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HE DESIGN AND PERFORMANCE OF A FALLOUT-TESTED MANNED SHELTER STATION AN ITS SUITABILITY AS A SINGLE-FAMILY SHELTER

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ABSTRACT

The design details, cost analysis and performance characteristics are presented for small, partially-underground fallout shelters utilized as manned stations during a nuclear weapon effects test. Four men occupied each shelter and operated radiation measurement and fallout collection instruments.

Two types of shelters were designed to withstand predicted overpressures: Type I for a 1-psi overpressure and Type II for a 5-psi overpressure. The basic structure consisted of an 8-ft diameter, 10-ft long, 12-gage corrugated steel, multi-plate pipe. A steel entranceway incorporating two right-angle turns provided access to the basic structure. Depending upon the amount of soil backfill, fallout gamma radiation protection factors up to 470,000 were obtained.

The overall performance of the shelters under the conditions experienced was excellent. It is suggested that shelters of this type have application not only for use as manned stations in nuclear weapon testing but can be adapted as well for use in residential areas as single-family fallout shelters.

SUMMARY

Problem

To present the design specifications, cost analysis and performance characteristics of 4-man fallout shelters used as manned stations to obtain experimental measurements during a nuclear weapon effects test.

Findings

Six 4-man shelters installed at the Nevada Test Site afforded protection, during fallout in a nuclear weapon effects test, to personnel operating instruments and collectors.

The design specifications, cost analysis and performance characteristics were determined. To meet the design specifications for the predicted overpressures, a Type I shelter was designed for a 1-psi overpressure and a Type II shelter was designed for a 5-psi overpressure.

Depending upon the amount of soil backfill, fallout gamma radiation protection factors up to 470,000 were obtained.

Shelters of this type have applications not only for use as manned stations in nuclear weapon testing out could be adapted as well for use in residential areas as single family fallout shelters.

CONTENTS

SECTION 1

INTRODUCTION

Radioactive fallout collection and gross sample analysis were recently completed by this laboratory during a nuclear weapon effects test at the Nevada Test Site. A major objective of the project was to measure, during fallout, the deposition dynamics of the event involving arrival time, mass deposition rate, and time of cessation. The short lead-time and unavailability of adequate "on the shelf" automatic instrumentation to measure the dynamics of the fallout event led to the choice of utilizing manned stations in the fallout path. From these manned stations, personnel were able to manually control the opening and closing of fallout collectors and start gamma-measuring instrumentation during the actual fallout event.

To satisfy the objectives of the project, six 4-man shelters were designed, fabricated and installed at the Nevada Test Site. This laboratory has had experience in the design and operation of the manned shipboard stations at Operation Wigwam,[1] Castle[2] and Redwing.[3] The design and operation of a manned fallout shelter was proof-tested at Operation Plumbbob.[4] The laboratory has also pioneered in developing the basic concepts of fallout shelter design,[5,6] performance and management.

It is the purpose of this report to present the design specifications and construction costs of the fallout shelters, to describe their performance, and to point out the adaptability of structures of this type as single-family fallout shelters.

SECTION 2

SHELTER SPECIFICATIONS

The fallout shelters utilized as manned stations were located as shown in Table 2.1 to maximize the probability of having one or more manned stations in the fallout pattern and thus enable personnel manning the shelters to control fallout collection and measuring instruments located in the extensive sampling array. The shelter specifications considered for each location the following factors: (1) initial weapons effects, (2) fallout effects, and (3) habitability requirements.

TABLE 2.1

Initial Weapons Effects
(Based on 2-KT Surface Burst)

Shelter	Distance From Ground Zero (feet)		Maximum Overpressure	Thermal	Initial Radiations	
	Planned	Installed	(lb/in^2)	(cal/cm^2)	Gamma (r)	Neutron (rem)
S1	4,000	4,500	1.5	3	34	16
S2	8,000	7,200	0.6	1	2	< 0.2
S3	12,000	8,900	0.3	0.3	0.2	0
S4	18,000	15,600	0.2	~ 0	~ 0	0
S5	26,000	25,400	0.1	0	0	0
S6	26,000	28,000	0.1	0	0	0

2.1 INITIAL WEAPON EFFECTS

Table 2.1 lists, for each planned shelter location, estimates of blast overpressures, thermal effects, and initial gamma and neutron radiations. The estimates were based on data from the Effects of Nuclear Weapons, 1962[7] for a 2-KT surface burst.

2.2 FALLOUT EFFECTS

The gamma dose and 1-hr gamma ionization rates at exposed positions along the downwind axis of the predicted fallout pattern were estimated to determine the shielding requirements for each shelter. The fallout pattern was based on a pre-publication version of a simplified fallout model.[8] The calculated doses shown in Table 2.2 for each of the planned shelter locations were further adjusted to conform with Jangle[9] monitoring data which led to higher accumulated doses than those predicted from the model. The times of peak radiation and cessation were taken from reference.[10]

A simple estimate of the shielding required at the shelters, to be achieved by means of attenuation of the gamma radiations through earth, was made by using the dose transmission curves in reference 7. Using a maximum expected stay time of 72 hours and allowing shelter personnel a total dose during occupancy of 100 r, the dose transmission factors (DTF) for each shelter obtained by Eq. 1 are presented in Table 2.3. The reciprocal of the DTF or protection factors (PF) are also given.

$$DTF = \frac{\text{allowable dose}}{\text{potential dose}} \qquad (1)$$

From the DTF curves in reference 7, the thickness of earth having a density of 100 lbs/ft3 that will give the necessary attenuation from a point gamma radiation source is also presented in Table 2.3 for each shelter location. The DTF obtained for the dose in the 4000-ft shelter (S1) was also used for the [illegible]000-ft shelter (S2), since the "saddle effect" predicted by the simplified fallout model at this location, as shown by the dose and dose rates in Tables 2.2 and 2.3, had not been verified for small-yield events.

TABLE 2.2

Planning Values for the Manned Stations
(2 KT-Surface Burst, 15-MPH Wind and No Shear)

	S1 4,000 ft	S2 8,000 ft	S3 12,000 ft	S4 18,000 ft	S5 26,000 ft	S6 26,000 ft
Time of Arrival (min)	3	6	9	13	20	20
Time of Peak (min)	6	12	18	27	40	40
Time of Cessation (min)	37	60	80	106	138	138
Max Field Dose Rate (r/hr)	4,700	110	310	142	63	63
Field Dose Rate at Cessation (r/hr)	2,900	75	212	100	46	46
Field Dose Rate at H+1 hr (r/hr)	1,650	75	305	214	150	150
Dose to Cessation (r)	2,100	80	290	172	97	97
Dose to H+1 (r)	3,000	80	207	75	23	23
Dose to H+72 (r)	7,700	296	1,070	640	360	360
Dose to ∞ (r)	11,200	455	1,700	1,060	630	630

TABLE 2.3

Dose Transmission and Protection Factors Required at
Shelters and Inches of Earth (100 lbs/ft^3) to Provide Required PF

Shelter	Potential Dose to H+72 (r)	Allowable Dose During Shelter Occupancy (r)	DTF	PF	Inches of Earth 100 lb/ft^3
S1	7,700	0.1	1.3×10^{-5}	77,000	120
S2	296	0.1	3.4×10^{-4}	2,960	90
S3	1,070	0.1	9.4×10^{-5}	10,700	95
S4	640	0.1	1.5×10^{-4}	6,400	90
S5	360	0.1	2.8×10^{-4}	3,600	85
S6	360	0.1	2.8×10^{-4}	3,600	85

2.3 HABITABILITY REQUIREMENTS

Habitability has to do with the maintenance of suitable environmental conditions within the shelter during the period of occupancy. The occupancy time in each shelter is also dependent upon the exterior field gamma dose rate which shelter occupants can enter and traverse without overexposure to radiation. In this operation, personnel were excluded from any radiation field in excess of 10 r/hr, and an evacuation dose of 1 r was permissible. The maximum H+1 hr gamma dose rate predicted at any of the shelter locations as indicated in Table 2.3 is 1650 r/hr. The reduction by radioactive decay of this dose rate to 10 r/hr would take approximately 72 hours. The 1 r evacuation dose allowed sufficient time for evacuation in the 10 r/hr field. Habitability requirements for the shelters were consequently based on a minimum shelter occupancy of 72 hours.

During this period, temperature, humidity and air purity must be maintained at levels consistent with human endurance. Shelter occupants must also be provided with food, water and other living necessities, such as sleeping and sanitation facilities, for the desired length of occupancy. Detailed information on habitability requirements and accommodations can be found in references 5 and 6.

SECTION 3

DESIGN DETAILS

3.1 PROTOTYPE SHELTER

A prototype shelter was fabricated and installed at the USNRDL Field Test Station at Camp Parks, California, prior to the production of the six shelters required for the weapon effects test. Direct measurements (described in Section 4.1) were made of the shielding afforded by the prototype shelter and entrance design. In addition the proposed manually operated sample collecting system was evaluated.

Experience gained in the fabrication, installation and operation of the prototype was incorporated into the final design of the field shelters. These are discussed in the following sections. To meet the design specifications for the predicted overpressures, a Type I shelter was designed for a 1-psi overpressure and a Type II shelter was designed for a 5-psi overpressure. Type II shelters were installed at S1 and S2, Type I shelters were installed at S3, S4, S5 and S6. Specifications for the shelter are indicated on the applicable drawings in Appendix A. A cutaway view of the shelter is shown in Fig. 3.1.

3.2 BASIC STRUCTURE

Previous experience with semi-circular underground fallout shelters[4,5,6] led to investigations for using similar circular structures. An evaluation of various tubular sections was conducted. The Armco* corrugated multi-plate pipe was selected.

*Armco Drainage and Metal Products, Middletown, Ohio.

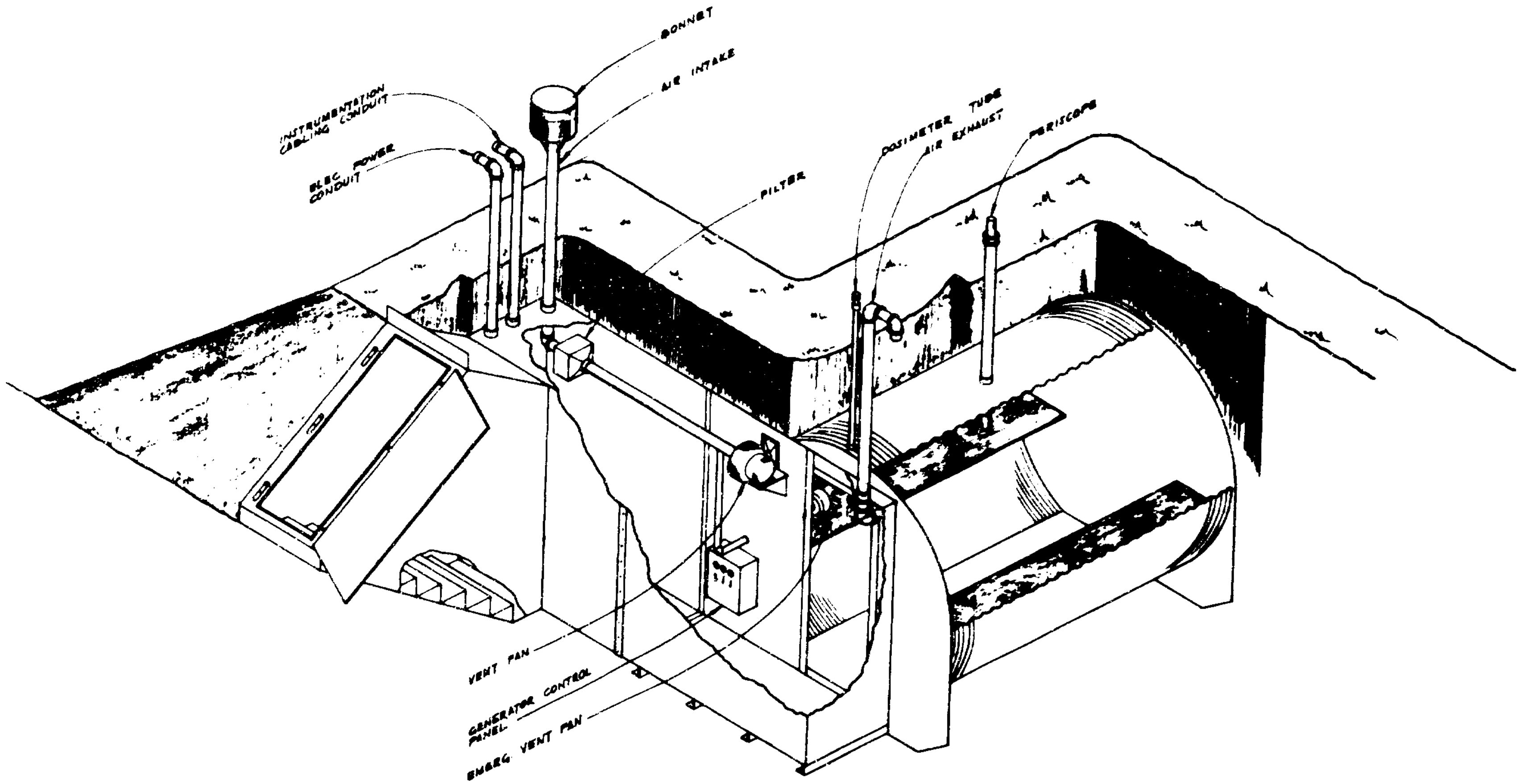

Fig. 3.1 Cutaway View of Shelter

In the final design (Figs. A.1 and A.2, Appendix A), the basic structure consisted of an 8 ft diameter, 12-gage corrugated steel multi-plate pipe. In the Type I shelters the 10-gage rear bulkhead was heavily reinforced by two vertical 6 in. I-beams and transverse headers of the same size steel. The forward bulkhead was also 10 gage and stiffening was provided by the entranceway. In the Type II shelters, 3/16-in. bulkheads were used.

The 4 ft wide x 8 ft long floor was 3/4-in. plywood supported on 2-in. x 4-in. joists resting 7 in. from the bottom of the multi-plate pipe. Plywood benches 2 ft wide x 8 ft long were installed with angle bars on the sides of the circular pipe. A 4-ft aisle was left for working space.

A simple 26-in. x 75-in. standard wood door equipped with a simple latch was installed in the bulkhead of the basic structure at the entrance end. Since the main access door was designed as a blast-resistant door, no attempt was made to make this internal door air-tight. Figure 3.2 is an interior view of the shelter area showing access door and benches.

3.3 ENTRANCE

The entrance design considered the following factors: (1) two right-angle turns to provide the necessary gamma attenuation, (2) shallow placement of basic structure and (3) ease of access for installation of equipment.

The entrance was made in two pieces for ease of handling and shipment. One rectangular piece, 3 ft wide, 7 ft high and 6 ft, 9 in. long, was welded directly to the end bulkhead of the shelter structure (Fig. A.1). The end joints of each entrance section were drilled for 1/2-in. bolts, 6-in. on center on all four sides. Gasket material was used to make the assembled entranceway water-tight. The second section (Fig. A.3) of the entrance formed a right angle on the horizontal plane with the fixed section and angled upward at approximately 30 degrees. Steps were fabricated from raised steel plate for this section and were welded in place. Type I shelters were fabricated out of 1/8-in. steel plate and the Type II shelters were fabricated out of 3/16-in. steel plate. Structural stiffening was accomplished with 3 x 3 x 1/4-in. angles in Type I entranceways and 4-in. I-beams in Type II entranceways.

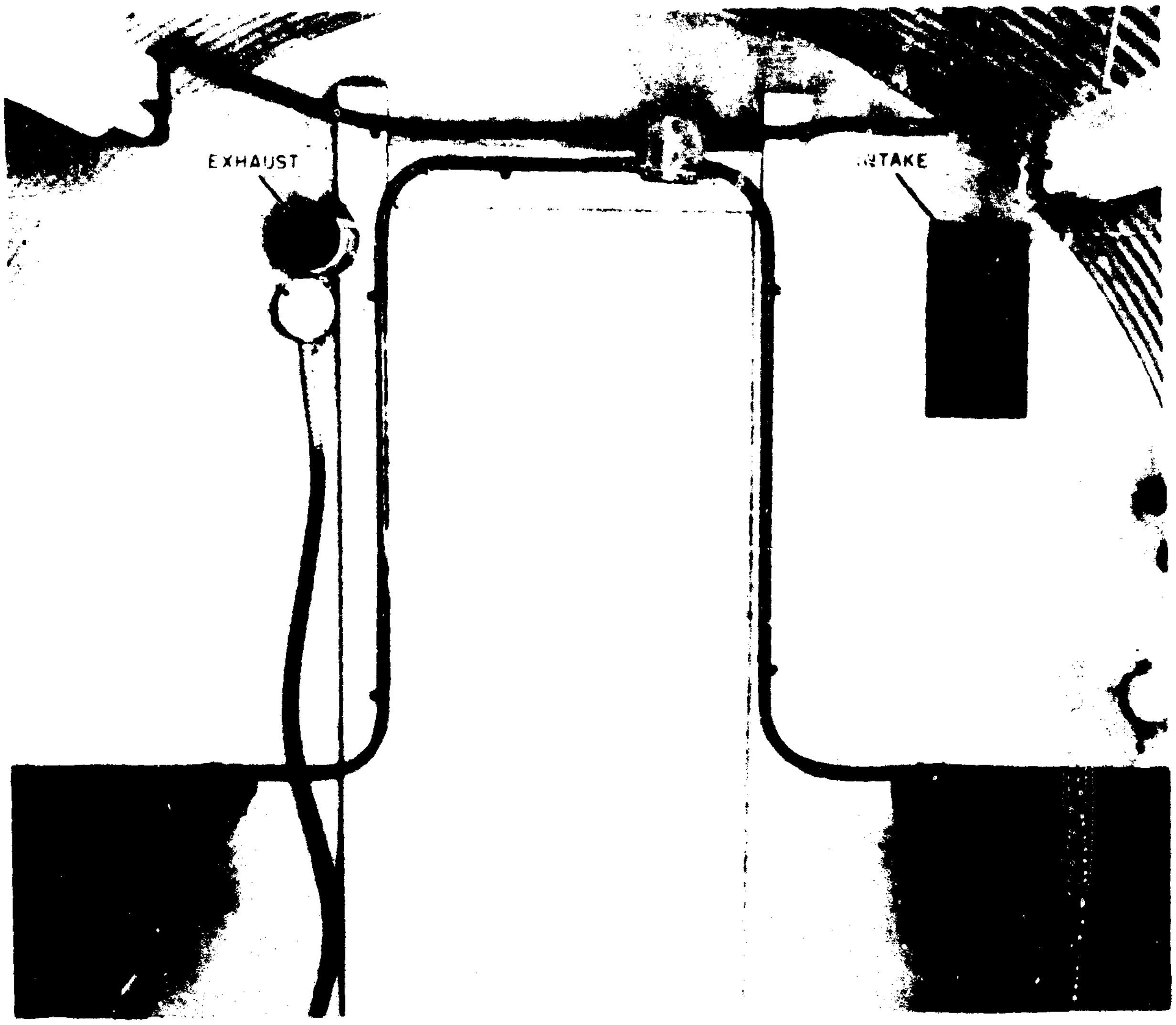

Fig. 3.2 A View of Shelter Area Showing Access Door and Benches (looking forward). The rectangular aperature on the right is the ventilation intake; the exhaust duct is to the left of the door.

At the top of the entrance steps, a metal blast- and fire-resistant door was fitted 30 degrees to the horizontal. Because of this mounting angle, the metal door had to be lightweight to allow a person of average strength to open it. To obtain the lightness and strength required, an aircraft fabrication technique was employed in which two 16-gage black iron mating pans were glued over an aluminum honeycomb core with a high tensile strength epoxy cement. Design specifications of similar doors using 18-gage plate are given in reference 6.

The door was hung with marine-type loose pin hinges. Closure against a metal coaming covered with a formed rubber gasket was effected by dog clamps. Because of warpages resulting from incorrect fabrication processes, sponge rubber adhesive weatherstripping was added to the door to insure an air-tight fit. Figure 3.3 is a view of the entrance assembled to the basic structure.

3.4 BLAST ANALYSIS

Since a fallout shelter requires a considerable thickness of material for shielding against gamma radiation, substantial protection against air blast is provided at small additional cost. Protection against the overpressures anticipated at the shelter locations was readily achieved by providing adequate strength at entrance and ventilation openings. The maximum anticipated overpressure, as indicated in Table 2.1 was 1.5 psi for the closest shelters, S1 and S2. These shelters were therefore designed for 5-psi overpressure to provide a safety margin, and the remaining four were designed for 1 psi.

The blast analysis was approached in two ways. The basic structure was regarded as a pressure vessel under a simulated hydrostatic pressure under (1) inelastic and (2) elastic conditions. Results varied widely due primarily to the fact that there was no direct formula to account for the corrugations which unquestionably added to the strength of the structure. The analysis of the structure was resolved by taking actual load test results with combined dead and live loads. Using the recommendations offered by the AASHO* "Standard Specifications", the H-20 type road loading was adopted as the criteria of strength. Further data for approved maximum loads was secured from the Armco Co. Total safe loading was then converted to actual pressure upon the structure using a fiber strength value of 20,000 psi.

*American Association State Highway Officials.

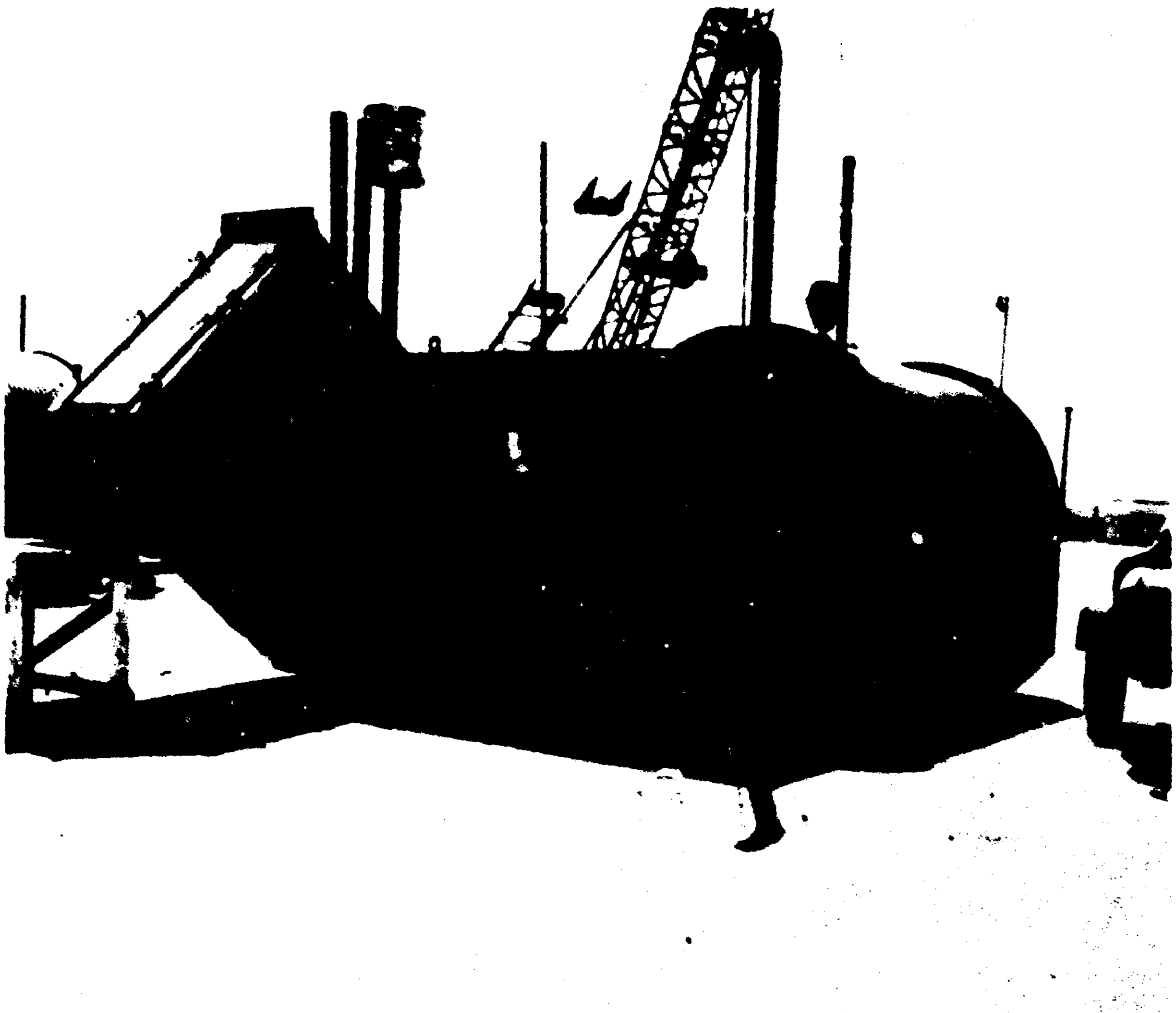

Fig. 3.3 The Assembled Entrance and Basic Structure

Table 3.1 presents the maximum overpressures as derived from the analysis that the shelters are capable of absorbing with no deformation. The calculated resistance values using standard formulae, are for the following conditions:

(a) shelter burial depth - 5 ft 6 in. (see Fig. A.6)
(b) compacted backfill of 3 ft on Type I shelter, 5 ft on Type II shelter
(c) soil density - 100 lbs/ft^3
(d) angle of repose of soil - 45^o

The reflected pressure was calculated from the equation in reference 11.

$$Pr = Po\ (2 + Po/20)$$

where Pr = reflected overpressure in lbs/in^2
Po = ambient overpressure in lbs/in^2

In solving for the end bulkhead resistance, the problem reduced to the case of a flat plate with edges fixed under uniform load pressure over the entire surface. The addition of stiffeners was solved jointly by superposition. Greatest stress was obtained at the restrained edges where the radial stress was the governing factor.

The entranceway was handled in a similar manner, except that the structure was designed to the minimum allowable overpressures. This kept the cost to a minimum and provided a lighter weight unit. Reduced weight was aided in the rigging and assembling of the bulky components in the field.

3.5 VENTILATION

The ventilation system (Fig. A.5) was designed to provide a total air flow rate of 200 cfm, or 50 cfm for each of the four people manning the shelter. The exterior ducts (Fig. 3.4) were of 4-in. standard pipe and the interior ducts were of 20-gage sheet steel. Both intake and exhaust ducts led into the shelter space proper via the entranceway and terminated on the forward bulkhead (Fig. 3.1). This design resulted in an entranceway which was unventilated but free of contamination.

The intake bonnet (Fig. 3.4) was 19-1/2 in. in diameter and fixed to the intake vent. The bonnets of the Type II shelters (S1, S2) were

TABLE 3.1

Summary of Blast Analysis on Shelter Components

Component	Material	Calculated Resistance (psi)
	Shelter Type I	
	(For 3-ft earth cover, 1-psi Overpressure and Frontal 2.05 Reflected Pressure)	
Shelter	10 ga. steel	132
Front Bhd.	1/8 in. steel	16.6
Entrance	1/8 in. steel	2.34
Door	16 ga. steel	35.0
	Shelter Type II	
	(For 5-ft earth cover, 5-psi Overpressure and Frontal 11.25 Reflected Overpressure)	
Shelter	10 ga. steel	132
Front Bhd.	3/16 in. steel	19.6
Entrance	3/16 in. steel	5.09
Door	16 ga. steel	35.0

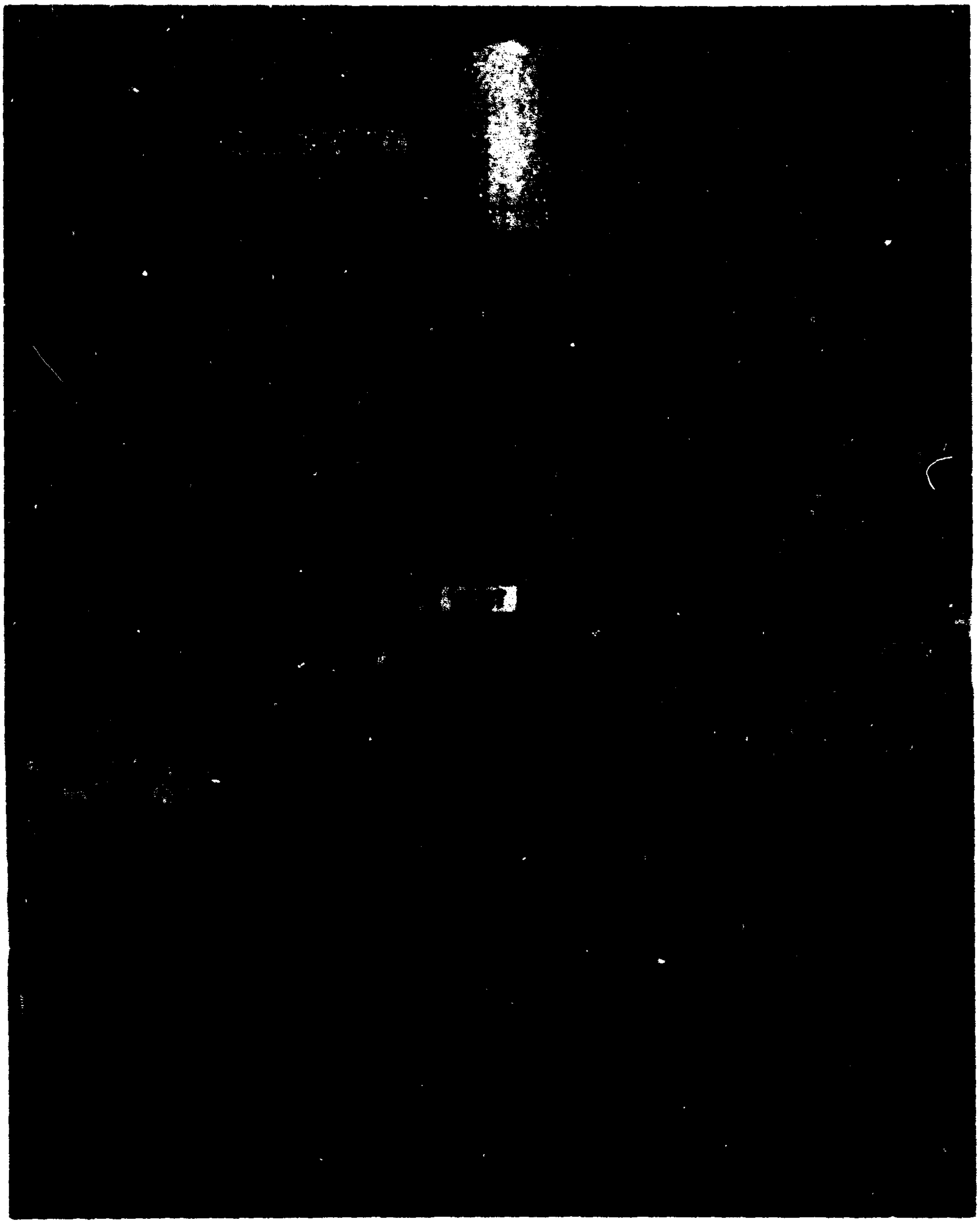

Fig. 3.4 Ventilation Intake and Exhaust Vents

made retractable and self-sealing as required for the predicted overpressures. A manual pull chain and latch was used to retract the bonnet. A fiberglass filter was installed in the bonnet to pre-filter the large quantities of dust generated by vehicular traffic near the shelters.

An absolute-type filter* was employed in the duct system to exclude radioactive particles from the interior of the shelter. The filter was encased in a removable transition piece so it could be readily changed. The location in the entranceway provided easy access to the filter housing and was so chosen that earth shielding was available between the filter and shelter occupants. In addition, in event of blockage of the intake system, the blast door could have been cracked and air admitted to the filter at the transition. Had this happened during fallout some radioactive particles would have been carried down the entranceway, but clean air still would have been delivered to the shelter proper.

A low-volume, 200 cfm high-pressure centrifugal fan was used to overcome the high head loss in the duct system due to the pressure drop across the absolute filter. In addition, a by-pass was provided to allow the use of an 30 cfm auxiliary hand-powered ventilation fan, adequate for the four occupants, in case of electrical power failure. Although the air intake and exhaust vents were in proximity, adequate shelter-air mixing was obtained by intake baffling when the power-driven blower was utilized. During use of the hand-operated fan, better air-mixing could have been provided by directing the intake air to the rear of the shelter via an inexpensive canvas duct.

Tests with the prototype ventilation systems showed that the bulkhead upon which the fan was mounted acted as a sounding drum in spite of liberal use of rubber bushings and gaskets. The noise level was finally reduced to an unobjectionable level by spraying the interior of the bulkheads in the basic structure with a 1-in. coating of vermiculite acoustical material.

The exhaust system (Fig. 3.4) was simply a 4-in. pipe duct that was run from the forward bulkhead of the shelter to the outside. It terminated in an inverted U-shaped loop. Air exhaust was effected by positive pressure in the shelter (supplied by the intake fan) and the natural rise of heated air.

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*Ultra-aire, manufactured by Mine Safety Appliance, Minneapolis, Minn.

Note: In order to insure complete safety, absolute filtration was employed in the intake system. Whether such heroic air cleaning measures were necessary is the subject of a current study for the Office of Civil Defense by this Laboratory.

3.6 POWER AND LIGHTING

Electrical power was provided from an external 12.5-KW 60 cycle AC gasoline-driven motor generator mounted on a 2-wheel trailer. The power cables were run through a 4-in. standard pipe to the generator control panel located at the base of the stairs in the entranceway. Provision was made for remote starting, stopping and voltage regulation. The generator was equipped with a 250-gal fuel supply, sufficient for 72 hours of continuous operation.

Two 8-ft fluorescent lamp fixtures (four 40-watt lamps) were mounted over the work benches. One incandescent fixture was provided in the entrance near the generator control panel. Convenience outlets were provided on each side of the main working area.

3.7 INSTRUMENTATION PACKAGE

A periscope, located in the approximate center of the shelter was installed for external viewing by shelter personnel. Consultation with optical manufacturers resulted in the selection of a 7 ft long periscope* fabricated from 1-1/2 in. dia. aluminum tubing. This periscope was equipped with two prisms and an eye-piece with a magnification factor of 1. The field of view of this simple but adequate periscope was 17 degrees.

Originally the periscope was designed so that it could be rotated and retracted. However it was concluded in prototype tests that retraction was unnecessary. A simplified design to hold the periscope in place with the rotational feature consisted of an exterior pipe casing with an ordinary pipe coupling attached to the periscope tube. The external prism was located 12-18 in. above the earth fill. In the shelter a portable stand enabled personnel to use the periscope. Grab rungs were attached to the shelter on each side of the periscope to provide the viewer stability.

The exterior gamma radiation dose rate was measured with a self-reading dosimeter and a remote-reading radiac. A dosimeter tube of

*Manufactured by Tinsley Laboratories, Inc., 6th and Dwight Sts., Berkeley, Calif.

1-in. pipe led from the interior of the shelter and terminated 3 ft above the earth fill over the shelter. When used to obtain an external dose rate reading, a dosimeter attached to the end of a rod was run up to the measuring position for a timed interval. The upper end of the dosimeter tube was capped to prevent contaminant from entering the working area. The remote-reading radiac (AN/PDR-39) was specially modified to allow direct readout in the shelter of the exterior dose rate. *

3.8 HABITABILITY PACKAGE

Equipment and supplies necessary for the planned 72-hr occupancy are itemized in Table 3.2. A chemical toilet was located in the corner of the entranceway behind the entrance door to the shelter proper. The exhaust vent of the chemical toilet was connected to the main exhaust vent of the shelter. In areas of significant overpressure (shelters S1 and S2) provision was made to connect the toilet exhaust vent to the main exhaust vent after passage of the blast wave. The bulk of the equipment and supplies was stored on shelves beneath the work benches in the shelter area.

3.9 INSTALLATION SPECIFICATIONS

The excavation plan for the shelters is shown in Fig. A.6. The shelters were buried to a depth of 5 ft, 6 in. and backfilled so that they were covered with the minimum earth cover indicated in Table 3.3. Selection of the depth of burial was controlled in this case by a 12 in. dia. pipe attached to the rear bulkhead of the shelter and leading outside to a fallout collection platform. This pipe was for the manual operation of fallout collection equipment on the platform by personnel in the shelter. The height of the opening for the pipe in the shelter had to be compatible with ease of operation.

The backfill requirements were based on the specifications outlined in Section 2.3 and listed in Table 2.4. To minimize the height of soil over the shelters and still maintain the attenuation requirements, the backfill was compacted with pneumatic tampers and water. Core samples were obtained periodically during backfill and compaction operations to

*P. A. Covey. A Remote Reading Radiac. Technical Report in preparation.

TABLE 3.2

Equipment and Supplies Furnished for 72 hr Occupancy by 4 Men

Quantity	Description of Item
2	Adjustable chairs
4	Sleeping bags
4	Air mattresses
2 cases, 24 rations per case	C-rations
1	Hot plate
1	Ice chest
1	10-gal water can
1 lot	Misc. cleaning supplies (wash & dri, hand cleanser, tissue)
1	Chemical toilet and supplies (chemicals, toilet paper, deodorant)
1	Electric clock
1	8-day mechanical clock
1	Flashlight
1	Hand lantern
1	First aid kit
1 lot	Tools (shovel, crowbar, sledge hammer)

TABLE 3.3

Results of Backfilling and Compaction at Shelters

Shelter	Minimum Depth* (in)	Density Achieved (lb/ft^3)	Equivalent Depth at 100 lb/ft^3 (in.)
S1	53	126	67
S2	58	126	73
S3	41	126	52
S4	43	126	53
S5	43	103	44
S6	43	103	44

*Center line thickness.

insure the proper soil density. The results of the backfilling are given in Table 3.3 along with the required depth of backfill from Table 2.4. The backfill depth was measured directly over the centerline of the shelter; hence it was the minimum thickness. This provided an average equivalent thickness that exceeded that shown in Table 2.4.

Before installation, the shelter and entrance were bolted together. The complete assembly was placed into the excavation (as one unit, a procedure greatly simplifying the field installation.

3.10 COST ANALYSIS

The specifications and costs for the construction and outfitting of the fallout shelters are given in Tables 3.4 and 3.5. Excluded from the cost analysis are the installation costs, i.e., assembly, excavation, and backfilling. The prototype shelter was installed at Camp Parks, California, using station labor. The costs of installing the shelters at the Nevada Test Site are atypical. Information on installation costs can be found in references 5 and 6 where a summary of typical costs of excavation, backfilling, and hauling are given. A brief description of each item is also listed. The shelters were designed, prefabricated and installed in less than four months. For this reason, some of the prices in Tables 3.4 and 3.5 are not necessarily the most economically available. To speed up the fabrication of the shelters, two separate contracts were issued, one for the basic structure and the other for the entranceways. In addition, premium pay for overtime work added 15 to 20 percent to the production costs. The costs are on a "one off" basis.

The costs of the Type I shelters, which would be the most commonly employed are given in Table 3.4 and the costs for the basic structure and entrances given in Table 3.5 are for the Type II shelter having heavier plate and stiffening members.

TABLE 3.4

Specifications and Cost for Type I Fallout Shelters

Item No.	Quantity	Description	Cost	Specification
			Basic Structure	
1	1	Shelter (Incl. painting and foundations)	$1,875.00	Fig. A.1
2	1	Elec. Work (lights & outlets)	265.00	Fig. A.1
3	1	Insulation	25.00	Sprayed Vermiculite
			$2,165.00	
			Entrance	
4	1	Entranceway	$950.00	Fig. A.3
			Ventilation System	
5	1	Vent. Ductwork	$125.00	Fig. A.5
6	1	Blower Main	84.00	Mod. 7 1/2 P, ILG Electric Ventilation Co., Chicago, Ill.
7	1	Blower, Aux.	74.95	Mod. FB-1, Chicago Blower Corp. Franklin Park, Ill.
8	1	Vent Cap	30.00	
9	1	Solenoid and Spring	5.00	
10	1	Outside Piping	75.00	Fig. A.1
11	2	Filters	48.00	"ULTRA AIRE"
		Sub-total	$441.95	

Continued

TABLE 3.4 (Contd)

Specifications and Cost for Type I Fallout Shelters

Item No.	Quantity	Description	Cost	Specification
		Accessories		
12	1	Periscope	$152.00	
13	1	Chemical toilet	26.00	Mod. D-0624 w/chemicals and ductwork
14	4	Sleeping bag	52.52	
15	1	Water container	13.00	10 gal.
16	2 ctns	C-rations	24.00	
17	1	Elec. clock	9.57	
18	1	Clock, manual	33.00	Aeroguide 7-day
19	1	First aid kit	9.50	
20	1	Snake bite kit	1.79	"CUTTERS"
21	1	Shovel, sq.	3.95	
22	1	Pick, miners	3.95	
23	1	Sledge hammer	2.95	
24	1	Tool box/w/misc. tools	15.00	
		Sub-total	$348.78	
		Total Cost	$3,905.73	

TABLE 3.5

Specifications and Cost for Type II Fallout Shelters

Item No.	Quantity	Description	Cost	Specification
		Basic Structure		
1	1	Shelter (including painting & fdns.)	$2,395.00	Fig. A.2
2	1	Elec. Work (lights & outlets)	265.00	Fig. A.2
3	1	Insulation	25.00	Sprayed vermiculite
		Sub-total	$2,685.00	
		Entrance		
4	1	Entranceway	$1,932.00	Fig. A.4
		Sub-total	$1,932.00	
		Ventilation System		
5-11*	1 lot	Vent system	$ 441.95	Items as previously listed
		Accessories		
12-24*	1 lot	Equipment	$ 348.78	Items as previously listed
		Total Cost	$5,117.73	

*See Table 3.4.

SECTION 4

PERFORMANCE

4.1 GAMMA ATTENUATION MEASUREMENTS

A complete set of shelter gamma attenuation calculations, supported by on-site radiation measurements, was made to assure that the entrance design and backfilling of the shelters were sufficient to provide the required protection factors listed in Table 2.4. The estimates were based on the comprehensive procedures outlined in reference 12 for calculating protection factors of typical structural types and fallout geometries. The procedures also include calculations of the scattered radiation that enters through entranceways. The various steps in the calculations, the equations, constants, etc., used, and the intermediate and final results, are given in Appendix B.

The on-site radiation tests were conducted using a traveling Co^{60} source.[13] The encapuslated 70-curie source was hydraulically pumped at a constant speed through 1000 feet of polyethylene tubing placed over the backfilled shelters. Pencil dosimeters, located 3 ft above the backfilled shelter and at various locations inside the shelter, measured the accumulated gamma doses.

The calculated and measured protection factors for each shelter are compared in Table 4.1. It is seen that in all cases except one, the minimum calculated or measured protection of factor is equal or better than the required protection factor.

4.2 ENVIRONMENTAL STUDY

An environmental study was conducted* in one of the installed shelters at the Nevada Test Site to demonstrate that short-term

*By LTJG C. W. Kelly, III, BuYards & Docks Program Officer, NRDL.

TABLE 4.1

Calculated and Measured Protection Factors at Shelters

	Front End		Back End		Required
	Calculated	Measured	Calculated	Measured	(Table 2.4)
S1	70,000	*	470,000	*	77,000
S2	70,000	*	470,000	*	3,000
S3	50,000	50,000	130,000	140,000	10,700
S4	63,000	71,000	190,000	140,000	6,400
S5	30,000	32,000	48,000	48,000	3,600
S6	30,000	(no data)	48,000	(no data)	3,600

*Data indicated faulty measurements; an investigation revealed that contaminated soil from a previous GZ site was used for backfill. It provided a background of approximately 0.2 mr/hr inside the shelter. This was sufficiently large to negate all attenuation measurements with the available 70-curie Co^{60} source.

occupancy would have no adverse physiological or psychological effects upon the occupants. Similar studies had been conducted in a series of long duration tests (5 days to 2 weeks) in the USNRDL 100-man Fallout Shelter at Camp Parks, California.[14,15] However, it was deemed desirable to conduct an environmental test prior to occupancy during a weapon effects test because of differences in soil composition, temperature, and humidity between Camp Parks and the Nevada Test Site.

Accordingly, four subjects entered one of the shelters in the early morning and spent 10 continuous hours in the shelter. The motor-generator was activated and all equipment that could contribute to the interior heat load was turned on. The ventilation blower was continuously operated and every half-hour measurements were taken of CO, CO_2 and O_2 concentrations, of wet- and dry-bulb interior air temperatures, and of dry-bulb ventilation air temperature.

The results of the measurements are summarized in Table 4.2. These may be interpreted by comparison with established shelter standards. The shelter occupants experienced no discomfort and found the shelter to be acceptably habitable.

TABLE 4.2

Summary of Environmental Study

Standard*		Manned Shelter Station
Maximum Permissible Concentration		
CO	0.015 %	Trace amounts only
CO_2	3 %	0.1 % - 0.4 %
Minimum Permissible Concentration		
O_2	14 %	17 % - 19.4 %
Maximum Effective Temperature (Temperature-Humidity Index)		
92°F (Point at which heat prostration commences)		79°F**
85°F (Occupant experiences some discomfort)		

* As established at the Shelter Symposium held at the Naval Medical Research Institute in December 1961.

**Established from following measured values:

Maximum Dry-Bulb Temperature	70°F
Maximum Wet-Bulb Temperature	90°F
Resulting Effective Temperature	79°F
Maximum Temperature of Intake Air	97°F

4.3 OPERATIONAL PERFORMANCE

The six shelters were manned during a recent weapon effects test. Four men occupied each shelter and operated fallout collection instruments and measuring devices. The length of occupancy ranged from 3 hours to 16 hours. All shelter equipment operated as planned. The blast wave was felt at the closest shelter but caused no damage. Initial effects at the other five shelters were negligible.

Three of the six shelters were in the path of significant fallout. The interior dose rate inside of the shelters was not reported since fallout samples were brought into the shelter for radioactive decay measurements, and the resulting radiation levels produced by the samples although in the low mr/hr range obscured the interior dose rate produced by the fallout on the exterior surroundings. The performance of the shelters under the conditions experienced was excellent.

SECTION 5

SHELTER MODIFICATIONS FOR A FAMILY FALLOUT SHELTER

The manned shelter stations described in this report, with certain design modifications and outfitting requirements, could be utilized as single family fallout shelters. Home shelters fall into two classes based on the protection required. In strictly rural areas, sufficiently distant from target areas, fallout protection alone is required. In metropolitan areas or near military target areas, shelters have to provide blast and thermal protection along with fallout protection.

The design specifications to meet the requirements for blast, thermal and fallout protection in metropolitan areas and near military targets are more stringent than those outlined in Section 2. A discussion of the design specifications along with the necessary modifications and outfitting requirements to adopt the shelters as single family shelters follows, along with a revised cost estimate reflecting the changes. There is no discussion however of the various furniture and sleeping accommodations possible.

5.1 BLAST PROTECTION

Ordinary engineering techniques allow us to design shelters for almost any given resistance to blast pressures. Costs however, rise steeply beyond the 35 psi limit, so that most shelter studies have concluded that a 35 psi design resistance probably represents the best compromise between cost and number of people protected.

Shelters having a higher degree of blast protection would survive very close to the fireball of the weapon, where initial radiation effects would be very great. This would force the shelter deeper into the ground for protection, and at this point a design other than the cut-and-fill type described here would become preferable, i.e., tunnel type structures.

Improved blast protection for the shelter described in this report can be obtained in two ways: (1) increasing the strength of the entranceway and (2) increasing the depth of burial. The basic structure, as described in Section 3.4, provides adequate blast protection for the specific design application.

Increasing the strength of the entranceway would involve increasing the thickness of the side and top plates to quarter inch steel and increasing the size of the I beam stiffeners from 4 to 6 in. These changes would bring the calculated resistance up to that of the door, i.e., 35 psi. No changes in door design would be necessary.

Increasing the depth of burial, making the top surface of the shelter flush with the grade line, would result in a lower earth-fill profile and consequently a lower side-on overpressure load on the buried structure. Also the additional material from the excavation would minimize the requirement of providing additional material for backfilling.

Blast protection requires complete sealing or severely restricting openings to the outside atmosphere during the period of blast passage. This is accomplished in the described shelter by providing a mechanical closure device for the air intake bonnet and a pipe cap to fit over the exhaust vent in the interior of the shelter.

5.2 THERMAL PROTECTION

Thermal radiation can be an important cause of personnel injuries to exposed people, however virtually any shelter at all offers complete protection from direct thermal radiation. Shelter design specifications, however, have to consider the protection against mass fires (fire storms) that may occur over or near the shelter. The primary concern is the possibility of carbon monoxide poisoning. Large quantities of carbon monoxide are formed when fires continue to smolder or burn for prolonged times. Of secondary concern is the possible increase of temperature in the shelter, although generally the earth cover required for radiation protection offers considerable insulation.

The shelter must therefore be capable of being sealed and have either sufficient air or air-regenerating equipment for a period of time ranging from 4 - 24 hours. Submarine experience indicates that if 300 cubic feet of air is available per person, no atmospheric modifications would be necessary for a 15-hour stay under sealed conditions.

As pointed out in the previous section, the described shelter has provision for complete sealing. The volume of the shelter, including the entranceway, is 980 cubic feet and provides adequate air for four persons for a period of 12 hours under sealed conditions.

5.3 FALLOUT PROTECTION

The problem of protection against radiation is simply one of getting the required amount of shielding material between the object to be protected and the radiation source. Various authorities[5,16] have stated that fallout shelters should provide a protection factor of between 1000 and 5000. In any event, the radiation exposure in a shelter should be limited to a nominal amount to permit allocation of most of the allowable dose to the post-shelter phase.

The protection factors measured and calculated for the designed shelters, as pointed out in Section 4.1, range from 30,000 to 470,000, adequate to provide virtually no-dose protection even in extremely high radiation fields. For example, a 1-hr radiation intensity of 50,000 r/hr 3 ft above the ground would lead to an unprotected infinite dose of 200,000 r; the poorest shelter described would limit exposure to 200,000/30,000 = ~ 7 r which is of little significance.

5.4 INCREASED ACCOMMODATIONS

The shelter, as it is now designed, can accommodate up to four people for a period of 12 hours under sealed conditions. The basic structure, however, could be lengthened with no significant decrease in strength and rigidity. To meet the air requirements under sealed conditions, 5 ft of length can be added for each additional occupant, or the diameter of the basic structure may be increased. Present costs indicate that the basic structure could be increased in length for approximately $50.00 per lineal ft. The entranceway is sufficiently large to accommodate a large increase in shelter habitants.

5.5 RELOCATION OF CHEMICAL TOILETS

For any prolonged occupancy of the shelter, the present location of the chemical toilets behind the shelter door entrance should be changed. This can be accomplished by extending the existing shelter entrance portion an additional 2-feet to form an end compartment which could be curtained for privacy.

5.6 EMERGENCY EXIT

Emergency escape from the basic structure in event of blockage by debris or structural damage to the normal entranceway can be provided by the incorporation of a "soft patch", a bolted sheet of corrugated iron installed just forward of the periscope. In emergencies, exit from the basic structure would be accomplished by removing the "soft patch" from the inside and excavating through the earth fill, allowing the fill material to enter the shelter.

5.7 POWER SUPPLY

A 12.5-KW gasoline-powered motor generator was provided to supply the necessary power for the shelter when used as a manned fallout station. This amount of power was required to operate the various measuring instruments. A much smaller power supply can be substituted when this shelter is adapted for home use. A 1.5-KW to 2-KW portable gasoline-powered motor generator would supply adequate power for both lighting and ventilation. The unit should be installed in a separate, blast-protected enclosure near the shelter to minimize noise and exhaust fumes. Blast protection can be provided by burying the enclosure in a pit and covering it with a layer of earth. Air intake and exhaust vents can be provided in the form of standard 1-in. pipes. Remote starting capability is available for most commercial generators of this type.

5.8 COST REDUCTIONS

The cost analysis presented in Section 3.10 pertained to the fabrication and outfitting of the shelters as manned fallout collection stations in a weapons effects test program. Adaptation of the shelter for a family fallout shelter would result in savings in overall cost. The principal cost however, is in the fabrication of the basic structure and entranceway and this cost would not be affected by the conversion for general use. Savings in overall cost however can be effected by the following methods:

Elimination of Periscope. Besides the cost of the periscope proper being saved, several auxiliary items in connection with the installation of this item can be omitted. These include the periscope gland supports, the special aluminum protective cap, and the grab rungs.

Removal of Benches. At present, work benches extend full length on each side of the shelter. These can be excluded almost entirely with a small section left for food preparation, working area, etc. Several folding type benches for sitting could be supplied as required.

Lighting and Power. The work done in the shelter required good lighting, hence 4 hour 40-watt fluorescent lamps were employed. A saving can be effected by installing two 100-watt incandescent lights as a substitute. Power outlets should be reduced to one or two duplex convenience outlets.

External Piping. The majority of the present pipework can be omitted: all pipework for sampling equipment; one large power conduit, and reduction in size of that remaining.

Ventilation. The need for an absolute filter was not demonstrated during the recent field experience. The absolute filters described in this report were removed following their use in the manned stations, and subsequent analysis showed no radioactivity detectable above background. The pre-filter installed in the bonnet probably retained most of the radioactive particles entering the intake system. It is not possible at this time however to extrapolate the results of this single example to the case where fallout intensities hundreds of times greater may be experienced.

If after further study, substitution of a less efficient filter with a lower pressure drop proves acceptable, a lower cost squirrel cage-type blower or the auxiliary electrical/hand-operated fan described could be substituted for the expensive centrifugal-type fan, a substantial savings in cost. To obtain proper air mixing however, the intake ventilation ductwork should be extended toward the rear of the shelter.

Insulation. With the low-pressure-type ventilation fan installed as recommended, the vermiculite sound-insulating material can be eliminated. The primary sound problem resulted from using a high-rpm fan in the original design to overcome the high pressure drop loss across the filter. Under the revised ventilation system, this requirement would no longer be necessary.

Miscellaneous. As shown in Table 5.1, a considerable number of the accessories have been eliminated. The cost estimate, although considerably reduced from the costs as shown in Table 3.4, still reflect the added cost of adequate blast protection up to 35 psi. If lower blast protection is required, additional savings can be made in the weight of the steel structures.

TABLE 5.1

Cost Estimate for Home Fallout Shelter

Item No.*	Quantity	Description	Cost
		Basic Structure	
1	1	Shelter (12 Ga.)	$1,900.00
2	1	Elec. Work	65.00
			$1,965.00
		Entrance	
3	1	Entranceway	$1,980.00
		Ventilation System	
4	1	Vent Duct Work	$ 100.00
5	1	Blower	74.95
6	1	Vent Cap	30.00
7	2	Filter	10.00
			$ 214.95
8	1	Chemical Toilet (w/duct)	$ 26.00
9	1	Water Container	13.00
10	1	Clock, Manual	3.95
11	1	First Aid Kit	9.50
12	1	Shovel	3.95
13	1	Tool Box/Misc. Tools	15.00
14	1	10 ft Ladder	27.00
15	1	Coil Rope	15.00
		Sub Total:	$ 103.40
		Total Cost:	$4,263.35

*See Table 3.4.

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APPENDIX A

ENGINEERING DRAWINGS OF SHELTER COMPONENTS

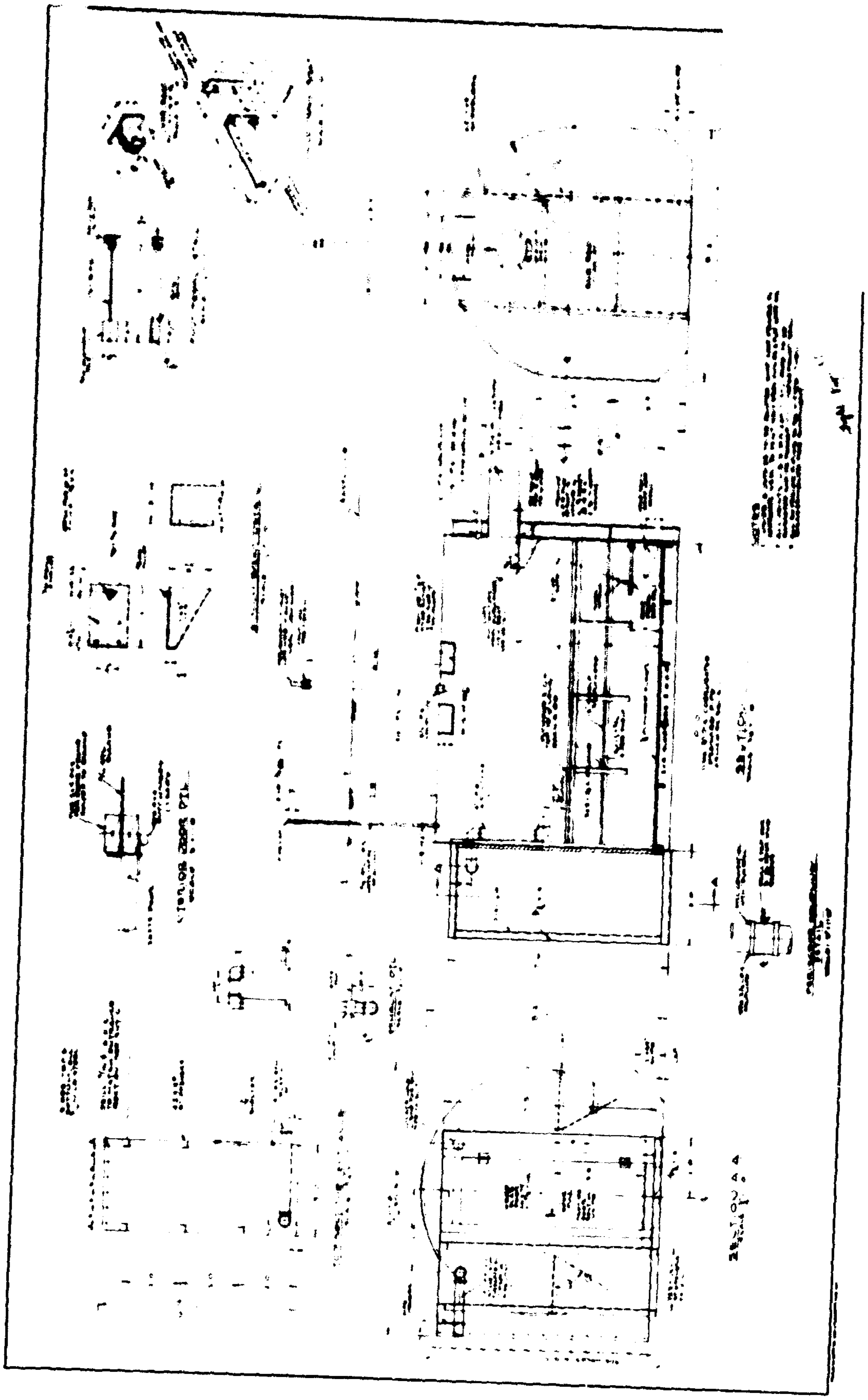

Fig. A.1 Shelter Arrangement and Details, Type I

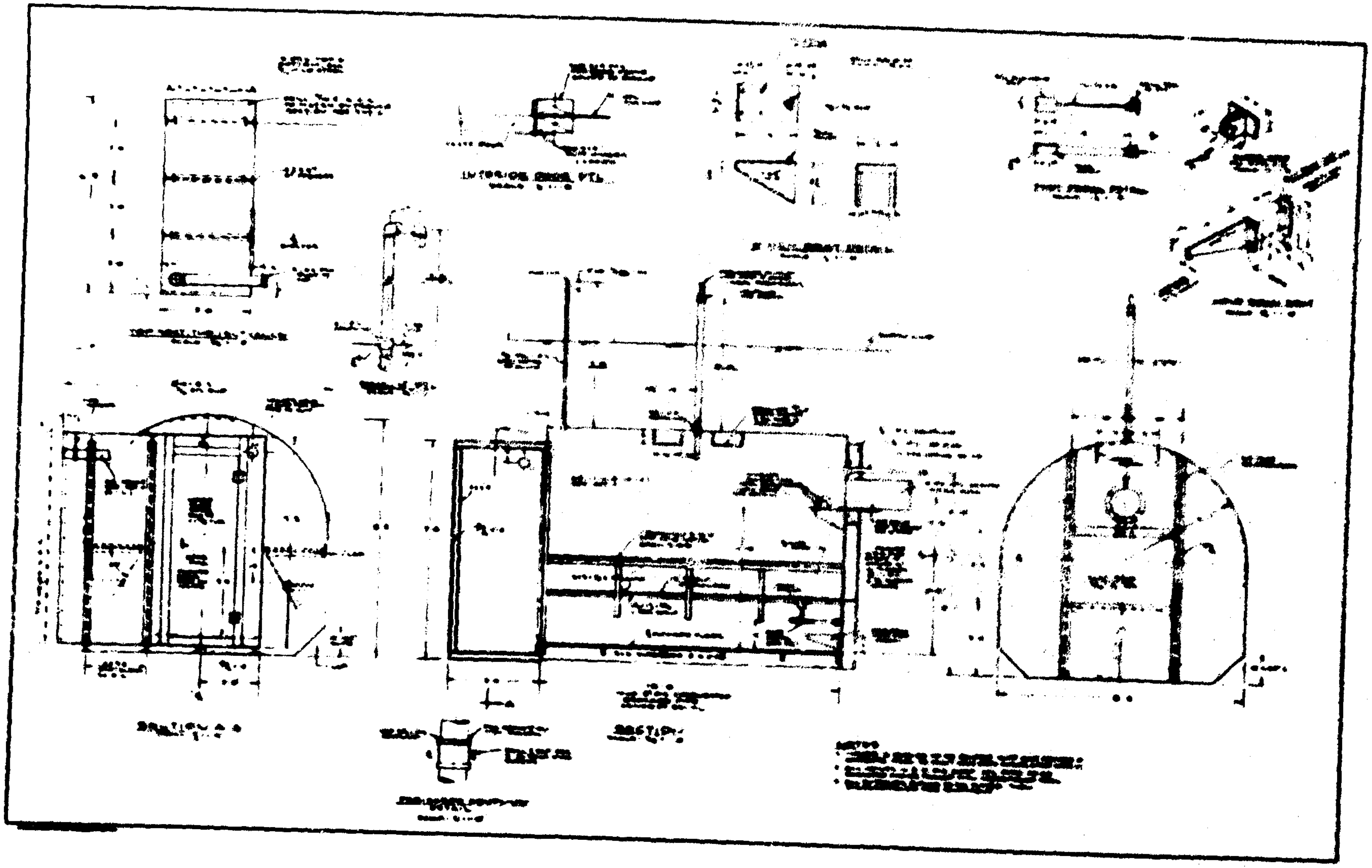

Fig. A.2 Shelter Arrangement and Details, Type II

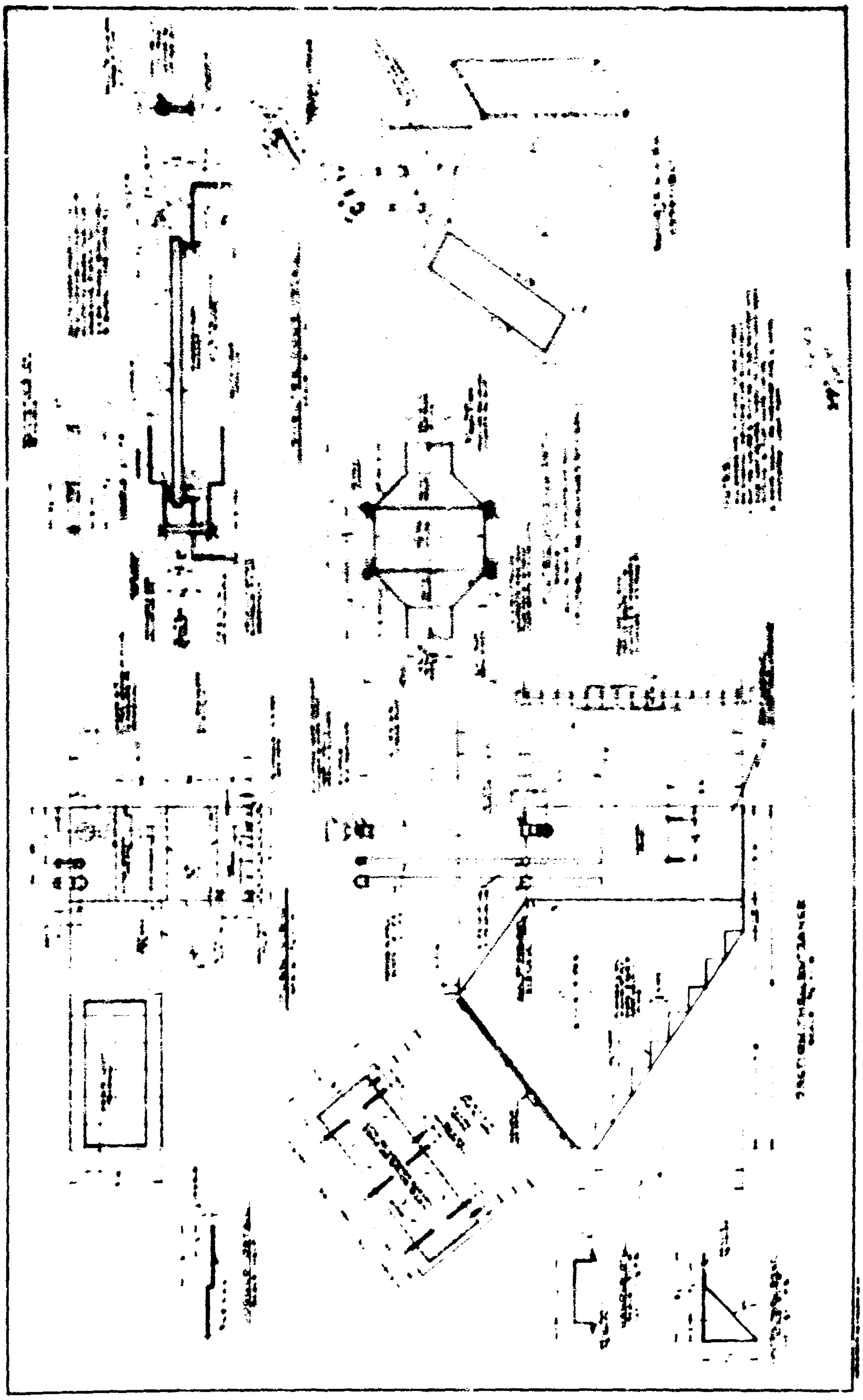

Fig. A.3 Entrance Arrangement and Details, Type I

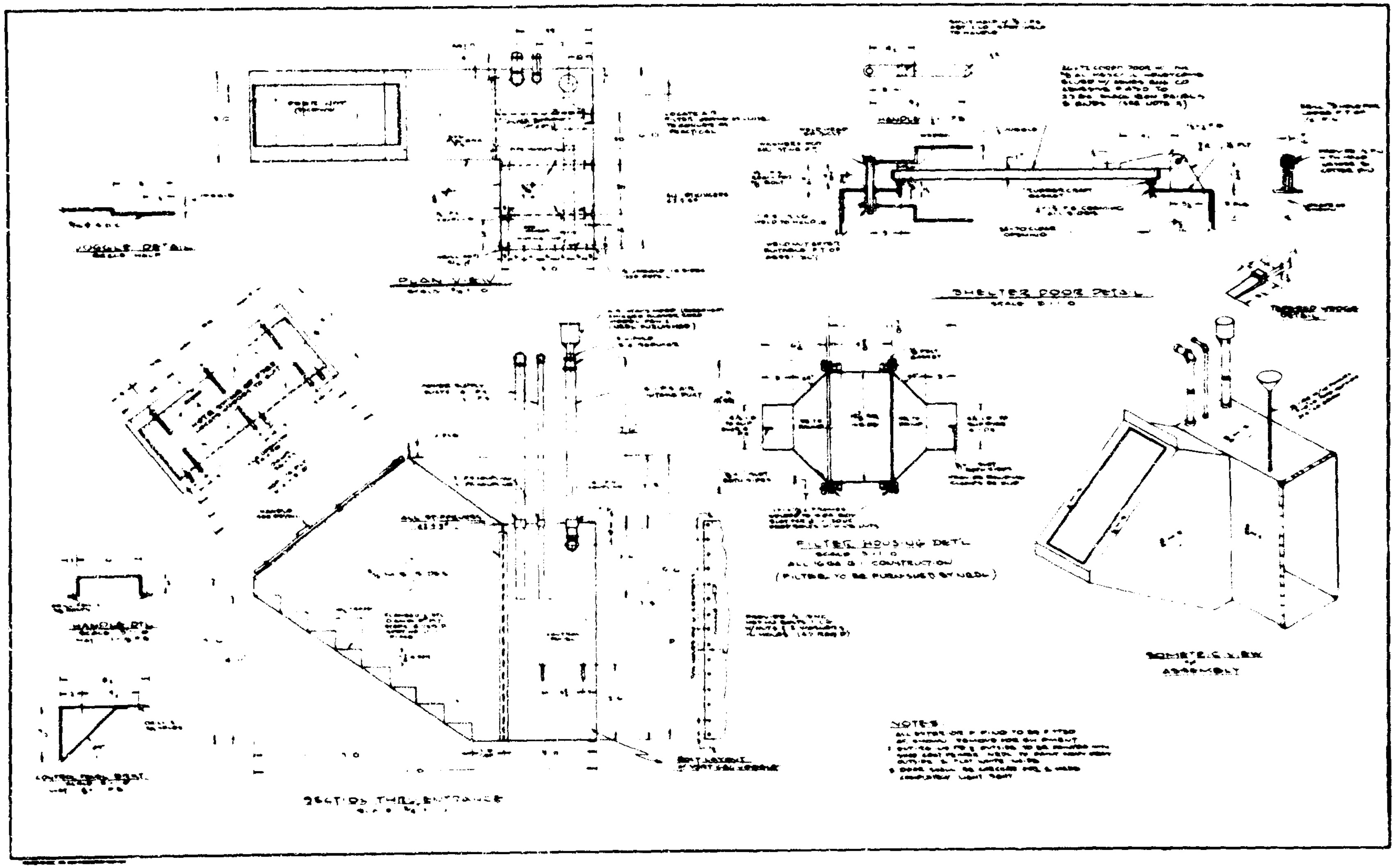

Fig. A.4 Entrance Arrangement and Details, Type II

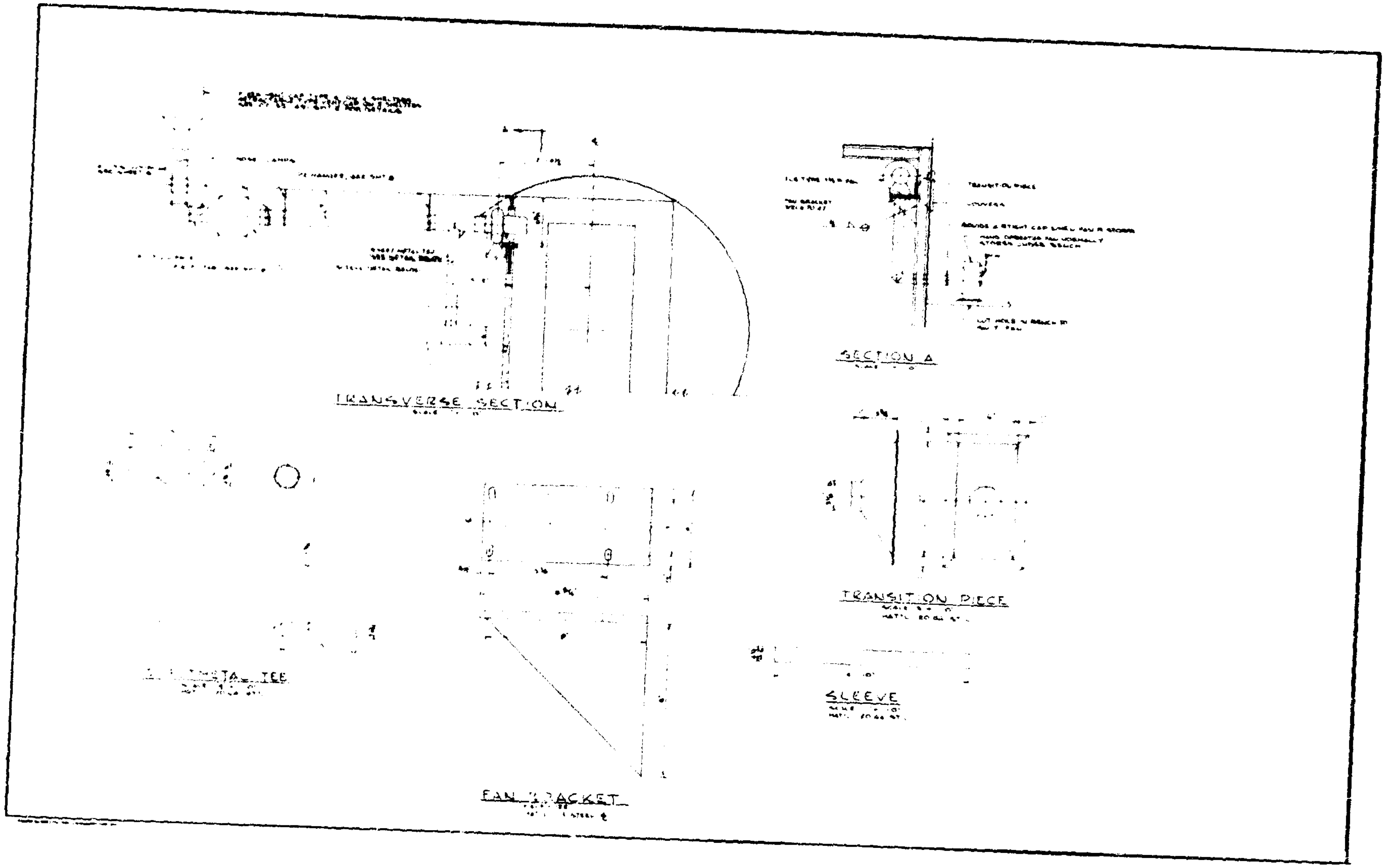

Fig. A.5 Ventilation Arrangement and Details

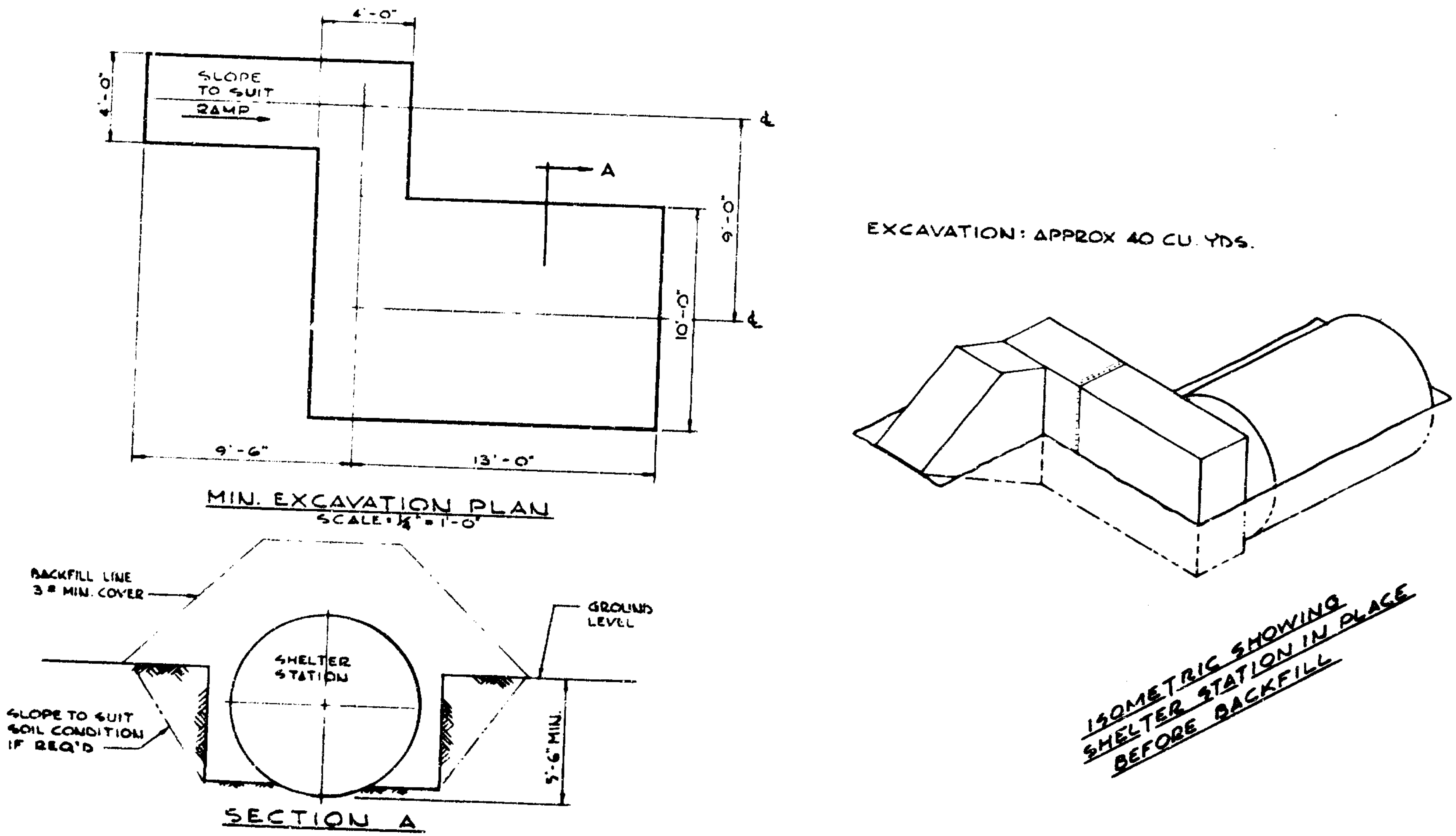

Fig. A.6 Excavation and Burial Plans

APPENDIX B

PROTECTION FACTOR CALCULATIONS

The methods for the calculations are taken from reference 12 "Design and Review of Structures for Protection From Fallout Gamma Radiation".

A. CALCULATION METHOD FOR REDUCTION FACTOR, OVERHEAD CONTRIBUTION

List of equations used:

$$n = 2Z/L \qquad (1)$$

n = normality ratio
Z = perpendicular distance between horizontal plane and detector
L = length of structure

$$e = W/L \qquad (2)$$

e = eccentricity ratio
W = width of structure

$$w = f_1(n,e) \quad \text{(Chart 3)} \qquad (3)$$

W = solid angle fraction

$$X_o = UT \qquad (4)$$

X_o = mass thickness overhead
U = unit weight of barrier
t = barrier thickness

$$Co = f_2(W,X_o) \quad \text{(Chart 4; also see example 3c)} \qquad (5)$$

Co = reduction factor for combined shielding effects, roof contribution

$$\Sigma Co = RF_o \tag{6}$$

RF_o = reduction factor, all components of roof.

B. CALCULATION METHOD FOR REDUCTION FACTOR, ENTRANCEWAY SCATTERED CONTRIBUTION

Step 1. Determine W_1

W_1 = solid angle fraction (entrance)

Step 2. $RF_1 = f_3$ (W, case 1 - A_h) (Chart 10)

RF_1 = reduction factor (at pt. 1)

Step 3. Determine W_2 and W_3

W_2 & W_3 = solid angle fraction from pt. 1 to pt. 2 and pt. 3 respectively

Step 4. Determine X_e (Chart 4)

X_e = mass thickness of wall between passageway and shelter

Step 5. $S_w = f_4$ (Xe) (Chart 7)

S_w = fraction of emergent radiation scattered in wall barrier

Step 6. $RF_2 = A_h \times W_2 \times 0.1 \times Sw$ (see Section 7b)

RF_2 = reduction factor at pt. 2

Step 7. $RF_3 = A_h \times W_3 \times 0.1 \times S_w$

RF_3 = reduction factor at pt. 3

Step 8. $RF_c = \left(\frac{R_{f_2} + R_{f_3}}{2}\right) \times W_x \times 0.5$ (see Section 7b)

RF_c = reduction factor at shelter center

Step 9. $RF_e = \left(\frac{R_{f_2} = R_{f_3}}{2}\right) \times W_e \times 0.5$

RF_e = reduction factor at far end of shelter

C. PROTECTION FACTOR FOR SHELTER

$P_f = 1/(RF_o + RF_s)$

P_f = protection factor

RF_o = overhead reduction factor

RF_s = scattered reduction factor

D. NUMERICAL VALUES USED AND OBTAINED

Z = 8 ft

L_1 = 10 ft (shelter center calculation)

L_2 = 20 ft (shelter end calculation)

W = 8 ft

U = 126 lb/ft^3 (shelters S1, S2, S3 and S4)

W_1 = 0.07

W_2 = 0.01

W_3 = 0.00375

W_c = 0.2

We = 0.09

Xe = 5 lb/ft^2

t values in ft

	S1	S3	S4	S5, S6
t_1	4	3.4	3.58	3.62
t_2	4.1	3.51	3.69	3.72
t_3	4.32	3.75	3.93	3.97
t_4	4.65	4.1	4.28	4.32
t_5	5.05	4.72	4.9	4.94

Co and Wo values

Center		End	
$C_o = 0.2$	$W_o = 0.04$	$C_o = 0.1$	$W_o = 0.027$
$C_o' = 0.4$	$W_o' = 0.08$	$C_o' = 0.2$	$W_o' = 0.060$
$C_o'' = 0.6$	$W_o'' = 0.12$	$C_o'' = 0.3$	$W_o'' = 0.085$
$C_o''' = 0.8$	$W_o''' = 0.15$	$C_o''' = 0.4$	$W_o''' = 0.11$
$C_o'''' = 1.0$	$W_o'''' = 0.18$	$C_o'''' = 0.5$	$W_o'''' = 0.14$

RF_o values (overhead, all values x 10^{-6})

S1,S2		S3		S4		S5,S6	
Center	End	Center	End	Center	End	Center	End
$C_o(W_o,X_o)$							
1.55	1.28	5.7	4.4	3.9	3.0	15	11
$C_o(W_o',X_o')-C_o(W_o,X_o')$							
0.4	0.46	2.0	2.2	1.35	1.5	6.3	6.6
$C_o(W_o'',X_o'')-C_o(W_o',X_o'')$							
0.1	0.1	0.65	0.7	0.35	0.35	2.6	2.1
$C_o(W_o''',X_o''')-C_o(W_o'',X_o''')$							
-	-	0.05	0.06	0.1	0.07	0.6	0.7

Continued

RF_c values (overhead, all values x 10^{-6})

S1,S2 Center	S1,S2 End	S3 Center	S3 End	S4 Center	S4 End	S5,S6 Center	S5,S6 End
			$C_o(W_o'''', X_o'''')-C_o(W_o''', X_o''')$				
-	-	-	-	-	-	0.05	0.07
			RF_o(x 10-6)				
2.05	1.75	8.4	7.36	5.7	4.92	24.55	20.47

RF_s values (scattered, all shelters)

$RF_{s_1} = A_h = 0.0125$

$RF_{s_2} = 1.25 \times 10^{-5}$

$RF_{s_3} = 3.75 \times 10^{-6}$

$RF_{s_c} = 0.81 \times 10^{-6}$

$RF_{s_e} = 0.365 \times 10^{-6}$

P_f values

	Front End (Pos. 2)	Center	Back End
P_f(S1, S2)	70,000	350,000	470,000
P_f(S3)	50,000	110,000	130,000
P_f(S4)	63,000	150,000	190,000
P_f(S5, S6)	30,000	40,000	48,000

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2	CO, U.S. Naval Civil Engineering Laboratory
1	U.S. Naval School (CEC Officers)
1	CO, Construction Battalion Center, Port Hueneme
1	CO, Construction Battalion Center, Davisville
1	CO, Construction Battalion Base Unit, Port Hueneme
1	CO, Construction Battalion Base Unit, Davisville
1	CO, Disaster Recovery Training Unit, Port Hueneme
1	CO, Disaster Recovery Training Unit, Davisville
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1	Commander, Naval Air Material Center, Philadelphia
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1	Director, Naval Weapons Laboratory, Dahlgren
2	CO, Naval Schools Command, Treasure Island

2	CO, Naval Damage Control Training Center, Philadelphia
1	U.S. Naval Postgraduate School, Monterey
1	CO, Fleet Training Center, Charleston
1	CO, Fleet Training Center, Newport
1	CO, Fleet Training Center, Norfolk
1	Commander Fleet Training Group, Guantanamo Bay
1	Commander Fleet Training Group, San Diego
1	Commander Fleet Training Group, Western Pacific
1	Commander Fleet Training Group, Pearl Harbor
1	CO, Nuclear Weapons Training Center, Pacific
1	CO, Nuclear Weapons Training Center, Atlantic
1	CO, David W. Taylor Model Basin
1	Commander, Naval Ordnance Laboratory, Silver Spring
1	Commander, Training Command, Pacific Fleet
1	Commander Training Command, Atlantic Fleet
1	Director/PWO, Atlantic Division, BuYandD, New York
1	Director, Southeast Division, BuYandD, Charleston
1	Director, Southwest Division, BuYandD, San Diego
1	Director, Northwest and Alaskan Division, BuYandD, Seattle
1	CO, Naval Training Device Center, Port Washington
1	Commandant, First Naval District (DPWO)
1	Commandant, Third Naval District (DPWO)
1	Commandant, Fourth Naval District (DPWO)
1	Commandant, Fifth Naval District (DPWO)
1	Commandant, Sixth Naval District (DPWO)
1	Commandant, Eighth Naval District (DPWO)
1	Commandant, Ninth Naval District (DPWO)
1	Commandant, Eleventh Naval District (DPWO)
2	Commandant, Twelfth Naval District (DPWO)
1	Commandant, Thirteenth Naval District (DPWO)
1	Commandant, Fourteenth Naval District (DPWO)
1	President, Naval War College
1	Director, Institute of Naval Studies, Newport
1	CO, Naval Engineering Experiment Station
1	CinC, Pacific Fleet
1	CinC, Atlantic Fleet
1	Commander Amphibious Force, Pacific Fleet
1	Commander Amphibious Force, Atlantic Fleet
1	CO, Fleet Anti-Air Warfare Training Center, Dam Neck
1	CO, Fleet Anti-Submarine Warfare School, San Diego
1	CinC, U.S. Naval Forces, Europe
1	Commander, U.S. Naval Forces, Azores
1	Commander, U.S. Naval Forces, Japan
1	Commander, U.S. Naval Forces, Iceland
1	Commandant, U.S. Coast Guard

MARINE CORPS

1 Commandant of the Marine Corps (AO3H)
1 Commandant, Marine Corps School (CMCLFDA)
1 Director, Marine Corps Development Center
1 CG, Fleet Marine Force, Pacific
1 CG, Fleet Marine Force, Atlantic
1 CG, First Marine Division
1 CG, Second Marine Division
1 CG, Third Marine Division
1 CO, Naval Medical Field Research Laboratory, Camp Lejeune

ARMY

1 Chief of Research and Development (Atomic Div.)
1 Chief of Research and Development (Life Science Div.)
1 Deputy Chief of Staff for Military Operations
1 Deputy Chief of Staff for Logistics
10 Chief of Engineers (ENGMC-EB)
5 Chief of Engineers (ENGMC-DE)
1 Chief of Engineers (ENGRD-S)
1 Chief of Engineers (ENGCW-E)
1 CO, Fort McClellan, Alabama
1 Commandant, Chemical Corps Schools (Library)
3 CO, BW Laboratories
1 CO, Chemical Research and Development Laboratories
1 Commander, Chemical Corps Nuclear Defense Laboratory
1 CG, Continental Army Command, Fort Monroe (ATLOG)
1 CG, CONARC (CD-CORG)
1 CG, Quartermaster Res. and Eng. Command
1 President, Quartermaster Board, Fort Lee
1 CO, Dugway Proving Ground
1 CO, Chemical Corps Field Requirements Agency
1 Combat Developments Experimentation Center, Fort Ord
1 CG, Engineer Res. and Dev. Laboratory
10 CG, Army Engineer Center, Fort Belvoir
5 Asst. Commandant, Army Engineer School, Fort Belvoir
2 Commandant, Air Defense School, Fort Bliss
2 Commandant, Command and General Staff College
2 Superintendent, U.S. Military Academy, West Point
2 Commandant, Army War College
1 CE, Ballistic Missile Construction Office
1 CG, Military Construction Supply Agency
1 Board of Engineers for Rivers and Harbors
1 CG, Army Air Defense Command (Engineer)

1	CG, Continental Army Command, Fort Monroe (Engineer)
10	CG, First Army (Engineer)
10	CG, Second Army (Engineer)
10	CG, Third Army (Engineer)
10	CG, Fourth Army (Engineer)
10	CG, Fifth Army (Engineer)
10	CG, Sixth Army (Engineer)
10	CG, Military District of Washington (Engineer)
10	CG, U.S. Army Alaska (Engineer)
10	CG, U.S. Army Caribbean (Engineer)
10	CG, U.S. Army Forces, Antilles (Engineer)
10	CG, U.S. Army, Europe (Engineer)
10	CG, Seventh U.S. Army (Engineer)
10	CG, U.S. Army Pacific (Engineer)
10	CG, U.S. Eighth Army (Engineer)
10	CG, USARYIS/IX Corps (Engineer)
10	CG, Southern European Task Force (Engineer)
10	CG, U.S. Army, Japan (Engineer)
2	Commandant, Army Armored School, Fort Knox
2	Commandant, Army Artillery and Missile School, Fort Sill
2	Commandant, Army Infantry School, Fort Benning
2	Commandant, The Quartermaster School, Fort Lee
2	Commandant, Army Ordnance School, Aberdeen
2	Commandant, Army Ordnance and Guided Missile School
2	Commandant, Army Signal School, Fort Monmouth
2	Commandant, Army Transportation School, Fort Eustis

AIR FORCE

1	Directorate of Operational Requirements (DCS/Operations)
1	Assistant Chief of Staff, Intelligence (AFCIN-3B)
6	CG, Aeronautical Systems Division (ASAPRD-NS)
1	Directorate of Civil Engineering (OFOCE-ES)
1	Director, USAF Project RAND
2	Commandant, School of Aerospace Medicine, Brooks AFB
1	CG, Strategic Air Command (Ops Analysis Office), Offutt AFB
1	CG, SAC, Offutt AFB (Dir. of Civil Engineering)
1	Office of the Surgeon General
10	CG, Special Weapons Center, Kirtland AFB
1	Directorate of Nuclear Safety Research, Kirtland AFB
1	Director, Air University Library, Maxwell AFB
2	Commander, Technical Training Wing, 3415th TTG
1	Commander, Cambridge Research Laboratories
1	Hq., Air Force Technical Applications Center

OTHER DOD ACTIVITIES

3 Chief, Defense Atomic Support Agency (Library)
1 Commander, FC/DASA, Sandia Base (FCDV)
1 Commander, FC/DASA, Sandia Base (FCTG5, Library)
1 Commander, FC/DASA, Sandia Base (FCWT)
1 OIC, Livermore Branch, FC/DASA
1 Director, Weapons Systems Evaluation Group
1 Joint Atomic Information Exchange Group
1 Director of Defense Research and Engineering
1 Assistant Secretary of Defense (Supply and Logistics)
1 U.S. Military Representative, SHAPE
1 U.S. Military Representative, NATO
1 U.S. Military Representative, SEATO
1 Director, Advance Research Projects Agency
6 Commander in Chief, STRIKE Command
30 Armed Services Technical Information Agency
2 Commandant, National War College
2 Commandant, Industrial College of the Armed Forces
2 Commandant, Armed Forces Staff College

OCD

50 Office of Civil Defense, Washington
1 OCD, Region 1, Harvard, Massachusetts
1 OCD, Region 2, Olney, Maryland
1 OCD, Region 3, Tomasville, Georgia
1 OCD, Region 4, Battle Creek, Michigan
1 OCD, Region 5, Denton, Texas
1 OCD, Region 6, Denver, Colorado
1 OCD, Region 8, Everett, Washington

OTHERS

1 Central Intelligence Agency
1 Research Analysis Corporation
1 AEC Division of Military Applications
1 Hq., U.S. European Communities

OTS

25 Office of Technical Services, Dept. of Commerce, Washington

USNRDL

54 USNRDL, Technical Information Division

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Naval Radiological Defense Laboratory
USNRDL-TR-647
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Two types of shelters were designed to withstand predicted overpressures: Type I for a 1-psi overpressure and Type II for a 5-psi overpressure. The basic structure consisted of an 8-ft diameter, 10-ft long, 12-gage corrugated steel, multi-plate pipe. A steel entranceway incorporating two right-angle turns provided access to the basic structure. Depending upon the amount of soil backfill, fallout gamma radiation protection factors up to 470,000 were obtained.

The overall performance of the shelters under the conditions experienced was excellent. It is suggested that shelters of this type have application not only for use as manned stations in nuclear weapon testing but can be adapted as well for use in residential areas as single-family fallout shelters.

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