifice bsmt floor space, sq ft
Plan A: 12 x 12 ft	16	easy	47	40-70	144	0
12 x 16 ft overhead barrier	24	easy	75	40-70	192	0
Plan B: 12 x 12 ft overhead barrier	32	diff.	69	40-75	144	0
Plan C: concrete-block sit-down shelter	16	easy	51	220-350	51	51
Plan F: lean-to-shelter	40	diff.	45	114-244	45	45
Plan E: tilt-up unit shelter	40	diff.	50	150-200	50	50
Plan W: Workbench shelter	4	easy	17.5	160-190	17.5	17.5

*Estimates based upon time for two men to construct.

Chapter 7

SUMMARY AND DISCUSSION

Cobalt-60 has been widely used in radiation shielding studies. The extent to which results obtained by using ^{60}Co can be applied to idealized fallout radiation has been discussed by Eisenhower¹ and implied by Spencer's extensive calculations.² For two source configurations cited,¹ about 10% more mass thickness is required to produce a given attenuation for 1-hr fission-product radiation than for ^{60}Co radiation.

Source configurations used in these studies were simulated line sources or area sources created by propelling a ^{60}Co source through a length of tubing appropriately placed over the area of interest. Source configurations were such that data could be added or integrated and used as a basis to obtain a total result that would simulate a ^{60}Co field from the structure out to an infinite distance. The protection factors obtained are for ^{60}Co and are assumed to apply to an idealized fallout situation to the extent mentioned above. An idealized fallout situation is defined as fallout having 1-hr fission spectrum, and existing uniformly on a smooth infinite plane.

The extent to which an idealized fallout situation is applicable to a real fallout situation is not known. The main differences lie in the change of spectrum with time and location, ground roughness and terrain effects, and nonuniform distributions of the fallout particles. The change of spectrum with time of fission products is well known. Less is known about neutron-induced activity and fractionation. Some limited ground roughness studies have been made.³⁻⁴

Experiments described in this report were conducted simultaneously with an architectural engineering study, outlined in Appendix A, to evaluate and demonstrate a practical means of improving the already inherent fallout radiation protection in homes with basements.

All the basic data are presented. A brief analysis of the results is given in enough detail to meet the objectives. The results contain roof and ground contributions, overall protection factors, and estimates of the area where the protection factors exceed 40 for each shelter.

As discussed in Appendix B, the corrected total contributions are expected to be accurate to within a standard deviation of $\pm 5\%$; the resulting protection factors, $\pm 8\%$.

In the bare basement of the simulated one-story house the protection factors (PF) at 3 ft above the basement floor ranged from 11 to 18. For the two-story house, the PF's ranged from 15 to 25. Shielding the basement windows had very little effect on the protection.

Calculations using the Engineering Manual⁵ were about 30% higher than corrected experimental data for roof contributions in the bare basement. A more detailed consideration of exact locations of beams, joists, stairways and partitions in the calculations may reduce this difference. Calculations of ground contributions were as much as 50% lower than experimental data. This difference is probably due to the inaccuracy of the Engineering Manual in handling "in-and-down" scattered radiation.

The 12 by 12-ft overhead barrier (Plan A) provided about 22 sq ft of floor space where the PF was greater than 40 in the one-story house; in the two-story house, about 50 sq ft. Increasing the barrier to 12 by 16-ft increased the floor space 60% where $PF > 40$.

Other overhead barrier experiments were made. The vertical position relative to the outside ground level of the overhead mass is relatively more significant than its thickness. The incremental mass layers were placed on top of the first floor. Adding more than about 50 lb/sq ft at that location would increase the protection very little. A limit is reached where all the ground contribution enters beneath the barrier.

Compared with other shelters, the overhead barrier technique in this experiment is rather uneconomical, based on the effort required to produce minimum* radiation protection. Its advantage, of course, is that it provides the minimum protection and still saves all the basement floor space for other uses. This technique is not to be recommended for basements where a significant portion of the basement wall is exposed above ground.

The sit-down, lean-to and tilt-up shelters all provide good protection (PF 70 to 270). The lean-to and tilt-up shelters are rather difficult to construct; the sit-down shelter is easy.

The expedient workbench can be built in about 4 hr. With shielding on top only, it provides protection from PF 40 to 59. Shielding placed also on the side increases the PF to at least 95.

In adding a simulated brick veneer, a decrease in the total contribution of about 5 to 10% for both the simulated one-story and two-story houses was observed.

By adding household furniture realistically through the first floor, a 10% increase in protection in the corners and 5% in the center for both the one-story and two-story houses was observed. Stacking this furniture in a corner of the first floor increased the protection by 6% in this corner of the basement but only about 2% in the center. This applies to both the one- and two-story houses.

The results and discussions are from data taken in an isolated two-story wood frame house in Area 1 at NTS and cannot necessarily be directly applied to all other similar structures. Variations in structural mass and in exposed basement walls would greatly influence the results, especially for the overhead barrier cases. The primary usefulness of the results is in evaluating and verifying the shelter designs in this particular house and in comparing the results with engineering calculations.

Data points at specific locations and from specific source geometries compared favorably with data from previous experiments.

The experience, general information, and specific data gained from this series of experiments are applicable to architectural engineering design

*Minimum refers to OCD's present criteria, establishing PF 40 as adequate radiation protection.

and evaluation of fallout shelters. The objectives were met and the experiment was conducted safely within the criteria established for the project.

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3. R. L. Mather, et al., Gamma Radiation Field above Fallout Contaminated Ground, USNRDL, WT-1225, 28 October 1959.
4. C. M. Huddleston, et al., Ground Roughness Effects on the Energy and Angular Distribution of Gamma Radiation from Fallout, USAEC Report CEX 62.81, July 1964.
5. "Design and Review of Structures for Protection from Fallout Radiation", PM-100-1, Department of Defense, OCD, February 1965.

Appendix A

FALLOUT PROTECTION FOR HOMES WITH BASEMENTS

**FALLOUT
PROTECTION
FOR...**

HOMES
WITH BASEMENTS

DEPARTMENT OF DEFENSE • OFFICE OF CIVIL DEFENSE

JANUARY 1966 H-12

FALLOUT PROTECTION FOR HOMES WITH BASEMENTS

January 18, 1965

"It is already clear that without fallout shelter protection for our citizens, all defense weapons lose much of their effectiveness in saving lives. This also appears to be the least expensive way of saving millions of lives, and the one which has clear value even without other systems. We will continue our existing programs and start a program to increase the total inventory of shelters through a survey of private home and other small structures."

LYNDON B. JOHNSON

President of United States

Excerpt from the President's message to the Congress

THE FALLOUT PROTECTION IN YOUR HOME

This booklet is about fallout protection. It will tell you what radioactive fallout is and how you can improve your protection against it if this country were ever attacked with nuclear weapons. But first of all, because your home has a basement, you already have some fallout protection. Let's see what that protection is:

The back cover of this booklet looks something like this:

Occupant
1234 Main Street
Washington, D. C. 20005

BASEMENT PF (PROTECTION FACTOR)		ADDED WEIGHT
CENTER	BEST CORNER	

Your own address is on the back cover of your booklet. Entered in the box labeled Basement "PF" are two numbers which tell you the fallout protection that was calculated for the "center" of your basement and the "best corner" of your basement. These numbers are based on the best engineering and scientific knowledge available. Information on the box labeled "Added Weight", is on page 23 of this booklet.

The "PF" above the box stands for "Protection Factor." Before going into the details of what your "Protection Factor" numbers mean, let's talk for a moment about what fallout is.

WHAT IS RADIOACTIVE FALLOUT?

When a nuclear weapon is exploded close to the ground, dirt and other debris are drawn up into the mushroom cloud and pick up the radioactivity created by the explosion. The heaviest pieces of dirt and debris drop back to earth within a few miles of the explosion. But the lighter pieces are carried by the winds for many miles before drifting back to earth.

These radioactive particles are called "fallout." Any part of the United States might be covered with deadly or dangerous amounts of radioactive fallout, depending on which way the winds were blowing and the size and number of nuclear weapons exploded. The radioactivity could cause serious health damage or fatal injury to unprotected persons. In a nuclear attack, the

blast, heat, and fire from the explosions would be very destructive, but the destruction would be in the areas near the explosions. Radioactive fallout, though, could spread in a thin layer over millions of square miles.

Radiation would come from the fallout wherever it settled—the ground, trees and bushes, or the roof of your home. *Fallout does not behave like a gas.* In areas that would be affected by dangerous amounts of fallout, the fallout particles would look like dirt or sand and you may see them after they have settled on the ground or other places. The exact amount of radiation given off by the particles can be measured only by special instruments.

HOW CAN YOUR PROTECTION BE IMPROVED?

There are three ways of improving your protection against fallout—time, distance, and getting some heavy material between you and the fallout (called “shielding”).

1. **Time**—Radioactivity decreases rapidly at first. After an attack, the radiation would be most intense during the first few days. Even so, radiation protection may be needed for an extended period—days or weeks.

2. **Distance**—The amount of radiation is less the further away you are from the source of radiation.

3. **Shielding**—Any material that is put between a person and the source of radiation cuts down the amount of radiation that reaches the person. The thicker and heavier the material, the better the protection.

In the event of an attack, you have little control over time and distance, but **YOU CAN DO SOMETHING TO IMPROVE YOUR PROTECTION BY MEANS OF SHIELDING.**

It is the principle of shielding that is employed in fallout shelters. Under the guidance of the Office of Civil Defense, a system of fallout shelters is being developed throughout the nation. It consists of public shelters, private shelters, industrial and home shelters.

THE FALLOUT SHELTER SYSTEM

As a result of the National Fallout Shelter Survey, in which existing large buildings were examined and evaluated for fallout protection, space for millions of people has been identified. Those community shelters having a protection factor of at least 40 and space for at least 50 people are now being marked with the familiar black and yellow shelter sign. Where necessary storage space is available, they are being stocked with food, water (if needed), sanitary and medical supplies, and radiation detection instruments. The survey is a continuing effort. Through it, a current inventory is maintained of shelters added by new construction.

The fallout protection found in homes with basements represents important additional shelter space.

Personal and other special considerations may make fallout protection at home more practical or desirable than community shelters for certain individuals or families. For example, in rural and suburban communities and even in many cities, families may live a considerable distance from the nearest community shelter. For these families, a home shelter will provide more accessible fallout protection. Fallout protection at home is usually more accessible to housewives and young children during the day and may be preferred by the whole family when at home.

HOW MUCH PROTECTION DOES YOUR BASEMENT PROVIDE AGAINST RADIOACTIVE FALLOUT?

In homes, basement areas provide the best shelter against fallout because they are mostly belowground. This gives them a natural shield. This booklet tells you the amount of protection your basement offers and what you can do to increase this protection to provide for your family's safety. Keep in mind that fallout shelter provides only limited protection against blast.

Look at the back of this booklet again. Two numbers are printed there which tell you the amount of fallout protection your basement offers. These numbers were calculated for your home from the information you gave in the recent questionnaire on Evaluation of Fallout Protection in Homes.

The numbers are given in terms of a “Protection Factor” or PF. This is the relation between the amount of fallout radiation

which would be received by a completely unprotected person compared to the amount which would be received by a person in a fallout shelter. For example, a person in a fallout shelter with a PF of 40 would receive about one-fortieth (or $2\frac{1}{2}\%$) of the radiation he would be exposed to if he were completely unprotected. The higher the PF for your home, the more protection your basement affords against radiation.

BASEMENT PF (PROTECTION FACTOR)		ADDED WEIGHT
CENTER	BEST CORNER	

The number in the box marked "center" (see back of your booklet) is the Basement Protection Factor (PF) calculated for the center of your basement. The other number is the PF calculated for the best corner of your basement. If your cover shows an X in place of either PF number, it means the PF is smaller than 10. Information on the box labeled "Added Weight," is on page 23 of this booklet.

WHICH IS THE BEST CORNER OF YOUR BASEMENT?

The best corner of your basement is the one which has the highest outside ground level—that is, the least amount of basement wall sticking up above-ground. In this corner make a triangle by measuring ten feet from the corner along each wall, and drawing a line between these points (see illustration).

The best corner protection factor listed on the back of this booklet is measured at point X, which means the *average* protection factor within the triangle is well above this value. This 50 sq. ft. area provides adequate fallout shelter space for 5 persons. However, if necessary, several more persons could crowd into the corner area without difficulty. If all the corners have equal outside ground levels, the most convenient corner may be used, and of course *all* corners may be used.

WHAT ABOUT THE CENTER OF THE BASEMENT?

In nearly all basements, the highest protection factor is in the corner and the lowest is in the center. This means the whole

basement can be thought of as a fallout shelter with a protection factor in the center equal to the first PF number on the back of your booklet and a higher protection factor in the best corner equal to the second PF number. Until the extent of the radiation threat in your town is determined by trained monitors using special instruments, you should stay in the best corner *as much as possible*. For essential needs, you can leave the best corner for a few minutes. Before leaving the shelter for longer periods of time, listen to your radio station for information and instructions. A battery operated radio should be available for this purpose.

STEPS YOU CAN TAKE TO INCREASE YOUR FALLOUT PROTECTION

If the protection factor in the best corner of your basement as indicated on the back cover is less than 40 and you wish to bring the PF up to the minimum recommended for public shelter, then you need additional shielding.

You can provide additional shielding for your basement by:

1. *Permanent shelters*—By making part of your basement into a shelter area or by building a permanent shelter which might also serve other purposes.
2. *Pre-planned shelters*—By locating shielding materials so that you can complete a shelter quickly in time of crisis.
3. *Improvised shelters*—By taking last-minute improvised actions if an emergency actually occurs.

The information contained on the following pages demonstrates some actions which you as a householder can take to provide fallout protection for yourself and your family. For quick reference, after you have finished reading this booklet, hang it up in the corner of your basement having the best protection so that it will be available in an emergency.

A WORD OF CAUTION TO THE HOME HANDY MAN

Fallout Shelter Plans A through F which follow are so simple that you may be tempted to construct them from the drawings in this booklet—and in many cases a thoroughly experienced "do-it-yourselfer" could do this. However, it requires very careful calculation of materials and fasteners to safely hold the heavy materials to be placed overhead; therefore, it is strongly recommended that you build from the detailed plans and lists of materials which are available by mailing the post card enclosed with this booklet.

PERMANENT SHELTER

Ceiling Modification To Basement PLAN A

Here is a shelter which can be permanently installed in the basement of your home without affecting the use of the basement in any way.

All that is needed is a basement, some basic wood-working skills and approximately \$165 for materials. The shelter can be accomplished while the basement is being built or it can be added to an existing basement by modifying the ceiling in the corner which furnishes the best protection.

Although desirable, it is not necessary to provide two additional walls to enclose the corner of the basement. A significant amount of protection can be achieved merely by inserting heavy material in the ceiling above the best corner. Fixtures and installation of ceiling tiles or walls will increase the cost a bit, but you will be able to achieve a significant amount of protection without interfering with the functions of the basement.

Because the basement area is almost all belowground level, you can increase the fallout protection by installing bricks or solid concrete blocks between the wood joists in the best corner. The filler materials are supported by sheets of plywood fastened to the floor joists. A beam and screw jack column may be needed to keep the floor joists from bending too much. A carpenter can tell you if this is needed.

Plywood sheets (2' x 8' x 1/2" cut to fit) should be securely fastened to the joists using 2 inch, #8 screws 10 inches apart. Bricks or blocks are then packed as tightly as possible into the openings between the joists. Be sure to fill as much space as possible. To get the most protection out of this improvement, one-quarter of the basement ceiling over the best corner should be filled with bricks or solid concrete blocks.

To obtain detailed plans, see page 24.

In fastening the plywood sheets to the joists, nailing is not enough. Nails will pull loose. Use two-inch screws in the manner shown here.

PERMANENT SHELTER

Alternate Ceiling Modification To Basement PLAN B

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If you need a minimum shelter which will not interfere with an existing corner of your basement, try this plan. It is so arranged that the shelter area can be enlarged at either end, depending upon the size of the basement.

This type of construction does not require a beam and screw jack column to support the joists. The protected area can be used as a workshop, recreation room, pantry area, laundry room or part of a family room. With ceiling tile covering the plywood panels, no one would recognize the area as a fallout shelter. Since the objective is to provide as much overhead mass as possible, the heaviest weight of solid brick or block (placed on an end if possible) should be used.

Wooden joists (2" x 12"), notched at the ends for bearing, are installed between existing floor joists. Plywood panels are then fastened to the 2" x 12" joists.

Brick or concrete blocks are packed into the spaces between the 10" and 12" joists; they are supported by the plywood panels.

This basement floor plan shows how the additional joists and the filler material might be used in the corner of the basement which furnishes the best fallout protection. To get the most protection out of this improvement, one-quarter of the basement ceiling should be filled with bricks or solid concrete blocks.

To obtain detailed plans, See page 24.

PERMANENT SHELTER

Concrete Block Shelter PLAN C

If the highest PF value printed in the box on the back cover of this booklet is either "X" or "10", this is generally because the basement sticks out of the ground too much. In such cases, adding overhead materials (as shown in Plans A & B) usually will not provide adequate protection unless heavy walls are also added.

The above concrete block shelter is designed to do this at low cost.

Its principal advantages are simple design, speed of construction and ready availability of low-cost materials.

It can be designed as a sit-down shelter, or by increasing the ceiling height to six feet or more, it could make a more comfortable shelter and serve a dual purpose as a storage room or similar facility.

Natural ventilation is provided by the entrance and the air vents in the shelter wall. Materials for this type of shelter will cost an estimated \$135-\$150 depending on its height and the area of the country.

To obtain detailed plans, see page 24.

If your basement ceiling is near ground level on three sides and exposed on one side (as with "walk-in" basements), the concrete block shelter (Plan C) must be modified to achieve the desired effectiveness. The following changes should be made:

1. Increase the thickness of the shelter wall facing the basement wall which has no ground cover by four inches of brick, concrete block or similar materials.
2. Place the shelter entrance on a side or end which does not face the exposed basement wall.

PRE-PLANNED SHELTERS

Snack Bar PLAN D

A snack bar built of brick or block can be converted into a fallout shelter in a short period of time by lowering a strong hinged false ceiling to rest on the snack bar.

The false ceiling section can then be loaded with brick or block. The bricks or blocks can be conveniently stored by incorporating them into recreation room furniture such as benches and room dividers.

An attractive bench unit for your recreation room can be made from blocks or brick. Pillows and a wood frame to enclose the bench will provide a finishing touch.

To obtain detailed plans, See page 24.

Bench unit for plan D

Tilt-Up Storage Unit PLAN E

A tilt-up storage unit in a corner of your basement is another approach similar to the snack bar. The top of the storage unit can be hinged to the wall and the unit can be used as a bookcase, pantry shelves, or for miscellaneous storage.

In an emergency, the storage unit can be tilted so that it rests on a wall of brick or concrete blocks stored for just such an emergency. Additional bricks or blocks can then be placed in the storage unit to provide an overhead shield.

To obtain detailed plans, see page 24.

PRE-PLANNED SHELTERS

Lean-To Shelter PLAN F

A simple and effective lean-to shelter can be built by constructing the components and storing them in your basement where they can be quickly assembled in an emergency. Components consist of a frame and filler materials, such as brick or blocks.

For detailed plans, see page 24.

A patio of brick or concrete block supported on a bed of sand will provide a ready source of shielding material which could be quickly removed for use in an emergency. See Plans D, E and F.

Enclosing your patio area with a solid masonry screen wall will give you privacy for lounging and cook-outs, and will provide a barrier shield to increase the PF in the basement area.

AN ELEVATED FLOWER GARDEN

Where basements are not completely belowgrade, here are some additional ideas which can be used to increase the shielding of exposed basement walls. A brick, masonry, or stone planter box along one or more sides of the house will improve protection substantially, and will provide an attractive setting for shrubs and flowers as well. If the partially exposed wall is at the rear or side of the house, an elevated garden could be built with masonry retaining walls.

If the partially exposed walls have windows, these can still be used by providing window wells within the planter box or elevated garden area.

Your basement's PF will also be increased by providing additional shielding to the exposed section. This can be done by piling patio block, sand, earth, cordwood or similar materials against the exposed wall.

IMPROVISED SHELTERS

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If a community shelter is not available and you have not provided your own fallout shelter, what would you do if you suddenly heard that the United States had been attacked with nuclear weapons?

You can still protect yourself and your family if you know what to do and if you act quickly. Pick out the corner of your basement with the highest ground level outside. That is the safest place in the basement. **NOW MAKE IT SAFER.**

If you have a sturdy table or work-bench, place it in the corner. Quickly fill drawers or boxes with the heaviest material which is readily available—sand or dirt, bricks—or if you have nothing heavier, newspapers or books. Stack these materials on the top and the sides of the workbench.

In belowground basements, it is most important to have shielding overhead; place most of the material there.

Be careful not to overload the table to the point where it will collapse.

If a workbench is not available, you can improvise a small shelter area by using furniture, doors, dressers or other materials. Remove doors from their hinges and place them over supports in the corner of your basement having the best protection. The supports for the table can be a TV cabinet, chest of drawers or anything that can take a heavy load. Use two or three doors for this table to provide sufficient strength to support the heavy loads placed on them. Place bricks, concrete blocks, sand filled drawers, books, etc., over the doors to provide an overhead shield and along the sides to provide a vertical shield. Use anything with weight that can be moved. The heavier the material, the more the protection.

IMPROVISED SHELTERS

Drinking water is not only required for survival but is also useful as a shielding material. A collapsible children's swimming pool filled with water and located over the best corner of your basement will help improve the fallout protection. A bath tub, if suitably located, can also be used for this purpose.

If you have nothing better to improve the shielding over corner of your basement, stack the heaviest furniture you can find over the area. Use kitchen appliances, dressers, television sets, or drawers filled with sand. Pack them together as tightly as possible. Books and magazines can also be placed on top of the furniture.

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FACTS ON SHIELDING

Radiation from fallout particles on the roof will usually have a significant effect on the fallout protection in your basement; thus the PF in the best corner of the basement can be improved by placing shielding in or over the basement ceiling. Virtually any material can be used—bricks, concrete blocks, sand, water—even furniture. The heavier the material, the better the protection.

Entered in the box labeled "Added Weight" on the back cover of this booklet is a number which tell you approximately how much additional weight of material should be placed over each square foot of the area over the best corner of your basement to obtain a PF of 40, the minimum recommended. The additional material would serve as a "shield" against radiation coming through the basement ceiling. The "shield" should be placed so that it rests on one-quarter of the ceiling over the best corner of the basement.

If the letter "Y" appears in the box labeled "Added Weight" this means that one or more walls of your basement sticks out of the ground too much. In this case, adding overhead materials alone will usually not provide adequate protection against radiation unless heavy walls surrounding the shelter area are also added. If you already have a PF of 40 or more in the best corner of your basement, a zero, "0", will be shown in the box on the back cover labeled "Added Weight" indicating that additional weight is not required.

BASEMENT PF (PROTECTION FACTOR)		ADDED WEIGHT
CENTER	BEST CORNER	

YOUR OWN NUMBER WILL APPEAR IN THIS BOX ON THE BACK COVER OF THIS BOOKLET.

Here are the weights of typical shielding materials:

- 4 inches of sand weighs approx. 35 pounds per sq. ft.
- 4 inches of wood weighs approx. 10 pounds per sq. ft.
- 4 inches of water weighs approx. 21 pounds per sq. ft.
- 4-inch cinder blocks weigh approx. 22 pounds per sq. ft.
- 4-inch bricks weigh approx. 32 pounds per sq. ft.
- 4-inch solid concrete blocks weigh approx. 48 pounds per sq. ft.
- 4 inches of library books weigh approx. 15 pounds per sq. ft.

DETAILED PLANS ARE AVAILABLE FREE OF CHARGE

Detailed plans of many of the shelters you have read about in this booklet are available free of charge.

These plans contain construction details, suggested construction sequences and lists of materials needed. The plans supplement the material presented in this booklet.

Before constructing any of the permanent shielding devices described here, you should check to see that the construction conforms to your local building code.

The plans may be obtained by sending the attached post card to the Jeffersonville Census Operations Office, 1201 East 10th Street, Jeffersonville, Indiana 47130

Be sure that you identify the plan or plans you want as they are designated in the booklet:

- PLAN A — CEILING MODIFICATION TO BASEMENT — See page 8
- PLAN B — ALTERNATE CEILING MODIFICATION TO BASEMENT — See page 10
- PLAN C — CONCRETE BLOCK SHELTER — See page 12
- PLAN D — SNACK BAR SHELTER — See page 14
- PLAN E — TILT-UP STORAGE UNIT — See page 15
- PLAN F — LEAN-TO SHELTER — See page 16

For further information on fallout protection and personal and family survival, consult your local Civil Defense Director and send for the personal and family survival booklet using the attached post card.

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Appendix B

DISCUSSION OF ERRORS

Estimates of error in the experimental results are briefly discussed in this appendix. All known sources of error were investigated. The magnitude of some errors is well known; others are given as the author's best judgement.

B.1 NORMALIZED ROOF DATA

The accuracy of the normalized data from the source areas on the roof is dependent upon:

1. Source calibrations
2. Source anisotropy
3. Consistency of speed of the source
4. Uniformity of tubing distribution
5. Source contribution from the shield to the area
6. Timing accuracy of exposures
7. Detector calibration
8. Detector reproducibility
9. Detector orientation
10. Energy response of the detectors
11. Air density correction for detectors

B.1.1 Source Calibrations

The effective source activity was measured for each source separately at a point perpendicular to the long axis of the source in a plane bisecting the center of the source, the source being inside the tubing as it is used for the experiment. Several separate measurements were made with several different primary and secondary standard detectors over a period of 3 years. All results for the four smaller sources agreed to within about 2%. Backscatter for the earth-interface was accounted for in all source calibrations.

Each standard detector had a rated accuracy of $\pm 3\%$. The effective source activities reported are therefore expected to be accurate to within $\pm 3.4\%$ for the sources used for roof contributions.

B.1.2 Source Anisotropy

The sources were not isotropic. Relative to the exposure rate in the direction of the calibration point, the exposure rate was 7% less at 30° , 20%

less at 60° and about 50% less at the ends. The simulated first-story roof exposure was the worst case. The basement centered detector "saw" the source within 30° of the direction of its calibration point about 85% of the time; a corner detector, about 60% of the time. Therefore, for normalized roof contributions, an estimated correction factor should be applied: 1.05 (± 0.025) for centered detectors and 1.08 (± 0.04) for corner detectors for the simulated one-story house, and 1.03 (± 0.015) and 1.05 (± 0.025), respectively, for the two-story house.

B.1.3 Consistency of Speed of the Source

The source traveled with no detectable variation in speed when the tubing was in a straight, level line. Its speed was about 1% slower going around corners, 5% slower going straight up and 5% faster going straight down. The tubing distribution on the roof was such that the source traveled in a straight, level line most of the time. Therefore, any errors in the results due to inconsistent speed of the source are considered negligible.

B.1.4 Tubing Distribution

Tubing locations were determined by measuring the distance from the edge of the house and not from each tube. Total areas covered by the tubing were determined accurately by physical measurements. Each tube was placed inside these areas as near as practical to its designated location. A more probable source of error lies in the difficulty of simulating a uniform radioactive source by line sources placed a finite distance apart. If a uniform shield existed between the source and detector, errors would be small if the dimensions of the source area were large compared with tube separation.* Errors incurred because the shield was not uniform are not known, but are probably not large. Care was taken to place the tubing perpendicular to roof and ceiling joists. For want of an estimate, a possible error of $\pm 2\%$ was chosen.

B.1.5 Source Contribution from the Shield to the Roof Area

Radiation exposure contributed while the source traveled from the shield to the edge of the house was negligible because the tubing was buried under 2 ft of earth. It required a total time of 10 sec for the source to ascend and descend between the ground and roof area. Minimum exposure time were 15 min, resulting in a possible error of 1% for normalized roof contributions if this effect were neglected. The error was probably less than this, however, because the tubing was placed on the outside of the fireplace bricks and because most exposures were about 30 min. Therefore, an error of 0.5% is estimated for neglecting this effect.

B.1.6 Timing Accuracy of Exposures

The exposures were timed from when the source entered the area until it left. Source location indicators were strategically placed for accurate

*Unreported data taken by the authors during an earlier experiment showed that with tubing separation distances of 6, 12, and 24 in. on top of a 6-in. concrete slab, differences in data taken below the slab were undetectable.

timing. Times of exposures were measured by a stop watch. For these reasons, timing errors are considered negligible.

B.1.7 Detector Calibration

Care was taken throughout the experiment to use only detectors which had a slow leak rate and to keep them clean at all times. Detectors were calibrated in a direction normal to their stems and in a plane bisecting the center of the detector. Calibration correction factors were considered almost as good as the standard source ($\pm 3\%$) used. Therefore, systematic errors due to detector calibration are estimated to be within $\pm 3.2\%$.

B.1.8 Detector Reproducibility

All detector readings by the charger-reader were reproducible to within 3.5% (standard deviation) for the upper 90% of scale. In all cases during the experiment, exposures were in the upper 90% of scale and two detectors were placed at each location. In most cases each detector read within 3.5% of the average of the two. Errors due to reading reproducibility are therefore estimated to be $\pm 2.5\%$ (standard deviation).

B.1.9 Detector Orientation

The detector response was not isotropic. Relative to the response in the direction of the calibration point, they responded about 8% low in the direction of the stem and about 6% low in the opposite direction. All detectors were placed with their stems pointing down. Since most of the roof contribution arrives at the detector from an upward direction, an estimated correction factor of 1.05 (± 0.025) should be applied to the data to correct for the nonisotropic response of the detectors.

B.1.10 Energy Response of the Detectors

The detector response was independent of gamma energy from 1.25 Mev (^{60}Co) down to approximately 150 kev. They responded 10% low at 80 kev and 20% low at 40 kev. Most of the radiation contribution from roof sources was from unscattered gamma rays. However, it is possible that errors of about 1% may have resulted from neglect of this effect.

B.1.11 Air Density Corrections for Detectors

Detector responses were corrected for an air density of 22°C and 760 mm pressure to correct for calibrations. Air density correction factors were calculated from temperature and pressure readings during each exposure of the experiment. Inaccurate readings would result in possible errors of $\pm 0.7\%$ due to air density corrections.

B.1.12 Summary of Errors for Normalized Roof Data

Corrections should be applied to the data to account for source anisotropy and non-isotropic response of the detectors. These correction factors are 1.10 and 1.13 for center and corner detectors, respectively, for the first story case and 1.08 and 1.10, respectively, for the second story case.

After these correction factors have been applied, the data are expected to be accurate to within a standard deviation of about $\pm 7\%$.

B.2 CLOSE-IN NORMALIZED GROUND DATA

The accuracy of the normalized data from close-in ground areas is dependent upon the same items as those listed in the previous section.

B.2.1 Negligible Errors

Possible errors considered negligible were due to (1) speed of the source (2) source contribution from the shield to the ground areas, and (3) timing of exposure.

B.2.2 Comparable Errors in Normalized Roof Data

Errors for the close-in normalized data having the same value as those for the roof-normalized data are for (1) source calibrations, (2) detector calibrations, (3) detector reproducibility, and (4) air density correction for detectors.

B.2.3 Source Anisotropy

The source always traveled in a direction such that its long axis was parallel to the nearest wall. This minimized the errors due to the source anisotropy. However, the centered detectors "saw" the source in a direction between 30° and 54° of its calibration point about 30% of the time. An estimated correction factor of 1.05 (± 0.02) should therefore be applied to all close-in ground normalized data for centered detectors.

B.2.4 Tubing Distribution

The tubing was placed 1 ft apart for the Ground 1 measurements and 4 ft apart for the Ground 2 measurements. Errors of simulating a uniform radioactive source by these line sources are considered negligible for these source configurations.

Another error for Ground 1 data is caused by tubing being distributed over the outside entrance instead of around it or instead of filling the outside entrance with earth. According to Table 4.1, scattering through the outside entrance accounted for up to 30% of the exposure to detectors located within about 10 ft of the entrance from the Ground 1 area source. This effect is unnoticeable for Ground 2 data.

B.2.5 Detector Orientation

Most of the radiation arriving at centered detectors from ground sources was from a direction within 45° of the calibration direction. An estimated correction factor of 1.025 (± 0.01) should therefore be applied to account for the non-isotropic response of the detectors.

B.2.6 Energy Response of the Detectors

Essentially all radiation received by the detectors from ground sources has been scattered at least once. Clifford¹ reports that "at angles greater than 30° above the horizon the bulk of air-scattered radiation and hence the bulk of the dose received is from radiation with energies less than 300 kev." The energy spectrum of the radiation received by the detectors from ground sources was not measured. However, this effect on the response

of the chambers was estimated to be about 3%. A correction factor of 1.03 (± 0.015) should therefore be applied to the data to account for the energy response of the detectors.

B.2.7 Summary of Errors for Close-In Normalized Ground Data

A correction factor of 1.105 should be applied to centered detectors to account for source anisotropy, detector energy response, and detector non-isotropic response.

After these correction factors have been applied, data for centered detectors are expected to be accurate to within a standard deviation of about $\pm 6\%$.

Scattering through the outside entrance contributed up to 30% of the exposure from Ground 1 sources recorded by detectors within 10 ft of the entrance.

B.3 FAR-OUT NORMALIZED GROUND DATA

B.3.1 Negligible Errors

Possible errors considered negligible were due to (1) speed of the source, (2) source contribution from the shield to the ring source, (3) timing errors and (4) source anisotropy.

B.3.2 Comparable Errors in Close-in Normalized Ground Data

Errors for the far-out normalized ground data having the same value as those for the close-in normalized ground data are for (1) detector calibrations, (2) detector reproducibility, (3) detector orientation, (4) detector energy response, and (5) air-density correction for detectors.

B.3.3 Source Calibrations

The 800-curie source was used most of the time for the 200-ft-radius ring source. Because of its high activity, its calibration was more difficult than for smaller sources. Its effective source activity, is known to an estimated accuracy of $\pm 5\%$.

B.3.4 Tubing Distribution

About 25% of the ring source had to be raised from 0 to 6 in. above the ground so that the source could "see" the exposed basement wall. A slight increase of exposure may have resulted due to ground backscatter. An estimated correction factor of 0.99 should be applied to the data to account for this effect.

B.3.5 Ring Source Simulation of Far-Out Ground Area Source

The equation used for determining the far-out ground contribution is valid provided the energy and angular distribution of D_c are the same as those of I_c . Figure B.1 shows angular distribution comparisons taken from data from an earlier experiment.² A larger radius, 300 or 400 ft, would produce a better fit for the angular distribution. However, a 200-ft-radius source is much more practical, providing a reasonable compromise. The use of the 200-ft-radius source may have resulted in about a 10% ($\pm 5\%$)

under-response to air-scattered radiation and a 10% ($\pm 5\%$) over-response to wall-scattered radiation contributions to the basement area. However, for this particular structure the wall-scattered contribution nearly equals the skyshine contribution, thereby tending to cancel the errors due to using the 200-ft-radius source. An estimated error of $\pm 7\%$ may have resulted due to this compromise.

B.3.6 Summary of Errors for Far-Out Ground Contribution

A correction factor of 1.045 should be applied to data for centered detectors.

In the equation $E_{fo} = (D_c \times E_m) / I_c$ the magnitude of the ratio $(E_m) / I_c$ is more accurate than the magnitude of E_m since both E_m and I_c were measured with the same sources and instrumentation. The ratio is estimated to be accurate to within about $\pm 5\%$.

The value of D_c was taken from Rexroad³ and is estimated to be accurate to within $\pm 6\%$.

The far-out normalized data for centered detectors are expected to be accurate to within a standard deviation of about $\pm 11\%$.

A summary of error estimates is listed in Table B.1.

B.4 TOTAL CONTRIBUTIONS AND PROTECTION FACTORS

The total radiation contribution is the summation of the contributions from the roof and ground sources. The standard deviation of the total contribution is therefore the quadratic summation of the standard deviations of each contribution. Sample data from all phases were chosen and in all cases a standard deviation of about $\pm 5\%$ was found for the total contributions.

Protection factors were calculated, assuming 500 mr/hr per mc/sq ft as the free-field exposure rate 3 ft above an infinite smooth plane of ^{60}Co . This value was assumed to be accurate to within $\pm 6\%$. The protection factors for ^{60}Co are therefore considered accurate to within a standard deviation of about $\pm 8\%$ after corrections have been applied for source anisotropy, detector energy response and detector orientation as discussed in preceding sections.

REFERENCES

1. C. E. Clifford, et al., Scattered Radiation from a Simulated Fallout Field Using Cesium-137, DCRL-296 (Defence Research Chemical Laboratories, Ottawa, Canada), January 1959.
2. Unpublished data by the authors.
3. R. E. Rexroad and M. A. Schmoke, Scattered Radiation and Free-Field Dose Rates from Distributed Co^{60} and Cs^{137} Sources, Report NDL-TR-2, Nuclear Defense Laboratory, September 1960.

TABLE B.1 - ERROR ESTIMATE IN PERCENT

Item	Roof contribution				Ground contribution		
	1st story		2nd story		Ground 1	Ground 2	Ground FO
	Center	Corner	Center	Corner	Center	Center	Center
Source calibrations	3.4	3.4	3.4	3.4	3.4	3.4	5.0
Source anisotropy	2.5	4.0	1.5	2.5	2.0	2.0	0
Source speed	0	0	0	0	0	0	0
Tubing distribution	2.0	2.0	2.0	2.0	0	0	0.5
Shield-to-area contribution	0.5	0.5	0.5	0.5	0	0	0
Timing of exposures	0	0	0	0	0	0	0
Detector calibrations	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Detector reproducibility	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Detector orientation	2.5	2.5	2.5	2.5	1.0	1.0	1.0
Detector energy response	1.0	1.0	1.0	1.0	1.5	1.5	1.5
Air density corrections	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Ring-source simulations							7.0
Combined errors	±7%	±7%	±7%	±7%	±6%	±6%	±11%
Estimated corrections* to be applied to data	1.10	1.13	1.08	1.105	1.105	1.105	1.045

*Factor, not percentage

Fig. B-1 - Exposure angular distribution 3 ft above the ground from a ring source of 200-ft radius and from an area source bounded by radii of 81 and 3000 ft.

Appendix C

COMPLETE DETAILED MASS THICKNESS DETERMINATIONS FOR ALL TEST PHASES

C.1 PHASE 1, TWO-STORY WOOD FRAME HOUSE

<u>Roof Assembly</u>							
<u>Item</u>	<u>Size</u>	<u>Quantity</u>	<u>Material</u>	<u>Density, lb/cu ft</u>	<u>Total mass, lb</u>	<u>Area, sq ft</u>	<u>Mass thickness, lb/sq ft</u>
1	2x10x13'	48	Fir rafters	26	1761	822	2.14
2	2x8x24'	24	Fir joists	"	1285	"	1.56
3	2x6x3'	16	Fir gable	"	790	"	0.96
4	2x4x10'	9	Fir collar ties	"	99	"	0.12
5	1" thick		Fir sheathing	"	2055	"	2.50
6	3/8" thick		Fir sheathing	"	822	"	1.00
7	210 lb/100 sq ft		Asphalt shingles		1728	"	2.10
8	15 lb/100 sq ft		Felt		123	"	0.15
9	2 cans		Tar		200	"	0.24
Total Roof Assembly					8863	822	10.77
<u>Second-floor assembly</u>							
1	2x8x33'	18	Fir joists	26	1265	786	1.61
2	1x24'x32.75'		Pine floor	31	1941	786	2.47
3	3/8"x24x32.75		Ply subfloor	26	786	786	1.00
4	3/8"x24x32.75		Ply ceiling	26	786	786	1.00
Total second-floor assembly					4778	786	6.08
<u>First-floor assembly</u>							
1	2x10x32.75'	20	Fir joists	26	1770	786	2.25
2	1x24'x32.75		Pine floor	31	1941	786	2.47
3	3/8"x24x32.75		Ply subfloor	26	786	786	1.00
Total first-floor assembly					4497	786	5.72
<u>Interior Partitions for 1st & 2nd floor</u>							
1	3/4x24'x8.35'	4	Ply sheathing	26	1304	786	1.66
2	2x4x8.35'	40	Fir studs	26	355	786	0.45
Total interior partitions for 1st or 2nd floor					1659	786	2.11
<u>Total Overhead Mass Thickness</u>							
Two-story wood frame house				= 10.77 + 6.08 + 5.72 + (2.11)(2)			
Total = 26.79 lb/sq ft							
One-story wood frame house				= (6.08 + 5.72 + 2.11)			
Total = 13.91 lb/sq ft							

Exterior Walls

Item	Size	Quantity	Material	Density lb/cu ft	Total mass, lb		Mass thick- ness, lb/sq ft	
					1-story	2-story	1-story	2-story
1	2x6x8'2"	113	Fir studs	26	1522	3044	6.71	6.43
2	2x6x116.2'	1	Fir sill	26	192	576	6.71	6.43
3	6x8x116.2'	1	Redwood plate	22	762	762	6.71	6.43
4	2112 sq ft x 3/4"		Fir sheathing	26	1715	3430	6.71	6.43
5	2112 sq ft x 1"		Pin siding	31	2730	5460	6.71	6.43
6	2112 sq ft		Felt	0.15*	158	316	6.71	6.43
Total					7081	13588	6.71	6.43

Apertures, Total for one-story house
132 sq ft $\approx$ 8.75%
Total for two-story house
257.1 sq ft $\approx$ 8.79%

C. 2 PHASE 2, OVERHEAD BARRIER

Area, sq ft

A	2x4x8	1917	Concrete blocks	4.75**	9106	148	61.5
	$\frac{1}{2}$ x12x12.3'	1	Plywood	26	160	148	1.1
B	2x4x8	1819	Concrete blocks	4.75**	8640	148	58.4
	$\frac{1}{2}$ x12x12.3	1	Plywood	26	160	148	1.1
C, D	2x4x8	2031	Concrete blocks	4.75**	9650	148	65.2
	$\frac{1}{2}$ x12x12.3	1	Plywood	26	160	148	1.1
F	2x4x8	2700	Concrete blocks	4.75**	12825	187	65.2
	$\frac{1}{2}$ x16x12.3	1	Plywood	26	213	197	1.1

C. 3 PHASE 3, SIT-DOWN SHELTER

Roof	4x8x16	133	Concrete blocks	34.5**	4585	57.8	79.4
mass	3/4"x5.25'x11'	1	Plywood	26	115	57.8	2
	2"x4"x5.25'	7	Fir joists	26	39	57.8	0.67
Wall	4x8x16	342	Concrete blocks	34.5**	11315	85.3	133

PHASE 3, LEAN-TO-SHELTER

Roof	Wood		Fir	26	376	54	7.0
mass	4x8x16	148	Concrete blocks	34.5**	5110	54	94.5
Wall	4x8x16	302	Concrete blocks	34.5**	10410	72	145

PHASE 3, WORKBENCH SHELTER WITH MAGAZINES ON TOP

Roof	Magazines and bench combined				725	17.5	41.4
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C. 4 PHASE 4, TILT-UP UNIT SHELTER

Roof	4x8x16	126	Concrete blocks	34.5**	4345	75	57.9
mass	2x8x97.2'	Total	Fir cases	26	218	75	2.9
	1x6x224'	Total	Case bottom	26	107	75	1.4
Wall	4x8x16	487	Concrete blocks	34.5**	16800	100	168

*lb/sq ft **lb/block

WORKBENCH SHELTER WITH CONCRETE WALLS & TOP

<u>Item</u>	<u>Size</u>	<u>Quantity</u>	<u>Material</u>	<u>Density, lb/cu ft</u>	<u>Total mass, lb</u>	<u>Area, sq ft</u>	<u>Mass thickness, lb/sq ft</u>
Roof	4x8x16	49.5	Concrete blocks	34.5*	1710	17.5	97.6
mass	Workbench		Fir	26	115	17.5	6.6
Wall							
mass	4x8x16	49.5	Concrete blocks	34.5*	1710	22.9	74.6

C. 5 PHASE 5, ALTERNATE DUAL PURPOSE SHELTER PLAN B

Roof	2x4x8	2107	Concrete blocks	4.75*	10000	148	67.6
mass	2x12x12'	12	Fir joists	26	4910	148	33.2
	$\frac{1}{2}$ "x12'x12.3'	1	Plywood	26	160	148	1.1

C. 6 PHASE 6, INCREMENTAL OVERHEAD BARRIER

Roof	2x4x8	750	Concrete blocks	4.75*	3560	144	23.75
mass (A) 1st layer							
(B) 2nd	2x4x8	1568	Concrete blocks	4.75*	7122	144	49.5
Layer							
(C) 3rd	2x4x8	2255	Concrete blocks	4.75*	10700	144	74.3

C. 7 PHASE 6, BRICK VENEER

Wall							
mass	2x4x8		Concrete blocks	4.75 lb/block x 5.21 blocks/sq ft			= 24.75 lb/sq ft

1. The brick chimney reduces the ground contribution by 6% due to the solid angle subtended.
2. Exposed basement concrete walls = 95.4 lb/sq ft - 20% for apertures = 79.5 lb/sq ft

C. 8 PHASE 6, E AND F

<u>Living room furniture</u>	<u>Total mass, lb</u>	<u>Dining room furniture</u>	<u>Total mass, lb</u>
1 ea. credenza	46.5	1 ea. dining room table	101.0
1 ea. stereo cabinet	148.5	8 ea. dining room chairs	100.0
1 ea. desk chair	12.0	1 ea. drop-leaf table	59.0
1 ea. desk	58.5	1 ea. pullman chair	68.5
1 ea. swivel rocking chair	58.5		
2 ea. cocktail tables	58.5	<u>Kitchen furniture</u>	
1 ea. sofa chair	56.0	1 ea. kitchen table	40.0
1 ea. sofa	120.5	4 ea. kitchen chairs	37.0
2 ea. corner tables	81.0	1 set household dishes	40.0
2 ea. love seats	137.0	1 ea. refrigerator**	131.0
		1 ea. gas stove**	131.0
		4 ea. cabinets**	150.0
		Total mass =	1762.5

Total mass used in Phase 6 F = 1222.5

Area covered = 132.sq ft

Mass thickness = 9.27 lb/sq ft

Total time for two persons to move the furniture into the corner was 5.5 minutes.

*lb/block

** Furniture not used in Phase 6 F

Appendix D

ENGINEERING CALCULATIONS

D. 1 ENGINEERING METHOD* (FALLOUT), ONE-STORY AND TWO-STORY WOOD FRAME HOUSE, BARE BASEMENT

ω	W	L	Z	e	n	ω	$G_a(\omega)$	$G_s(\omega)$
ωu	24.7'	33.3'	23.6'	0.74'	1.42	0.175	0.096	0.46
$\omega'u$	24.7'	33.3'	13.3'	0.74'	0.80	0.36	0.091	0.42
$\omega''u$	24.7'	33.3'	4.17'	0.74'	0.25	0.74	0.065	0.26
$\omega'''u$	24.7'	33.3'	3.5'	0.74'	0.21	0.78	0.059	0.23

$$SW(Xe) = S'W(6.16) = 0.14$$

$$S''W(5.91) = 0.14$$

$$S'''W(79.5) = 0.69$$

$$E(e) = E(0.74) = 1.40$$

$$Be(Xe, H) = B'e(6.16, 3) = 0.85$$

$$B''e(5.91, 3) = 0.86$$

$$B'''e(79.5, 3) = 0.15$$

$$B'o(X'o) = B'o(11.80) = 0.40$$

$$B''o(5.72) = 0.58$$

$$B'''o(79.5) = 0.017$$

Roof Contribution

$$Co(Xowu) = C'o(26.79, 0.175) = 0.0265 = 2\text{-story house} = 13.25 \text{ mr/hr per mc/sq ft}$$

$$C'o(Xowu) = C''o(11.80, 0.31^{***}) = 0.065 = 1\text{-story house} = 32.50 \text{ mr/hr per mc/sq ft}$$

Ground Contribution

Functional Equation

$$C_g = [Be(Xe, H)] [B'o(X'o)] \{ [G_a(\omega u) - G_a(\omega'u)] [1 - SW(Xe)] + [G_s(\omega u) - G_s(\omega'u)] [SW(Xe)] [E(e)] \}$$

Contribution Through Second-Floor Wall

$$C'g = (0.85) (0.40) \{ (0.096 - 0.091) (1 - 0.14) + (0.46 - 0.42) (0.14) (1.4) \}$$

$$C_g = 0.00413$$

*Design and Review of Structures for Protection from Fallout Gamma Radiation, PM-100-1, Department of Defense, Office of Civil Defense, February 1965

**See Note 2 of Appendix C

***For 1st-story roof contribution only (W = 21.9, L = 29.6)

Contribution Through First-Floor Walls

$$C''g = (0.86) (0.58) \{ (0.091 - 0.065) (1 - 0.14) + (0.42 - 0.26) (0.14) (1.40) \}$$

$$C''g = 0.0268$$

Contribution Through Basement Walls

$$C'''g = (0.15) \{ (0.065 - 0.059) (1 - 0.69) + (0.26 - 0.23) (0.69) (1.4) \}$$

$$C'''g = 0.00463$$

Total Contribution for Two-Story Wood Frame House

$$Cg = C'g + C''g + C'''g = 0.0356 \text{ corrected and normalized, total ground}$$

$$\text{contribution} = \frac{0.0356}{1.06*} \times 500$$

$$\approx 16.8 \text{ mr/hr per mc/sq ft}$$

$$Co = 0.0265; \text{ corrected and normalized, roof contribution} = 0.0265$$

$$\times 500 \approx 13.25 \text{ mr/hr per mc/sq ft}$$

$$\text{Total contribution} = 30.05 \text{ mr/hr per mc/sq ft}$$

$$\text{Protection Factor} = 16.7$$

Total Contribution for One-Story Wood Frame House

$$Cg = C'g + C'''g = 0.0314; \text{ corrected and normalized, total ground}$$

$$\text{contribution} = \frac{0.0314}{1.06*} \times 500$$

$$\approx 14.8 \text{ mr/hr per mc/sq ft}$$

$$Co = 0.065; \text{ corrected and normalized, roof contribution} = 0.065$$

$$\times 500 \approx 32.45 \text{ mr/hr per mc/sq ft}$$

$$\text{Total contribution} = 47.30 \text{ mr/hr per mc/sq ft}$$

$$\text{Protection Factor} = 10.6$$

D. 2 FROM SPENCER**, ⁶⁰Co, ROOF CONTRIBUTION INTO BARE BASEMENT

Spencer suggests the following equations be used

$$D/Do = L(x) Lb(x, w_u) La(x, w_u'') \text{ or} \quad (1)$$

$$D/Do = L(x) Lb(x, w_u) Pa(x, w_u'') \quad (2)$$

depending upon whether w_u is very large or very small.

2nd-Story Roof

$$X = 26.9 \text{ psf}, w_u = 0.17, w_u'' = 0.74$$

$$L(26.9) Lb(26.9, 0.17) = 0.0260 \text{ from Fig. B47}$$

$$La(26.9, 0.74) = 0.78 \text{ from Fig. B29}$$

$$\begin{aligned} Pa(26.9, 0.74) &= \frac{1}{P(x)} \left[P^{(o)}(x) + P^{(s)}(x) Pa^{(s)}(s, w_u'') \right] \\ &= \frac{1}{0.285} \left[0.17 + (0.116) (0.84) \right] = 0.93 \end{aligned}$$

*1.06 correction due Note 1 of Appendix C

**L. V. Spencer, Structure Shielding Against Fallout Radiation From Nuclear Weapons, NBS Monograph 42, U. S. Department of Commerce, National Bureau of Standards, June 1962.

$$D/D_o = 0.0203 \text{ or } 0.0242; D_{\min} = 10.1 \text{ mr/hr per mc/sq ft}$$

$$D_{\max} = 12.1 \text{ mr/hr per mc/sq ft}$$

1st-Story Roof

$$X = 14 \text{ psf}, w_u = 0.31, w''_u = 0.74$$

$$L(14, 0.31) = 0.063 \text{ from Fig. B47}$$

$$La(14, 0.74) = 0.72 \text{ from Fig. B29}$$

$$Pa(14, 0.74) = \frac{1}{P(x)} \left[P^{(o)}(x) + P^{(s)}(x) P^{(s)}(x, w''_u) \right]$$

$$= \frac{1}{0.325} \left[0.25 + (0.085)(0.86) \right] \approx 1.0$$

$$D/D_o = 0.0454 \text{ or } 0.063; D_{\min} = 22.7 \text{ mr/hr per mc/sq ft}$$

$$D_{\max} = 31.5 \text{ mr/hr per mc/sq ft}$$

D.3 ROOF CONTRIBUTION, PHASE 2CD, CORNER POSITION UNDER SHELTER

w	W	L	Z	e	N	w
w_u	49.3	66.7	23.6	0.74	0.71	0.40
w'_u	43.8	59.2	13.3	0.74	0.45	0.57
w''_u	24	24	4.17	1.00	0.347	0.70

$$X_o = 86 \text{ psf}$$

$$X'_o = 73.3 \text{ psf}$$

A. Engineering Manual (fallout)

$$Co(x_o, w_o) = Co(86, 0.40) = 0.021; \text{ 2nd-story contribution}$$

$$= 1/4 Co \times 500 = 2.62 \text{ mr/hr per mc/sq ft}$$

$$C'o(x'_o, w'_o) = C'o(73.3, 0.57) = 0.036; \text{ 1st-story contribution}$$

$$= 1/4 C'o \times 500 = 4.50 \text{ mr/hr per mc/sq ft}$$

B. Spencer, ⁶⁰Co

$$\text{Use equation } D/D_o = L(x) Lb(x, w) La(x, w')$$

$$\text{2nd Story; } D/D_o = L(86) Lb(86, 0.40) La(86, 0.70) = (0.017)(0.80)$$

$$= 0.0136; \text{ contribution} = 1/4 (0.0136)(500) = 1.70 \text{ mr/hr per mc/sq ft}$$

$$\text{1st Story; } D/D_o = L(73) Lb(73, 0.57) La(73, 0.70) = (0.030)(0.80)$$

$$= 0.024; \text{ contribution} = 1/4 (0.024)(500) = 3.00 \text{ mr/hr per mc/sq ft}$$

D.4 CAPS-2 COMPUTER PROGRAM, FALLOUT, PHASE 1, BARE BASEMENT

John Dirst* of OCD calculated by the CAPS-2 computer program roof and ground contributions to several points in the basement. These results are given in Table D.1.

*Unpublished data, John Dirst, Office of Civil Defense

TABLE D.1 - CAPS-2 CALCULATIONS OF RADIATION CONTRIBUTIONS, PHASE 1

Position	Height, ft	Radiation contributions mr/hr per mc/sq ft		Total Ground	PF 1	PF 2
		Roof 1	Roof 2			
1	3	25.2	12.1	11.6	13.6	21.2
2	3	22.2	10.7	9.6	15.7	24.5
3	3	18.4	9.7	6.4	20.2	30.9
4	3	21.5	10.4	9.7	16.0	24.8
5	3	23.3	11.2	11.6	14.3	21.9
6	3	25.9	12.1	13.7	12.6	19.3
7	3	23.8	11.4	12.3	13.9	21.1
8	3	21.2	10.5	10.4	15.8	24.0
9	3	23.3	11.2	12.3	14.0	21.3
10	3	24.9	11.8	13.8	12.9	19.6
11	3	26.2	12.0	14.9	12.2	18.7
12	3	30.5	13.2	13.6	10.2	15.7
26	3	27.8	12.5	16.2	11.4	17.5
27	3	27.8	12.5	16.2	11.4	17.5
28	3	27.8	12.5	16.2	11.4	17.5
29	3	34.1	14.3	20.7	9.1	14.3

Appendix E

MATERIAL LIST OF TEST SHELTERS *

E. 1	12 x 12-FT SOLID OVERHEAD BARRIER SHELTER, PLAN A		
	Masonry		
	2-1/4" x 4" x 8" solid blocks	2031	
	Plywood sheets		
	1/2" 5-ply, utility B-C grade		
	2' -0" x 8' -0" (cut to fit exact joist spacing)	6	
	2' -0" x 4' -0" (cut to fit exact joist spacing)	6	
	Hardware		
	No. 7 x 1-1/2" cad. -plated wood screws	2 gross	
	16c common nails	3 lb	
E. 2	12 x 16-FT SOLID OVERHEAD BARRIER MODIFIED, PLAN A		
	Masonry		
	2-1/4" x 4" x 8" solid blocks	2700	
	Plywood sheets		
	1/2" 5-ply utility B-C grade	12	
	Hardware		
	No. 7 x 1-1/2 cad. -plated wood screws	2-1/2 gross	
	16d common nails		
E. 3	12 x 12-FT SOLID OVERHEAD BARRIER, PLAN B		
	Masonry		
	2-1/4" x 4" x 8" solid blocks	2107	
	Lumber (construction grade)		
	New joists 2 x 12, cut to fit existing span	12	
	Blocking		
	2 x 8 x 1' -0-3/4" (cut to fit)	20	
	2 x 4 x 1' -0-3/4" (cut to fit)	10	
	Plywood sheets		
	1/2" 5-ply utility B-C grade		
	2' -0" x 8' -0" sections (cut to fit)	6	
	2' -0" x 4' -0" sections (cut to fit)	6	
	Hardware		
	No. 7 x 1-1/2" cad. -plated wood screws	1 gross	
	16d common nails	3 lb	

*These materials are slightly different from that provided in original plans.

E. 4 CONCRETE BLOCK SIT-DOWN SHELTER, PLAN C

Masonry	
4" x 8" x 16" solid blocks	460
4" x 8" x 8" solid blocks	18
2-1/4" x 4" x 8" solid blocks	104
Lumber ("construction" or "No. 1")	
Posts 2" x 4" x 8"*	6
Joists 2" x 4" x 6"*	7
Beams 2" x 4" x 12"*	2
Frame 2" x 8" x 6"*	2
Header 2" x 8" x 3"*	2
Plywood 2' x 8' x 3/4" utility B-C grade*	4 pieces
4' x 8' x 3/4" utility B-C grade*	2 pieces
Hardware	
8d nails	2 lb
10d nails	2 lb
3/8" bolt size multiple-expanding machine bolts	18
3/8" x 3-1/2" square-head unfinished anchor bolts	18

E. 5 LEAN-TO SHELTER, PLAN F

Masonry	
4" x 8" x 16" solid blocks	146 blocks
2-1/4" x 4" x 16" solid blocks	18 blocks
Entrance wall 4' x 8" x 16"	142 blocks
2-1/4" x 4" x 8"	114 blocks
Lumber ("construction" or "No. 1" grade)	
Stringers 2' x 8" x 10"*	9 pieces
Boards 1" x 6" x 3' T&G	69 pieces
1" x 10" x 3'	60 pieces
Blocking 2" x 8" x 1' -3-1/2" stress grade lumber	6 pieces
4" x 4" x 1' -3-1/2" (rip lengthwise at 45° to provide the 6 pieces required)	3 pieces
Hardware	
No. 10 2" barbed roofing nails	3 lb
3/8" diameter x 2-1/2" lag screws & washers	12 ea
3/8" expanding lead shields	12 ea
16d common nails	1 lb
glue, protein emulsion (must develop 450 psi)	1-1/2 pints

E. 6 TILT-UP UNIT SHELTER, PLAN E

Masonry	
Roof 4" x 8" x 16" solid blocks	126 blocks
Walls 4" x 8" x 16" solid blocks	433 blocks
2-1/4" x 4" x 8" solid blocks	16 blocks
Doorway 4" x 8" x 16" solid blocks	48 blocks
2-1/4" x 4" x 8" solid blocks	27 blocks
Lumber	
Posts 2" x 4" x 8' (cut to fit)	5 pieces
Beam 2" x 8" x 12' (cut to fit)	1 piece
3 cases plus half case	
2" x 8" x 6' -2-3/8"	8 pieces
2" x 8" x 1' -4"	9 pieces
2" x 8" x 2' -9-5/8"	6 pieces
1" x 6" x 1' -7-1/4" T&G	13 pieces
1" x 6" x 3' -1" T&G	39 pieces

*cut to fit 9'7" (45° diag. cut at both ends)

Hardware	
3" x 6" x 1/8" unfinished steel strap hinges	8
No. 12 x 1-1/2" wood screws, c. s.	64
3/8" diam. x 6" square-head unfinished anchor bolts	20
3/8" bolt size multiple-expanding machine bolt anchor	20
glue, protein emulsion (must develop 450 psi)	1-1/2 pints
16d common nails	3 lb

E. 7 WORKBENCH SHELTER, PLAN W

Masonry	
4" x 8" x 16" solid blocks	97 blocks
4" x 8" x 8" solid blocks	9 blocks
Lumber	
2" x 6" x 6'	3 pieces
2" x 6" x 14'	1 piece
1" x 6" x 10'	1 piece
2" x 8" x 7'	6 pieces
Hardware	
No. 10 flathead c. s. wood screws	30 ea
16d common nails	1 lb
glue, all joints	1/2 pint

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations, the Atomic Energy Commission conducts certain 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 vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. The following is a partial list of reports available from studies that have been completed. All reports listed are available, at the prices indicated, from the Clearinghouse for Federal Scientific and Technical Information, U.S. Department of Commerce, Springfield, Va.

- CEX-58.1, Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J.A. Auxier, J.O. Buchanan, C. Eisenhauer, and H.E. Menker, 1959, \$2.75.
- CEX-58.2, The Scattering of Thermal Radiation into Open Underground Shelters, T.P. Davis, N.D. Miller, T.S. Ely, J.A. Besso, and H.E. Pearse, 1959, \$0.75.
- CEX-58.7, AEC Group Shelter, AEC Facilities Division Holmes & Narver, Inc., 1960, \$0.50.
- CEX-58.8, Comparative Nuclear Effects of Biomedical Interest, C.S. White, I.G. Bowen, D.R. Richmond, and R.L. Corsbie, 1961, \$1.00.
- CEX-58.9, A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves, I.G. Bowen, R.W. Albright, E.R. Fletcher, and C.S. White, 1961, \$1.25.
- CEX-59.1, An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J.F. Batter, Jr., A.L. Kaplan, and E.T. Clarke, 1960, \$0.60.
- 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, Z.G. Burson, 1966, \$1.50.
- 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, Z.G. Burson, 1964, \$1.50.
- CEX-59.7B (Pt. III), Experimental Radiation Measurements in Conventional Structures. Part III. The Attenuation of Air-scattered Radiation in a Basement, Z.G. Burson, 1965, \$1.00.
- CEX-59.13, Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T.D. Strickler and J.A. Auxier, 1960, \$0.50.
- CEX-59.14, Determinations of Aerodynamic-drag Parameters of Small Irregular Objects by Means of Drop Tests, E.P. Fletcher, R.W. Albright, W.C. Goldizen, and I.G. Bowen, 1961, \$1.75.
- CEX-60.1, Evaluation of the Fallout Protection Afforded by Brookhaven National Laboratory Medical Research Center, H. Borella, Z. Burson, and J. Jacovitch, 1961, \$1.75.
- CEX-60.3, Extended- and Point-source Radiometric Program, F.J. Davis and P.W. Reinhardt, 1962, \$1.50.
- CEX-60.5, Experimental Evaluation of the Fallout-radiation Protection Afforded by a Southwestern Residence, Z. Burson, D. Perry, and H. Borella, 1962, \$0.50.
- CEX-60.6, Experimental Evaluation of the Radiation Protection Provided by an Earth-covered Shelter, Z. Burson and H. Borella, 1962, \$1.00.
- CEX-61.1 (Prelim.), Gamma Radiation at the Air-Ground Interface, K. O'Brien and J.E. McLaughlin, Jr., 1963.
- CEX-61.4, Experimental Evaluation of the Fallout-radiation Protection Provided by Selected Structures in the Los Angeles Area, Z.G. Burson, 1963, \$2.25.
- CEX-62.01, Technical Concept—Operation BREN, J.A. Auxier, F.W. Sanders, F.F. Haywood, J.H. Thor-gate, and J.S. Cheka, 1962, \$0.50.
- CEX-62.2, Nuclear Bomb Effects Computer (Including Slide-rule Design and Curve Fits for Weapons Effects), E.R. Fletcher, R.W. Albright, R.F.D. Perret, Mary E. Franklin, I.G. Bowen, and C.S. White, 1963, \$1.00.
- CEX-62.11, Distribution of Weapons Radiation in Japanese Residential Structures, J.S. Cheka, F.W. Sanders, T.D. Jones, and W.H. Shimpough, 1965, \$1.00.
- CEX-62.14, An Experimental Investigation of the Spatial Distribution of Dose in an Air-over-Ground Geometry, F.F. Haywood, J.A. Auxier, and E.T. Loy, 1964, \$4.00.
- CEX-62.50, Neutron-field and Induced-activity Measurements—Operation BREN, F.M. Tommvec and J.M. Ferguson, 1965, \$1.00.
- CEX-62.81 (Final), Ground Roughness Effects on the Energy and Angular Distribution of Gamma Radiation from Fallout, C.M. Huddleston, Z.G. Burson, R.M. Kinkaid, and Q.G. Klinger, 1964, \$1.75.
- CEX-63.3, Barrier Attenuation of Air-scattered Gamma Radiation, Z.G. Burson and R.L. Summers, 1965, \$1.00.
- CEX-63.7, A Comparative Analysis of Some of the Immediate Environmental Effects at Hiroshima and Nagasaki, C.S. White, I.G. Bowen, and D.R. Richmond, 1964, \$2.00.
- CEX-64.3, Ichiban: The Dosimetry Program for Nuclear Bomb Survivors of Hiroshima and Nagasaki—A Status Report as of April 1, 1964, J.A. Auxier, 1964, \$0.50.
- CEX-65.01, Feasibility Study: Intense 14-MEV Neutron Source for Operation HENRE, T.G. Provenzano, E.J. Story, F.F. Haywood and H.T. Miller, 1966, \$1.00.
- CEX-65.02, Technical Concept—Operation HENRE, S.F. Haywood and J.A. Auxier, 1965, \$1.00.
- CEX-65.03, Operations Plan—Operation HENRE, Technical Director's Staff, 1965, \$1.00.
- CEX-65.4, Biological Tolerance to Air Blast and Related Biomedical Criteria, C.S. White, I. Gerald Bowen, and D.R. Richmond, 1965, \$2.75.