SHELTER ENTRANCEWAYS AND OPENINGS

September 1967

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Final Report

Prepared for:

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310

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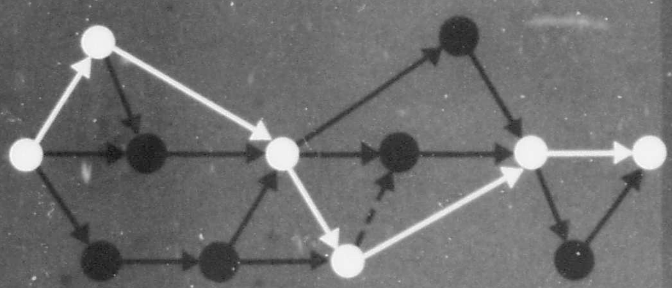

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SUMMARY OF SHELTER ENTRANCEWAYS AND OPENINGS

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SUMMARY

Introduction

The objective of this investigation was to develop, test, and evaluate low cost shelter entranceways and openings for providing protection against the effects of nuclear weapons in the overpressure regions up to 20 psi. In past studies, the entranceway and its component elements have generally been considered by designers as an engineering problem, where the most important factor was to provide an adequate and safe entry of shelterees into the shelter proper while assuring serviceability of the entranceway under the design conditions. The usual engineering assumptions were made concerning weapon effects, structural design, and traffic flow through the entranceway. Although these studies included a number of design factors, it was found that due to their limited scope, very little effort had been expended to identify the many interacting factors that can actually influence or control the entranceway design and cost. Therefore, before a study of specific entranceway configurations in this program was undertaken, an examination was made of the factors that influence the design of shelter entranceways. With this information available, a basis for evaluating or judging the more important factors could be established. To identify the factors, a survey was made of selected references that were concerned with the entranceway design problem and with other aspects of civil defense, such as shelter design, movement of people, warning concepts, and weapon effects.

Influencing Factors

Although a large number of factors were identified as influential in the design of entranceways, many are beyond the scope of any entranceway study program. For example, it is apparent that a general solution to the entranceway problem depends to a large extent on a solution or decision concerning a national shelter program. Therefore, the approach adopted in this study was (1) to identify all possible factors that influence, limit, or constrain the entranceway design, (2) to attempt to identify the multitude of interacting situations, and (3) to establish the situations most important to the entranceway design problem.

From the review of the pertinent literature in the general area of entranceways, more than 100 factors were identified as influencing the entranceway design. A preliminary examination of the complexity of the interactions among the numerous factors indicated that for this study it would be necessary to simplify the problem by reducing the variables to a manageable quantity. This was accomplished by arranging the many factors into 15 major categories and establishing their relative importance. Since no absolute rating system could be devised to order the factors by assigning values to each interacting situation, the procedure adopted was to examine in detail the influence of each major grouping of factors on every other factor group and to rate this influence on an arbitrary scale.

The process was primarily subjective, and each rating depends largely on a judgment of the influence on system cost of each interacting situation. The results of this study are summarized on Table S-1. As noted, each of the groups shown represent more than one factor, e.g., No. 1, Type of Shelter System Factors, includes seven factors, such as single purpose, dual purpose, fallout, and fallout plus direct effects; and No. 4, Movement to Shelter Factors, includes 18 factors, such as warning delay time, travel delay time, number of people, and the rate of arrival at the entrance. On the basis of this analysis, parameters were selected from the first 10 groups to perform cost analyses for various conceivable entranceway configurations. The factors selected included weapon effects, orientation, configuration, entranceway elements, code requirements, structural design, movement to shelter, and others.

Table S-1

RELATIVE INFLUENCE OF FACTOR GROUPS
ON ENTRANCEWAY COST

1. Type of Shelter System Factors
2. Economic Factors
3. Risk Assumption Factors
4. Movement to Shelter Factors
5. Attack Input Factors
6. Entranceway Design Factors
7. Shelter Warning Concept Factors
8. Design Concept Factors
9. Site Factors
10. Structural Design Factors
11. Psychological Factors
12. Environmental Factors
13. Shelter Management Factors
14. Security Factors
15. Equipment Factors

Cost Analysis

Because of the lack of definitive cost data for entranceways of the type examined in this study and because detailed cost information was required to determine the cost differential due to variation of parameters, it was necessary to prepare detailed designs and cost estimates for individual entranceways. To select the entranceways for further study from among the many possible types, emphasis was placed on those types of civil defense shelter entranceways that were appropriate for use by the general public. Although the primary interest was on entranceways for single purpose shelters, the design and cost data apply to many dual purpose type shelters, such as schools, community recreation structures, or operational centers, if local codes are considered. The data would not apply to such dual purpose structures as underground parking garages or department store basements where large openings exist. However, even in these cases, the cost data would be appropriate for situations where separate pedestrian entranceways were provided for emergency use. The primary construction materials considered for the permanent type of entranceways were reinforced concrete and steel. Entranceways constructed of timber, sand bags, or motarless masonry, while appropriate for expedient-type shelters, were not included. Also, since only the lower overpressure regions were considered, entranceways with elaborate interlock systems were not included.

In general, the procedure used was to (1) select an appropriate entranceway configuration, (2) perform a preliminary structural design to obtain the approximate size and strength requirements, (3) determine the adequacy of the entranceway for providing protection from fallout radiation, or, if required, from initial radiation, (4) modify the original dimensions if necessary to meet the radiation requirements, and (5) make a detailed construction cost estimate.

Designs and cost estimates were prepared for 36 entranceways and 2 escape exits, which for convenience were divided into the 14 categories or types shown in Table S-2. The estimates reflect construction costs in the San Francisco Bay Area during the spring of 1967 and include all material and labor costs, labor burden, and contractor's profit. They do not include such costs as preconstruction costs, finance costs, operation and maintenance costs, or government costs.

From the basic cost estimate data for individual entranceways, it was possible to develop the total cost of shelter entranceways for loading capacities up to 1,000 persons/min as shown on Figure S-1 for the following six types:

Table S-2

TYPES OF SHELTER ENTRANCEWAYS

	Type and Description	Capacity Range (persons/min)
Underground fallout shelter entranceway		
A	Reinforced concrete--single stair	45 - 180
B	Reinforced concrete--dual stair	120 - 270
C	Reinforced concrete covered stairwell--interior location	90 - 180
D	Reinforced concrete open stairwell--exterior location	67 - 180
E	Reinforced concrete escape exit	--
F	Reinforced concrete covered stairwell--exterior location	90
G	Circular steel pipe--vertical orientation	22 - 45
H	Circular steel pipe--single stair	67
I	Reinforced concrete class C ramp	67
Underground blast shelter entranceway		
J	Reinforced concrete--single stair	90 - 120
K	Reinforced concrete--dual stair	180 - 225
Aboveground fallout shelter entranceway		
L	Reinforced concrete--without basement	120 - 240
M	Reinforced concrete--with basement	120 - 240
N	Reinforced concrete escape exit	--

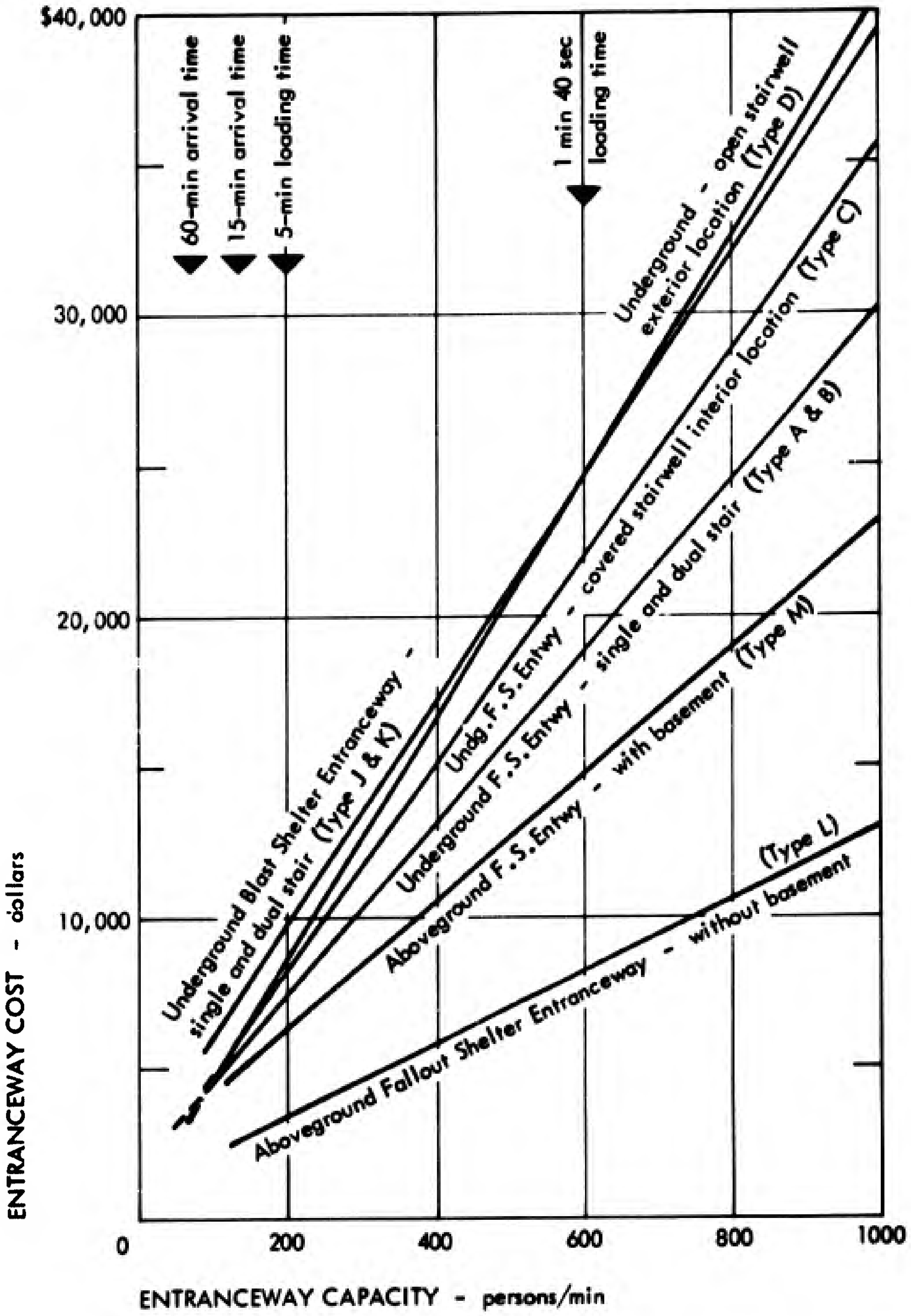

Figure S-1

ENTRANCEWAY TOTAL COST VERSUS CAPACITY FOR REINFORCED CONCRETE ENTRANCEWAYS (Loading times are for a 1,000-person shelter)

1. Underground shelter, reinforced concrete entranceways.
    a. Single and dual stair--fallout (Types A and B)
    b. Covered stairwell--interior location--fallout (Type C)
    c. Open stairwell--exterior location--fallout (Type D)
    d. Single and dual stair--fallout plus direct effects (20 psi) (Types J and K)
2. Aboveground shelter, reinforced concrete entranceways.
    a. Surface entranceway--no basement--fallout (Type L)
    b. Surface entranceway--with basement--fallout (Type M)

To obtain the curves shown on the figure, an examination was made of the total cost of numerous combinations of entranceways of each type. From this information, it was possible to select the combination of entranceways that yielded the minimum cost for any particular entranceway capacity. Also, the entranceway cost data, although shown as a smooth line, actually increase in finite steps due to the requirement for a change in entranceway width of one-half exit unit width to obtain an increase in capacity. However, since a step function is difficult to use in most analytical procedures, and because of the errors inherent in estimating construction costs, it was felt that the information would be more meaningful if an averaging technique was used to obtain a continuous function.

Since the entranceway capacity required for an actual situation could not be determined in a general manner beforehand, loading capacities were considered for the following cases:

- A 1-min, 40-sec loading time to conform to the evacuation time in the Building Exits Code of the National Fire Protection Association.
- A 5-min loading time based on an average entranceway capacity usually used for design.
- A 15- and 60-min time of arrival based on a more realistic rate of arrival of shelterees from studies of the movement of people to shelter.

If the total shelter population is known, for loading times of 1 min, 40 sec and 5 min, the entranceway capacity can be determined by simply dividing the shelter population by the available time. For example, for a 1,000-person shelter and a 5-min average loading time, an entranceway capacity of 200 persons/min would be required. However, to establish a more realistic basis for estimating entranceway capacity, it was necessary to examine the movement of people and their rate of arrival at the entranceway. For this study, the rate of arrival curves for the 15- and 60-min arrival times were developed from a model presented in an Operations Research, Inc., report on concepts for the movement of people. From this information, the number of persons arriving at the shelter each minute after the alert was determined for a 500 and a 1,000 person shelter. Figure S-2 indicates that for a 1,000-person shelter and a 15-min time of arrival, the maximum rate of arrivals is 250 persons/min. If it is desirable to prevent formation of a queue, it would be necessary to provide for this maximum rate. However, for the 1,000-person shelter, an entranceway capacity of 134 persons/min would dissipate the queue in about 12 minutes, i.e., the queue would dissipate within the 15-min time available.

In a similar manner, it was found that for a 60-min arrival time, the peak rate of arrivals was only 62 persons/min. Therefore, other factors such as the minimum size of entranceway permissible would govern the entranceway design capacity for the 60 min arrival time. For the purpose of comparison, the total cost of entranceways to satisfy the assumed entranceway criteria are shown on Figure 1 for a 1,000 person shelter.

Conclusions

Many individual and interacting factors control or influence the design and cost of entranceways for civil defense shelters. Because of the many conceivable types of shelters and the diversity of entranceway requirements, it is difficult to form definite conclusions without prior knowledge of a specific shelter program. However, the following conclusions apply in general to the design of personnel entranceways for civil defense shelters, when consideration is given to the many complex influencing factors:

- If the entranceways for dual purpose or other civil defense shelters are required to meet fire codes equivalent to the Building Exits Code, there are two factors that will usually control the total cost. These are (1) the requirement that the minimum width of any entranceway be 44 in. and (2) the requirement to provide entranceway capacity sufficient to permit the entire shelter population to evacuate in 1 min, 40 sec.

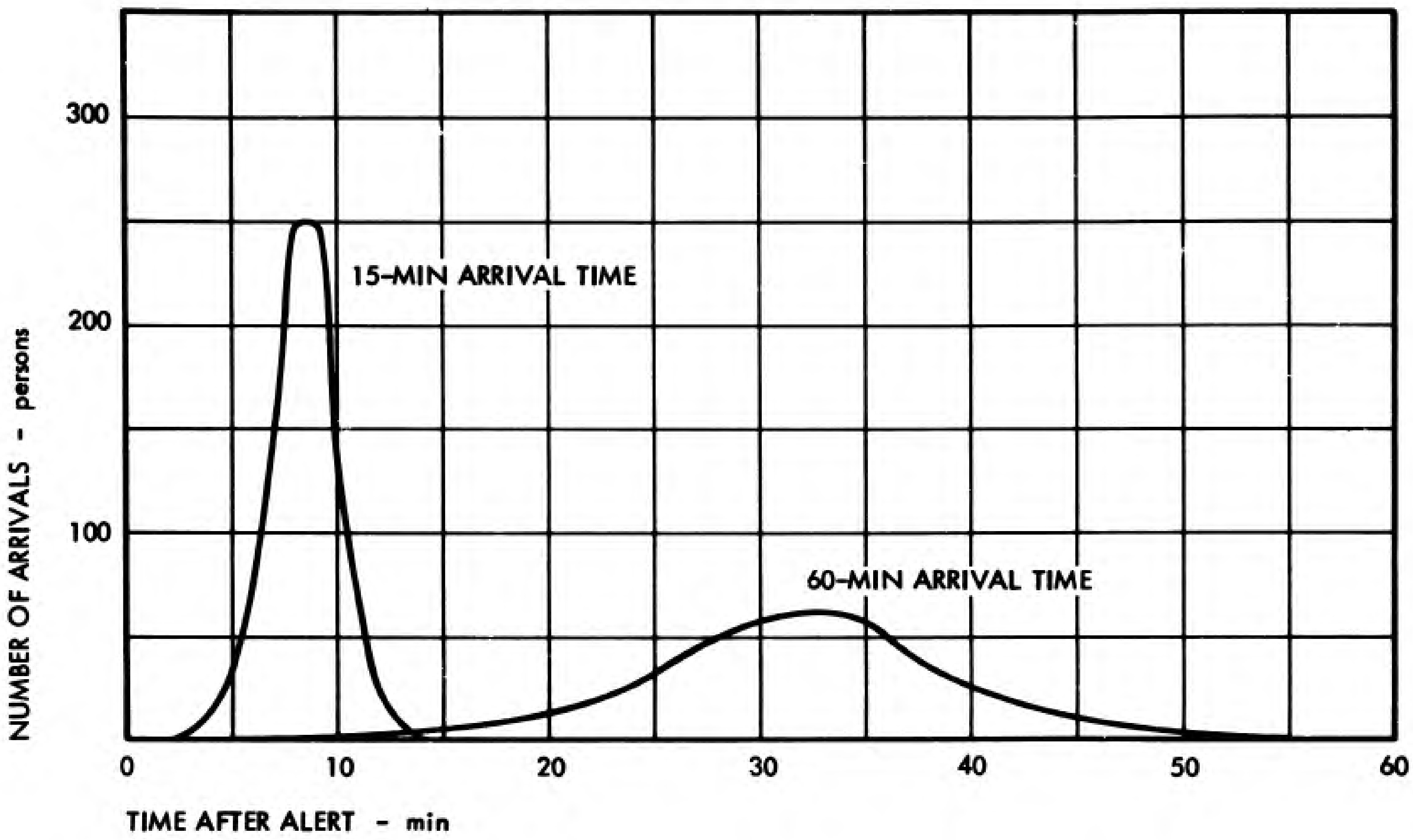

Figure S-2

ARRIVAL OF SHELTEREES FOR 1,000-PERSON SHELTER FOR WARNING TIMES OF 15 MIN AND 60 MIN

- For short warning times such as 15 min, a reasonable design entranceway capacity can be determined by assuming an average loading time of 7 min for the entire shelter population to enter the shelter. Although this results in a queue larger than for the usual 5-min loading time, the queue would probably be dissipated within the 15-min time available after the alert for any assumed realistic rate of arrival of shelterees.

- For longer rates of arrival such as 60 min, it appears reasonable to determine the design entranceway capacity by assuming an average loading time of 15 min for the entire shelter population to enter the shelter. However, since this leads to minimum size entranceways, factors such as the psychological problems of entranceways that are small in relation to the shelter size and population should be considered. Also, for shelters with capacities smaller than 1,000 persons, the width of the entranceway determined in this manner is narrower than that permissible by the Building Exits Code.

- On the basis of the entranceway cost/person, the narrower the width of the entranceway, the greater the cost/person for a particular type of entranceway. This implies that if minimum entranceway cost is a criterion for a national shelter program, for situations where the cost/person is meaningful, consideration should be given to the minimum size of shelter. As noted in the body of the report, for all average loading times and shelter sizes considered in this study, the entranceway cost/person increased with decreasing shelter size. Also, for any specific entranceway capacity, there is a shelter size below which there is a relatively rapid increase in entranceway cost/person.

- For the permanent type of entranceways considered in this study, it was found that for underground shelters, a reinforced concrete box section was the most economical when consideration was given to the loading rate through the entranceway.

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ABSTRACT

The objective of this investigation was to develop, test, and evaluate low cost shelter entranceways and openings for providing protection against the effects of nuclear weapons in the overpressure regions up to 20 psi. The approach adopted was (1) to identify as many factors as possible that influence, limit, or constrain the entranceway design; (2) to attempt to identify the multitude of interacting situations; and (3) to establish the situations most important to the design of entranceways for civil defense shelters. From an examination of the numerous influencing factors, parameters were selected as the basis for performing cost analyses for various entranceway configurations. Cost estimates were then prepared for 36 individual entranceways and 2 escape exits. From these data, it was possible to develop the total construction cost of shelter entranceways for loading capacities up to 1,000 persons/min for six general types of entranceways applicable for civil defense fallout and blast shelters. Since the loading capacity required for a specific entranceway system cannot be determined in a general manner beforehand (as explained in the body of the report), the cost data are presented on the basis of the entranceway cost/person for shelter capacities up to 10,000 persons for the six entranceway types and for entranceway loading capacities between 67 and 1,000 persons/min.

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I INTRODUCTION

Under contract to the Office of Civil Defense, Stanford Research Institute conducted an investigation of entranceways for civil defense shelters. The purpose of the study was to develop, test, and evaluate low-cost shelter entranceways and openings for providing protection against the effects of nuclear weapons in the overpressure regions up to 20 psi. The initial effort was primarily concerned with identifying the numerous factors that must be considered in the design of shelter entranceways, examining the influence of the more important factors on entranceway cost, and analyzing the total cost of selected types of entranceways appropriate for civil defense use.

Background

In many instances, entranceways have been designed and built in conjunction with hardened protective shelters for military application and for inclusion in nuclear weapon field tests. In general, these were special cases in which it was possible to expend considerable effort to study in detail the attack environment, the structural requirements, and the operational procedures. The entranceways were usually designed for the higher overpressure regions and were equipped with elaborate opening and closing mechanisms not generally adaptable for civil defense use. Cost was usually a secondary consideration relative to the operational requirements.

A number of entranceways have also been designed and built specifically for both fallout and blast resistant type of civil defense shelters. Past investigations have included nuclear weapon field tests, as well as limited examination of the design parameters and their influence on entranceway cost. In most instances, however, entranceways have been designed for specific shelters, and very little effort has been expended to determine the more important design parameters and their relative influence on the cost and performance of entranceways for a wide variety of civil defense applications. Therefore, the approach adopted in this study was (1) to identify all possible factors that influence, limit, or constrain the entranceway design; (2) to attempt to identify the multitude of interacting situations; and (3) to establish the situations most important to the design of entranceways for civil defense shelters

Report Organization

Section II contains a general discussion of the numerous entranceway system factors identified in this study that affect the design of entranceways for civil defense shelters. From this information, the more important design factors were selected for detailed consideration in Section III. Section IV contains the cost analysis for a number of individual entranceway configurations applicable to civil defense use and presents total cost data in relationship to the loading capacity for various types of entranceways. Section V contains conclusions and recommendations developed in the study.

The method used to analyze the blast entranceways for initial radiation streaming, together with an illustrative example, is given in Appendix 1. Although standard procedures are available for fallout shielding analysis, the entranceway problem is a special case that is sufficiently different to warrant a discussion with sample calculations in Appendix 2. Sketches of each entranceway considered in this study are presented in Appendix 3, and the development of the cost data with a sample cost estimate is included in Appendix 4.

Acknowledgements

The author gratefully acknowledges the assistance and guidance of James F. Halsey of Stanford Research Institute and Norbert E. Landdeck of the Office of Civil Defense during the conduct of this program. In addition, special acknowledgements are due H. L. Murphy of the Institute for the calculation of the fallout radiation protection factors for entranceways and the preparation of Appendix 2 and to J. Kwapil, SRI construction cost consultant, for the preparation of all entranceway cost estimates.

II ENTRANCEWAY SYSTEM FACTORS

Introduction

In past studies, the entranceway and its component elements have generally been considered by designers as an engineering problem, in which the most important factor was to provide an adequate and safe entry of shelterees to the shelter proper while assuring serviceability of the entranceway under the design conditions. The usual engineering assumptions were made concerning weapon effects, structural design, and traffic flow through the entranceway. Although these studies included a number of design factors, it was found that, because of the limited scope of the studies, very little effort had been expended to identify the many factors and interacting situations that can actually influence or control the entranceway design and cost. Therefore, before a study of specific entranceway configurations in this program was undertaken, an examination was made of the various factors that influence, limit, or constrain the designer. With this information available, a basis for evaluating or judging the more important factors could be established. To identify the various factors, a survey was made of selected references that were concerned with the entranceway design problem and with other aspects of civil defense, such as shelter design, movement of people, warning concepts, and weapon effects (see References and Bibliography).

Although a large number of factors are identified in the next subsection as important to the design of entranceways, many are beyond the scope of any entranceway study program. It is apparent that a general solution to the entranceway problem is dependent to a large extent on a solution or decision concerning a national shelter system program. For instance, if a tactical warning concept was adopted for the civil defense shelter program, this would be an overriding constraint on both the shelter and the entranceway systems.

Although many factors would influence the system design, as far as the entranceway is concerned, the short time available after tactical warning is received (say 15 minutes), together with the unavoidable delay of arrivals at the shelter entrance, would be the controlling parameter in the design. Cost would be secondary and would be traded off or compromised for speed of entry, which would require shallow steps or ramps, wide corridors and doors, elaborate initial door opening and interlock systems, and so forth. On the other hand, a number of the identified entranceway problem areas can be investigated independently and the results applied to any specific shelter program. In some instances, entranceway factors such as cost can be considered as important influencing factors or inputs to any shelter system program. The factors identified and investigated are presented in the next subsections.

Factor Evaluation

From the review of the pertinent literature in the general area of entranceways, more than 100 factors were identified as influencing the entranceway design problem. As listed on Table 1, the factors have been arbitrarily placed in two categories--entranceway design factors and influencing or limiting factors, or constraints. An examination of the list indicates the complexity of an analysis of the entranceway system. This is due in part to the large number of factors and also to the interdependency between many of the factors and their mutual constraints on each other and on the system as a whole. In an attempt to identify the factors that are important to entranceway design, a matrix was established for investigating the various interacting situations. From a preliminary examination of the complexity of the interactions among the numerous factors, it became obvious that for this study it would be necessary to simplify the problem by reducing the variables to a manageable quantity. This was accomplished by establishing the relative importance of factors from among the 15 major categories shown in Table 1. Since no absolute rating system could be devised to order the factors by assigning values to each interacting situation, the procedure adopted was to examine in detail the influence of each major grouping of factors on every other factor group and to rate this influence on an arbitrary scale. Although the influence of many of the interactions among the individual factors within each group was also considered during the evaluation, the process was primarily subjective, and each rating is largely dependent upon a judgment of the influence on system cost of each interacting situation. The results of this study are summarized in Table 2. It is realized that both the establishment of a list of influencing factors and the relative rating of their influence on the entranceway problem is an arbitrary procedure not subject to rigorous analytical proof. However, since the conduct of a sensitivity analysis to study the influence of each factor was beyond the scope of this project, the method outlined was employed to establish a relative rating basis on which cost comparisons of the various types of entranceways of interest could be made.

Table 1

FACTORS THAT INFLUENCE SHELTER ENTRANCEWAY DESIGN

ENTRANCEWAY DESIGN FACTORS

- Weapon parameters
- Configuration
- Entranceway elements
- Orientation
- Code requirements
- Blast interlock system
- Door type, size, number, and location
- Direction of door opening
- Decontamination area
- Emergency exit
- Debris
- Entry during button-up
- Sealing requirements
- Location in shelter
- Prevent water entry
- Functional characteristics

INFLUENCING OR LIMITING FACTORS, OR CONSTRAINTS

Shelter Warning Concept Factor
- Strategic
- Tactical

Type of Shelter System Factors
- Single purpose
- Dual purpose
- Personnel
- Operations
- Fallout
- Fallout + fire
- Blast + fire + fallout

Risk Assumption Factors
- Human tolerance level
- Entrance system resistance

Design Concept Factors
- Worst condition
- Balanced design
- Balanced attack input probability
- Nominal design
- Safety factor
- Damage criterion
- Austere entranceway
- Unique concepts

Psychological Factors
- Public acceptance
- Mental preparation
- Response to warning
- Panic
- Entranceway appearance
- Training
- Lighting

Economic Factors
- Initial cost
- Long-term cost
- Maintenance cost

Environmental Factors
- Air blast
- Nuclear radiation
- Heat
- Air quality
- Noxious gases
- Length of stay
- Shelter capacity
- Entry hazards

Shelter Management Factors
- Shelter assignment plan
- Initial door opening
- Control operational procedures
- Control ingress flow
- Traffic control
- Control overloading
- Door operation and integrity
- Insure egress
- Button-up requirements
- Safety
- Inspection

Security Factors
- Prevent illegal entry
- Vandalism
- Insure closure
- Environmental control

Site Factors
- Location
- Distribution versus population
- Terrain
- Building density and proximity
- Shelter depth
- Soil conditions
- Water table
- Flooding
- Exposure

Attack Input Factors
- Air blast
- Initial nuclear radiation
- Residual nuclear radiation
- Thermal radiation
- Conflagration
- Chemical and biological agents

Movement to Shelter Factors
- Warning delay time
- Reaction delay time
- Travel delay time
- Entranceway delay time
- Shelter delay time
- Age and physical condition
- Number of people
- Population distribution
- Shelter location
- Travel distance
- Rate of movement
- Rate of arrival at entrance
- Shelter loading rate
- Time of day
- Transportation
- Weather
- Traffic congestion
- Obstacles

Structural Design Factors
- Blast loading
- Blast arrival time
- Negative phase
- Soil loading
- Impact loads
- Relative motion
- Material type and properties
- Turns and bends in corridor
- Fire resistance
- Door design
- Design procedure

Equipment Factors
- Ventilation
- Power
- Other mechanical
- Shelter support items
- Decontamination
- Blast interlock system

Table 2

RELATIVE INFLUENCE OF FACTOR GROUPS ON ENTRANCEWAY COSTS

1. Type of Shelter System Factors
2. Economic Factors
3. Risk Assumption Factors
4. Movement to Shelter Factors
5. Attack Input Factors
6. Entranceway Design Factors
7. Shelter Warning Concept Factors
8. Design Concept Factors
9. Site Factors
10. Structural Design Factors
11. Psychological Factors
12. Environmental Factors
13. Shelter Management Factors
14. Security Factors
15. Equipment Factors

Although the attempt was made to rate the groups of factors according to their estimated influence on entranceway cost, it is obvious that certain factors can place an overriding constraint on the system. For example, the type of warning concept adopted can affect drastically the entire shelter system concept, which can be a primary influence on entranceway requirements and cost. The influence of such a factor is difficult to evaluate quantitatively, since the adoption of the shelter warning concept requires a policy decision at a considerably higher level than that of the shelter designer or planner. However, it was generally not too important to resolve such factors directly for this study, since realistic limits could often be selected for the problem. Studies of the mobility and movement of people to shelters show a time distribution of the arrival of shelterees at the entranceway. For minimum warning times of about 15 minutes, an examination of realistic shelter situations would indicate a probable upper limit on the rate of arrivals. On the other hand, as will be discussed subsequently, for warning times longer than about one hour, the rate of arrivals is such that a minimum size entranceway system may be limited by building codes or other factors, and not by the rate of arrival of the shelterees. Therefore, even though the warning concept may not be known beforehand, a range of realistic rates or arrival could be established for investigating the cost of alternative entranceway systems.

Such information for various types and capacities of entranceways could be used as input data for operational and cost-effectiveness studies that are concerned with many facets of civil defense such as movement of people, the risk of additional exposure, and probability of survival for various shelter programs.

In addition to the overriding type of constraint, other factors, which are also beyond the control of the designer, can affect the entranceway system indirectly. For instance, an examination of the influence of the degree of training of the population on the other factors indicates that it affects many factors that directly affect entranceway design. It is difficult for a designer to estimate the level of training of a potential shelter population and to determine its influence on such factors as delay times, the movement of people to shelter, the loading rate through the entranceway, the door operating procedures, the psychological factors, and others. Also, even the assumptions regarding the calculation of the entranceway protection factor for fallout radiation are influenced by the training of the shelterees to wash down the entranceway steps during the postattack period. Although such situations are difficult to quantify, it was felt adequate for the purpose of developing the cost data in this report to use the current published information regarding such factors as the movement of people to shelter or conservatively to assume for radiation calculations that washdown would not be provided.

Study Parameters

Based on the above analysis, the parameters shown in Table 3 were selected as the basis for performing cost analyses for various conceivable entranceway configurations. The Shelter Warning Concept Factor, which ranks higher than the Site Factor, is not included as a study parameter in the table since it requires a higher order policy decision. This is not too important to the results of this study, since its effect is indirectly included by consideration of a range of arrival times for the shelterees.

A desirable goal for any shelter system or shelter component study would be to optimize all factors so that planners or analysts could readily select an optimum system for any assumed condition. For example, what is the influence of the steepness of steps on entranceway cost, on rate of loading, or on injury? Or when considering initial nuclear radiation streaming through an entranceway, what is the effect of orientation on entranceway cost, on radiation dosage, or on the probability of casualty or mortality of shelterees. Within the scope of this study, it was not possible to include a detailed examination of the influence of each of

Table 3

SUMMARY OF STUDY PARAMETERS

Type of Shelter System Factors

- Single purpose, fallout, new construction
- Single purpose, fallout + direct effects, new construction

Economic Factors

- Initial cost
  - Nominal design
  - Austere design

Risk Assumption Factors

Not considered explicitly in this study. However, it is implicit in assumptions for people movement.

Movement to Shelter Factors

- Rate of arrival, implicit in this factor are many factors such as delay times, population distribution, and travel distance.
  - 1-min 40 sec loading time*
  - 5-min loading time
  - 15-min arrival time†
  - 60-min arrival time†
- Entranceway capacity*
  - Stairs
  - Corridors
  - Doors
- Number of shelterees
  - 500 person shelter capacity
  - 1,000 person shelter capacity

Attack Input Factors

- Air blast
  - No air blast
  - 20 psi overpressure region
- Residual radiation – use entranceway PF
- Initial radiation – consider as necessary

Entranceway Design Factors

- Weapon yield, 200 kt
- Configuration
  - Straight entranceway
  - L entranceway
  - Tee entranceway

Table 3 (concluded)

Entrance Design Factors (continued)

- Entranceway elements
  - Entrance section
  - Stairs
  - Corridors
  - Door
- Orientation, use worst condition
- Blast doors as required
- Code requirements
  - Use code
  - Use structural requirements only

Design Concept Factors

- Nominal design with usual safety factor
- Austere design

Site Factors

- Aboveground shelter configuration
- Underground shelter configuration

Structural Design Factors

- Standard loading procedures
- Reinforced concrete and steel
- Conventional structural design procedures

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* Conforms to NFPA Building Exits Code (Ref. 26).

† Use distribution presented in Ref. 30 to conform to the assumed available time.

the numerous factors. Rather, it was usually necessary to select what was considered a reasonable value; that is, for the stairs, the tread and riser dimensions were selected from applicable fire exit codes, without the benefit of a study of the influence of varying combinations. For the initial radiation, only three burst point locations were selected to determine a worst case orientation. A study of the influence of the burst point orientation radiation dose on entranceway cost was not made, nor were such parameters as spatial attenuation of the radiation entering the shelter through the entranceway included. However, for a specific case, or for a national shelter program, a sensitivity study of many factors probably would be warranted, since substantial cost savings could result from a consideration of the probability of the occurrence of various events and of the risks entailed in the selection of less conservative, but more optimum design values.

III ENTRANCEWAY DESIGN CONSIDERATIONS

Introduction

The design of a specific entranceway requires that a number of system input factors be considered, such as the type of shelter system, the location and size of the shelters, the level of protection required, the distribution and movement of people and their rate of arrival at the shelter, and the shelter environment. In general, many of these factors, although influencing the entranceway design, would be known quantities to the designer. Many other factors would not be inputs to the designer and would require various engineering assumptions. These include the entranceway configuration and elements, the structural design and radiation analysis procedures, the loading, the material properties, and the door type and operation. In this investigation, where the interest was primarily in the entranceway cost in relationship to the various design factors and not in case studies, it was necessary to make assumptions concerning the system inputs, in addition to the usual engineering assumptions. A detailed discussion of the more important factors considered in preparing the entranceway designs for the cost analysis is presented in the following subsections. In the discussion of this information, it is assumed that the reader is familiar with the basic air blast phenomena and structural design techniques (e.g., Refs. 1, 2, and 3).

Weapon Parameters

In the area of protective shelters, the usual practice has been to select the peak side-on overpressure level of interest and to assume an appropriate weapon yield for determining the other pertinent weapon parameters, such as duration, range, or initial radiation intensity. Although it would have been desirable to examine the effect of various overpressure levels on shelter entranceway cost, this study was limited to a single overpressure of 20 psi. For the purpose of performing the structural designs required for the cost estimates, it was sufficient to assume a long-duration loading pulse, such as that from megaton size yields. This assumption is felt to be justified since the variation in structural design for a large range of practical yields would not significantly alter the cost for the short span lengths found in entranceway structures.* On the other hand, for calculation of the free-field initial radiation intensities, the yield is an important design parameter and therefore an important cost factor for a specific overpressure level. This is because of the difference in overpressure and radiation scaling laws, where, for any given overpressure level, as the weapon yield increases, the blast load duration increases, while the radiation intensity decreases. The variation in radiation intensity with yield can be illustrated by the following tabulation for a surface burst at the 20 psi overpressure region (Ref. 1):

Yield	Initial Nuclear Radiation
20 Mt	~1 rad
2 Mt	~400 rads
200 kt	~12,000 rads

Because of the order-of-magnitude variation in radiation intensities shown, it is obvious that the weapon yield could appreciably affect the entranceway cost, and would also be a desirable parameter to investigate. However, since a range of radiation intensities could not be studied within the scope of this project, only the 200-kt yield was considered for the purpose of including initial radiation as a parameter. This was justified on the basis that 200 kt was a representative low yield case for OCD application. For the low overpressure region considered in this study, the total cost of the reinforced concrete entranceway selected for the blast shelter was not appreciably affected by the additional requirement for the initial radiation, since only a short length of corridor and a barrier wall had to be added to the basic blast entranceway configuration to provide adequate protection from radiation.

Air Blast Loading

An important factor in predicting the air blast loading on an entranceway structure is determining the free-field pressure-time relationship just before the interaction of the wave front with the entranceway.

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* This is not to imply that the yield is not an important parameter in dynamic structural analysis, but that a small additional concrete thickness or percentage of reinforcing steel would not significantly affect the total entranceway costs.

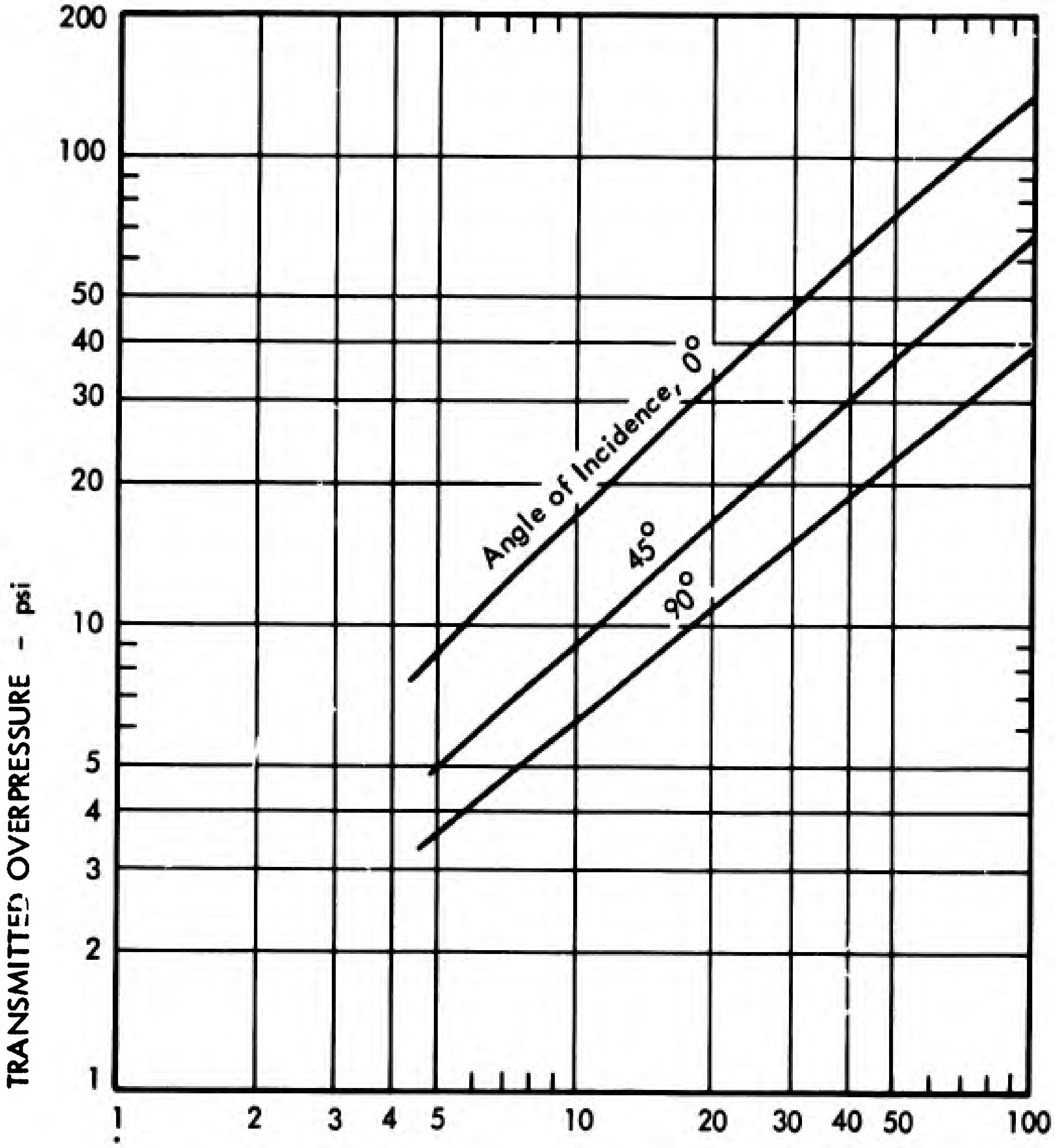
For this study, it was assumed that the blast wave characteristics could be calculated by standard procedures (Ref. 1 and 4) for ideal waves propagating radially outward over an ideal rigid reflecting surface and that the entranceway was located in the Mach region.

As discussed in Refs. 5 and 6, the loading of entranceway structures is a time function of the exterior loading, due to the interaction of the direct air blast and soil-transmitted dynamic loading with the structure, and the interior loading, due to the propagation of the air blast through the entranceway. The actual loading depends on the magnitude and duration of the air blast, as well as the orientation of the entranceway, the type and depth of soil, the response of the structure, the length of the corridor and the number of bends, and the location of blast doors.

Although there has been considerable research conducted in recent years to investigate the transmission of blast waves into tunnels (e.g., Refs. 7-14) available information for guidance in the design of entranceways is limited. For this study, it was sufficient to use the general procedure outlined in Ref. 5 to determine the loading on the blast shelter entranceways. However, the information from Refs. 6 and 7, which is reproduced on Figure 1, was used to determine the strength of the diffracted shock front within the entranceway.

Several factors should be mentioned concerning the influence of the location of blast doors on air blast loading in entranceways. It is obvious that a door mounted horizontally in the same plane as the ground surface would be subjected to the same pressure-time distribution as the side-on overpressure. However, for vertically mounted doors, the determination of the loading is much more complex, since the location of the door and the entranceway configuration can substantially modify both the magnitude and duration of the blast loading. The loading on doors exposed aboveground can be determined for classical air shocks by conventional techniques and depends on the orientation of the door with respect to the direction of wave propagation, the magnitude of the air blast, and the size of the reflecting surface. For doors mounted within the entranceway, the peak pressure of the air blast entering the entranceway will be attenuated in a manner indicated by Figure 1. However, since reflection of the shock front will occur in closed tunnels, the location of the door can result in considerable difference in the air blast loading on the door and on the interior surfaces of the entranceway.

Unfortunately, because of the complex behavior of shock waves in geometries such as entranceways, both the magnitude and duration of the reflected pulse are subject to uncertainty. Because of the unknowns involved, limited nuclear field test data were used in Ref. 5 on which to



INCIDENT OVERPRESSURE - psi

Figure 1

INCIDENT OVERPRESSURE VERSUS
OVERPRESSURE TRANSMITTED INTO TUNNELS

SOURCES: Refs. 6 and 7.

base the recommendation that it would be conservative to assume that blast closures in tunnels would be subjected to an infinite duration step pulse with a maximum pressure equal to twice the free-field side-on overpressure. However, for the limited cases considered in this study, it was assumed that the magnitude of the blast wave entering the entranceway could be obtained from Figure 1 and that the reflected pressure could be calculated by assuming regular reflection at normal incidence. For blast doors located close to the entrance opening, the clearing time of the reflected peak pressure was determined in the usual manner (Ref. 1), whereas for doors located within the entranceway, it was assumed that the duration of the reflected peak was infinite when compared with the natural frequency of the structural members.

Initial Radiation

Although considerable research effort has been expended in recent years to study the penetration of initial nuclear radiations through openings in protective structures (e.g., Refs. 15-19), definitive radiation analysis procedures applicable to entranceways are lacking. Therefore, for the purpose of determining the adequacy of entranceways for providing protection against the initial radiation for this investigation, the simplified method as outlined in Refs. 5 and 6 was used. Although it was not the purpose of this program to investigate nuclear radiation, a summary of the method used is presented in Appendix 1, since it may be useful for preliminary design purposes or where a computer program such as discussed in Ref. 17 is unavailable. For a more detailed discussion of the problems encountered in entranceway shielding, the reader should consult Refs. 5, 6, and 19. There is no intent to judge or endorse the validity of the method, since the primary use in this study was to provide a check of the radiation protection of the entranceway for cost studies and not to evaluate various procedures. However, considering the state of knowledge as published in the current literature and the many variables connected with weapon yield and type, possible burst location, and entranceway orientation, it appears that the simplified method may provide reasonable accuracy for many civil defense design purposes.

In this study, a consideration of the initial radiation from a 200-kt weapon yield at the lower overpressure levels resulted in only a small increase in the cost of the basic blast shelter entranceways. However, for higher overpressures or smaller yields, the initial radiation can be a controlling cost parameter for entranceways. Although not investigated, consideration should be given in these cases to the influence of both the permissible radiation dose for shelterees and the spatial distribution in the shelter of the radiation streaming through the entranceway. At present, it is usual design practice to ensure that the entranceway radiation does not exceed a safe level at the point of entry into the shelter. Although this is justified on the basis of the unknowns involved and was felt to be adequate for the designs prepared herein, it is apparent that the shelter provides space, distance, walls, roof, floor, and interior mass that can result in additional spreading and attenuation of the radiation entering through the entranceway. Unfortunately, the total influence of the attenuation inside the shelter on the permissible dose of the shelterees needs additional investigation before its effect on entranceway design and cost can be determined sufficiently for comparisons to be made between the various types of entranceways.

Fallout Radiation

The current standard methodology employed for the analysis of civil defense shelters for fallout radiation is given in Ref. 20. The determination of the adequacy of a shelter entranceway for providing fallout radiation protection depends on the reduction of the accumulated free-field radiation dose through the entranceway and the maximum permissible dose inside the shelter. For a specific entranceway problem, where the free-field radiation and the permissible dose are both known, the required entranceway attenuation can be calculated. However, for a general examination of only the entranceway portion of the shelter system, it is necessary to establish a basis for comparison. Since the ability of a shelter to reduce the fallout radiation intensity is usually expressed as a protection factor, the PF was adopted as a measure of the fallout radiation penetrating the entranceway system. Although the fallout radiation analysis procedures presented in Ref. 20 are applicable to shelter systems, several innovations were necessary for application of the methods to entranceway structures. These are discussed, together with pertinent illustrative examples, in Appendix 2.

Another factor that could not be properly evaluated for this study was the ingress of fallout particles into the entranceway structure and the assurance that management control would provide for a postattack washdown to reduce the radiation hazard. Therefore, a particulate trap was included in the design and cost for most of the underground shelter entranceways at the bottom of the stairs to prevent the ingress of fallout material into the shelter proper. For the fallout radiation calculations, it was assumed that no washdown was accomplished and that the radiation particles that entered the entrance opening were uniformly distributed over an area equal to the horizontal projection of the stairs and particulate trap. It is obvious that a washdown of the trap would increase the PF significantly over those calculated herein.

For the underground shelter entranceways in Appendix 3, the PF was found to be in excess of 210 (generally much higher) at a detector located 3 ft from the entry door inside the shelter at a height of 3 ft above the floor. For the aboveground shelter entranceways, the PF provided by the entranceway was in excess of that provided by assuming that a solid wall replaced the entranceway opening.

Thermal Radiation

The effect of thermal radiation and secondary fires from nuclear weapons on shelters and shelterees has received considerable attention in recent years. Although the problems of fire and the transmission of heat through entranceways could be an important parameter, its influence on entranceway design and cost could not be included in this study because of a lack of definitive information. However, for the cost estimates in this study, the cost of the blast doors included the impregnation of a chemical fire retardant, and all other entry doors were of the hollow metal type with a fire rating of three hours. As noted in Refs. 21-24, the problem of direct thermal induced fires and secondary ignited fires are of primary importance in shelter design. Since recommended design procedures are not available at the present time, the problem of fire on entranceways and the possible cost of providing adequate protection against heat transmission through the entranceway was not considered directly in this initial program.

Entranceway Orientation

The orientation of the entrance opening relative to a nuclear detonation is an important factor in determining the magnitude of the air blast loading and the attenuation of the initial radiation streaming through the entranceway. Since the location of a nuclear attack cannot be determined with a high degree of reliability, it is usually recommended to design for the worst orientation for both the air blast and the initial radiation. In most instances, this results in several assumed weapon locations for a single design problem. For the underground blast shelter entranceways in this study, it was found sufficient to consider two weapon locations for determining the worst case orientation for the air blast loading. The worst orientation for the L-shaped entranceways was that of a direction of wave propagation parallel to the axis of the entrance opening. However, for the tee-shaped entranceways with dual stairs, it was found that the worst orientation was that of a direction of wave propagation normal to the axis of the entrance stairs. Although the blast wave for this case is attenuated by diffraction through a 90 degree angle upon entering the two entrance sections, the reflection of the interacting shock fronts at the tee results in the highest door loading.

The hazard from the initial radiation streaming through an entranceway depends on the free-field radiation intensity and the angle between the burst location and the longitudinal axis of the first section of the entranceway as shown on Figure 1-2 in Appendix 1. Therefore, the burst orientation that optimizes the hazard for either function may not produce the maximum hazard. Both Refs. 5 and 6 conclude that the worst case orientation for initial radiation streaming is generally considered to be for a burst located on the line of sight along the longitudinal axis of the entrance section. However, as noted in Appendix 1 for the limited cases investigated herein, the worst orientation was found to be for a grazing line of sight between the top step of the entranceway and a point located at the first bend in the entranceway.

Entranceway Configuration

Usually, several possible geometries are available to the designer for the selection of an appropriate entranceway configuration to meet the requirements of a particular problem. From a preliminary examination of the referenced documents, it was found that there were a number of different types of underground entranceways that have been variously categorized as straight line, angle, Z, U, tee, interior and exterior stairwell, ramp, slide, ladder, and so forth. Generally, to assist in the selection of acceptable types of configurations for a specific entranceway system, the designer considers certain known constraints, such as the shelter system design, shelter location and environment within the city, and the type of shelter population. These, in turn, assist in defining such design inputs as the overpressure level, initial radiation intensity, aboveground or underground location, and code requirements. However, for the more general applications in this study, where definitive input data were not available, it was necessary to establish a limited number of basic entranceway types from which meaningful cost data could be developed that would reflect current design concepts. Therefore, the approach adopted was to select from among all possible configurations those believed to be the most appropriate for wide civil defense application and to determine the cost of various size (i.e., loading capacities) entranceways for each configuration. The following 10 basic configurations were considered for detailed investigation:

1. Underground entranceway types.
    a. Straight line--reinforced concrete.
    b. Single stair, 90° angle--reinforced concrete and steel pipe.

    c. Dual stair tee--reinforced concrete.
    d. Open exterior stairwell--reinforced concrete.
    e. Covered exterior stairwell--reinforced concrete.
    f. Covered interior stairwell--reinforced concrete.
    g. Circular stair--steel pipe.
    h. Ramp--reinforced concrete.

2. Aboveground entranceway type.
    a. With basement--reinforced concrete.
    b. Without basement--reinforced concrete.

Entranceway Elements

Many factors enter into the final selection of individual entranceway elements. For instance, it is obvious that the size and number of entranceways required for any shelter system are influenced or controlled by the total shelter population and the time available for loading. However, the capacity and cost of an individual entranceway is controlled by the design of its elements, which in turn are influenced by the design and fire codes, aboveground or underground shelter location, type of material, and so forth. The dimensions of the entranceway elements and their loading capacities for protective shelters has been treated in a number of reports (e.g., Refs. 5, 6, and 25) which reviewed the available experimental information on the movement of people through doors, corridors, and stairs under various conditions. Unfortunately, however, there is no definitive information available on the size of elements in relationship to the actual movement of people through entranceways into civil defense shelters under emergency conditions. In general, there has been agreement among past entranceway studies in the dimensioning of the stair, corridor, and door elements and in adopting the unit of exit width concept* from the NFPA

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* The unit of exit width concept is defined as the space necessary for the free passage of one file of persons and is an important concept of the Building Exits Code of the NFPA. Elements of exits are described as one-unit, two-unit, or more, where one unit of exit width is specified as 22 in. subject to minor deductions. Fractions of a unit of exit width are not counted in measuring the units, except that 12 in. is counted as one-half unit, since it increases the flow of people by permitting an intermediate staggered flow (Ref. 26).

(National Fire Protection Association). However, due to both the limitations and interpretations of the limited experimental data on the rate of movement of people through entranceways for emergency shelters, there is a variation in the design loading capacity assigned to the unit of exit width, as indicated in the summary in Table 4.

Table 4

CAPACITY OF ENTRANCEWAY ELEMENTS

Source	Capacity (persons/min/exit unit width) Horizontal Exit Average	Horizontal Exit Peak	Descending Stairs Average	Descending Stairs Peak
Ref. 5	50	70	40	60
Ref. 25	50	70	--	80
Ref. 6	50	--	50	--
Ref. 26	60	--	45	--

Because of the general nature of this investigation, the provisions of the Building Exits Code of the NFPA (Ref. 26) were adopted for the dimensioning of the entranceway elements, as well as the determination of the loading capacities. The rates recommended by the Building Exits Code are based on information on the egress, rather than on the ingress, of people from buildings under fire emergency conditions, and it is therefore well to keep in mind the following appropriate statement from Ref. 5:

> However it must be noted that the exit codes were developed to enforce the safety of human traffic moving outward from the fire risk or threat generated in a crowded interior to the relative safety of the outdoors. The exit codes therefore imply a lack of traffic restraint beyond the exit bottleneck. Precisely the opposite situation exists in the shelter case since traffic will flow from the unrestricted open into the relatively congested conditions of the shelter and one must assume some feedback affecting traffic in the entrance system.

Nevertheless, because of the lack of definite information applicable to civil defense and because the code recommendations are based on the best data available and are within the range of other reported data, the

Building Exits Code was adopted for the entranceway designs in this report. In any event, the accuracy of the code traffic rates when applied to civil defense use is probably better than other important assumptions, such as the rate of arrival of shelterees at the entranceway.

Although there are limitations on the minimum and maximum width of exit elements permitted by the Building Exits Code, the basic criterion for the capacity of a single unit of exit width of 22 in. is 45 persons/min for stairs and 60 persons/min for corridors and doors. For the shelter entranceway designs in this study, the dimensions for the various elements, together with the rated loading capacities, are summarized in Table 5. In general, when designing an individual entranceway an attempt was made to size the various elements to provide a balance between the capacities. The capacities noted on the table are compatible for stairs with a maximum riser height of 7-3/4 in. and a tread width of 9-1/2 in., which meet the requirements in the code for a Class B stairs for new construction. Other applicable code requirements are discussed in the next subsection.

The primary construction materials considered for the elements of the permanent type of entranceways in this study were reinforced concrete and steel. Entranceways constructed of timber, sand bags, or mortarless masonry, while appropriate for expedient type shelters (Ref. 27), were not included.

Code Requirements

The question of whether the construction of civil defense emergency type shelters would be required to meet the local building and fire codes is beyond the scope of this study. However, since situations will occur, such as dual occupancy where code conformity will probably be required and since the relaxing of code requirements for single purpose emergency shelters is an uncertain factor, both code and noncode entranceways were included in this investigation. In addition to the code requirements mentioned in the previous subsection, there are numerous sections of the Building Exits Code (Ref. 26) applicable to the design of entranceways. A few of the more important influencing code requirements are:

1. Emergency shelters for more than 10 persons require at least two separate means of exit.

2. The minimum nominal doorway width is 30 in.

3. The maximum single door width is 48 in. and the minimum single opening width for multiple doors is 28 in.

Table 5

DIMENSIONS OF ENTRANCEWAY ELEMENTS

Element	Height	Nominal Width	Units of Exit Width	Capacity (persons/min)
Stair	7'-0"	2'-6"	1	45
	7'-0"	3'-0"	1½	67
	7'-0"	3'-8"	2	90
	7'-0"	4'-8"	2½	112
	7'-0"	5'-6"	3	135
	8'-0"	7'-4"	4	180
Door	6'-8"	2'-6"	1	60
	6'-8"	3'-0"	1½	90
	6'-8"	3'-8"	2	120
	6'-8"	4'-8"*	2½	150
	6'-8"	5'-6"*	3	180
	6'-8"	7'-4"*	4	240
Corridor	7'-0"	2'-6"	1	60
	7'-0"	3'-0"	1½	90
	7'-0"	3'-8"	2	120
	7'-0"	4'-8"	2½	150
	7'-0"	5'-6"	3	180
	8'-0"	7'-4"	4	240

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* Widest single door is 4'-0", Ref. 26.

4. All doors will swing with the exit travel.

5. Panic hardware devices required for doors for places of assembly of more than 500 persons.

6. The minimum width of stairs is 44 in., except for stairs serving less than 50 persons where 36 in. is permissible.

7. The maximum height between landings is 12 ft.

8. The minimum dimensions of landings in direction of travel is 44 in.

9. All new stairs are to be of noncombustible construction.

10. There is to be no decrease in the width of stairs or landings in the direction of travel.

11. Doors on stairs require level landings on both sides.

12. All stairs require handrails on both sides, and intermediate handrails are required for stairway widths of 88 in. or more.

13. The minimum width for ramps is 30 in. and the maximum slope is 1 in 6 (16.66 percent) for a rated capacity of 45 persons/min/unit of exit width.

In addition to the above, there are several Building Exits Code (Ref. 26) requirements that could, if applicable, control the cost of entranceways for dual purpose and large [illegible] shelters classified as places of assembly:

1. The total number of persons that can be served by an exit unit width is 100 persons for level exits and 75 persons for stairs. This is based on an evacuation time of 1 min, 40 sec, exclusive of the time for the first person to reach exit and for the last person to reach a place of safety after entering the exit.

2. For places of assembly of over 1,000 person capacity, at least four separate exits are required.

3. For places of assembly of capacities between 200 and 1,000 persons, at least two separate exits are required, or if over 600 persons, at least three exits are required. Each exit must be of at least two exit unit widths.

For the purpose of this study, it was felt sufficient to account for the above requirements by including in the analysis the cost of entranceway systems with a 1 min, 40 sec loading time.

Structural Design

An investigation of current structural design procedures and their possible influence on entranceway cost was not considered an important parameter for study in this initial investigation. However, for the preparation of the cost data, it was necessary to calculate approximate member thicknesses and the percentage of steel reinforcement. For this purpose, the general dynamic design procedures in Ref. 2, and the application of these procedures to the design of specific entranceway elements in Ref. 5, together with the applicable sections of Ref. 28, were felt to be adequate.

As recommended in Ref. 5, to determine the structural resistance of reinforced concrete members for dynamic loading, a ductility factor of 3 and an increase in the yield strength of the steel reinforcement to 42,000 psi was used. Also, the flexural steel reinforcement was maintained at less than 2 percent to assure ductile behavior. For the design of timber blast doors, a ductility factor of 3 was used, together with an increase in the normal allowable unit stress by a factor of 4 for dynamic loading. Rebound resistance of the door during the dynamic loading was provided for by including in the cost sufficient dog-type latches to resist one-half the design overpressure loading. A simple gasket-type seal was sufficient for the low overpressures considered.

Blast Interlock System

A blast interlock system is often included in an entranceway so that late arrivals can enter the shelter during a button-up period without the risk of exposing the shelter occupants to air blast. The interlock concept has been used for various shelter system designs and can consist of a simple and inexpensive two blast door system, separated by a length of corridor. An interlock system can also consist of expensive multicorridor elements with elaborate automatic opening and closing devices that would not restrict the design traffic flow through the entranceway. Although the cost of interlock systems was not examined, if a high rate of entry were required during a button-up period, an elaborate interlock system would probably be the controlling entranceway cost parameter. On the other hand, if a high rate of entry were not required during button-up, it would probably be sufficient for most civil defense shelter systems to provide a blast interlock system on only one entranceway in a multiple entranceway system. Even for a relatively elaborate interlock system, the additional cost of blast interlock system for a single entranceway would probably not affect the total system cost significantly. For the blast shelter entranceway designs in this study, a blast interlock system was not included in the cost. However, as noted in the next section, if a relatively simple system was compatible with the shelter operational procedures, the additional cost of providing dual blast doors would not significantly alter the cost data for individual entranceways.

It seems feasible that an entranceway with an interlock system that restricts normal traffic flow could be assigned a dual capacity. One capacity rating could reflect the normal flow during periods when an attack was not imminent, and a lower capacity could reflect the flow during periods of button-up when the interlock was in use. By taking into account the higher rate of loading for a portion of the shelterees, the system could be optimized for minimum cost for any rate of arrival and attack assumptions.

Movement to Shelter

Included in the time of movement to shelter are many influencing factors, such as warning, reaction, and travel delay times, and age, number, and distribution of the population and its rate of movement. Because of the importance of the influence of these factors on the cost of entranceway systems, the movement of people to shelter is considered in some detail. The arrival time of shelterees at the entranceway is a primary input to any shelter system design. If, for instance, a leisurely loading time of several hours were available, factors other than the time rate of arrivals would probably control the entranceway design and cost. On the other hand, for short warning times, the arrival time may dictate the location of the shelter, as well as control the size, number, and cost of the entranceway system.

As far as the design of an entranceway system is concerned, it would be desirable if the effect of the movement of people could be expressed as the loading time available. Given a total shelter population and a loading time, it would not be necessary for a designer to be concerned with such complex influencing factors as the warning concept to be used, the movement of people, and the risk of a queue formation. The difficulty of this approach, however, is the determination of a total entranceway loading time that reflects a realistic arrival of shelterees that can be expressed as an average traffic rate. However, because of the lack of definitive information, it is usual when designing an entranceway for short warning times, such as 15 min, to assume that a five-min loading time is adequate for calculating the average entranceway capacity required. For instance, for a 1,000 person shelter and a five-min loading time, an entranceway capacity of 200 persons/min would be required. Since it is implicit in such a procedure that both the warning time and the rate of arrival at the shelter are well-defined parameters, it is of interest for cost analysis purposes to examine the available data on the movement of people to shelter. It may then be possible to use more realistic rates of arrival in an attempt to estimate the adequacy of the usual design procedures or to establish a more rational basis for estimating the required entranceway capacity.

A major problem in any shelter program is the determination of the movement of people to shelter after receiving warning. A discussion of various aspects of this problem is contained in Refs. 29 and 30, together with a review of the pertinent literature and the development of a mathematical model for estimating the time rate of arrival of the population at the shelter. In addition, Ref. 30 contains a demonstration of the effectiveness of the method in three cities. From a study of realistic shelter situations, it was found that in general no shelterees arrive at the shelter location within the first few minutes after warning. With increasing time, the shelterees arrive at an increasing rate until a maximum rate of arrival is reached, after which the rate decreases to zero. For purposes of illustrating the influence of the rate of arrival on the capacity of entranceways, the data in Ref. 30 were used to determine the number of entranceway lanes required for a hypothetical shelter situation. The method is based, essentially on the division of the area served by a shelter into concentric rings surrounding the shelter and requires assuming such factors as the population density and distribution, travel velocity and route, and departure time distribution. Ref. 30 also considers a hypothetical shelter located to serve a total population of 1,100 persons in a subarea of 0.239 square miles. The arrival at the entranceway of the population in the subarea is shown in Figure 2 for each minute of the assumed 15-min time available. This information is also presented in Table 6, together with the excess population (queue) for each minute for three possible entranceways: a four-lane design, a two-lane design, and a one-lane design. It was assumed that each lane had a capacity of 55 persons/min. It can be seen from Table 6 that to achieve a no queue situation, a five-lane entranceway would be required (275 divided by 55), and for each of the assumed entranceways, a queue would form at the shelter entranceway at some time during the 15-min arrival time. For the four-lane entranceway, the maximum additional exposure time resulting from the queue formation would be only one min for a relatively minor portion of the shelterees--an insignificant amount compared with a no queue situation. For the two-lane entranceway, although all persons would pass the

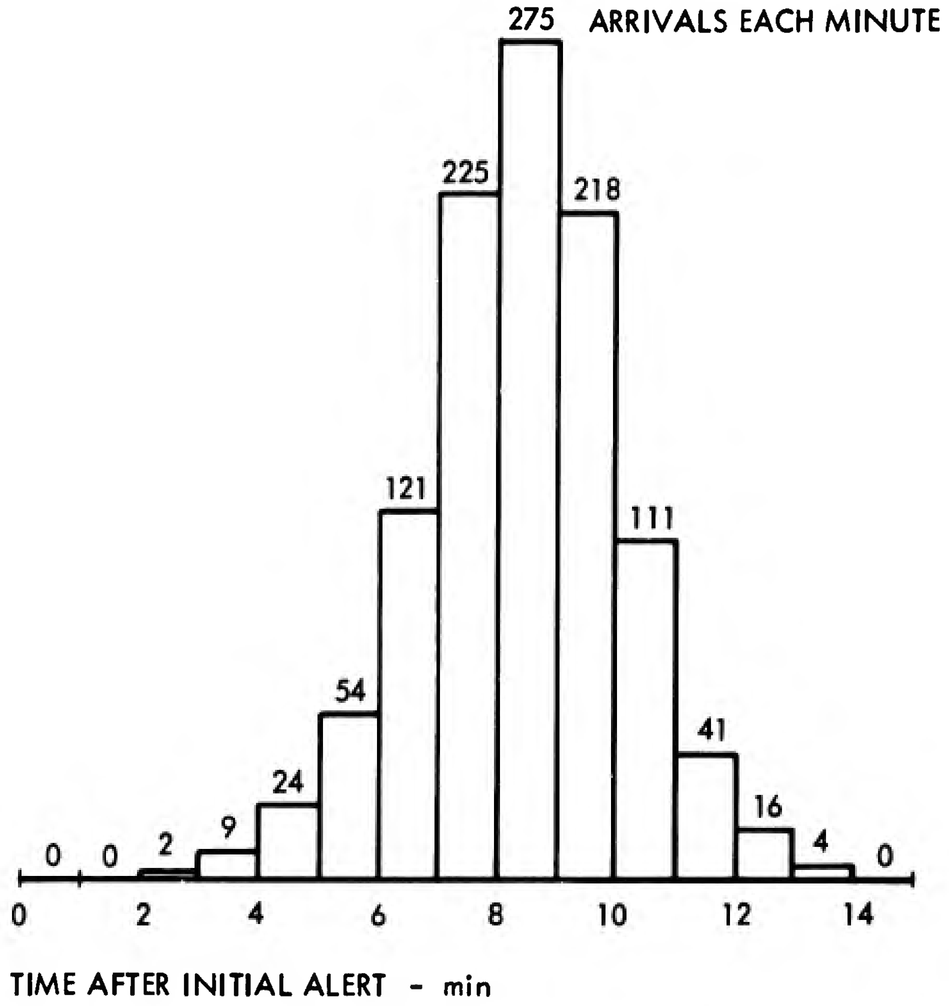

Figure 2

ARRIVALS AT SHELTER ENTRANCE FOR EACH MINUTE AFTER ALERT IN HYPOTHETICAL SITUATION

SOURCE: Ref. 30

Table 6

POPULATION ARRIVAL COMPARED WITH EXCESS AT ENTRANCE*

Time After Alert† (min)	Arrivals at Shelter† (no. each min)	Cumulative Excess Population at Entranceway (number each min) 4–Lane	2–Lane	1–Lane
1	0	0	0	0
2	0	0	0	0
3	2	0	0	0
4	9	0	0	0
5	24	0	0	0
6	54	0	0	0
7	121	0	11	66
8	225	5	126	236
9	275	60	291	456
10	218	58	399	619
11	111	0	400	675
12	41		331	661
13	16		237	622
14	4		131	571
15	0		21	516
16			0	461
17				406
18				351
19				296
20				241
21				186
22				131
23				76
24				21
25				0

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* Based on entrance traffic rate of 55 persons/min/lane.
† From Ref. 30.

entrance within the 15-min time interval, 679 of the 1,100 shelterees would be subjected to longer outside exposure times because of the queue formation, as shown in Table 7. For the one-lane entranceway, not only is the total time for entering the entranceway extended approximately ten min, but also some shelterees are exposed an additional 13 or 14 min after arrival time at the shelter. The exposure time of the total shelter population for the three situations is shown in Figure 3.

Table 7

ADDITIONAL EXPOSURE OF SHELTEREES FOR A 2-LANE AND 1-LANE ENTRANCEWAY

Additional Exposure* (min)	2-lane (number of persons)	1-lane (number of persons)
1-2	92	0
2-3	169	42
3-4	288	55
4-5	130	94
5-6		71
6-7		55
7-8		55
8-9		94
9-10		71
10-11		55
11-12		100
12-13		125
13-14		16

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* In excess of the exposure for the four-lane entranceway.

A decision on the optimum entranceway system for this simple hypothetical situation must consider many factors, such as the risk due to variation in exposure time and the cost differential among the various size entranceways. Even without the benefit of supporting studies, it

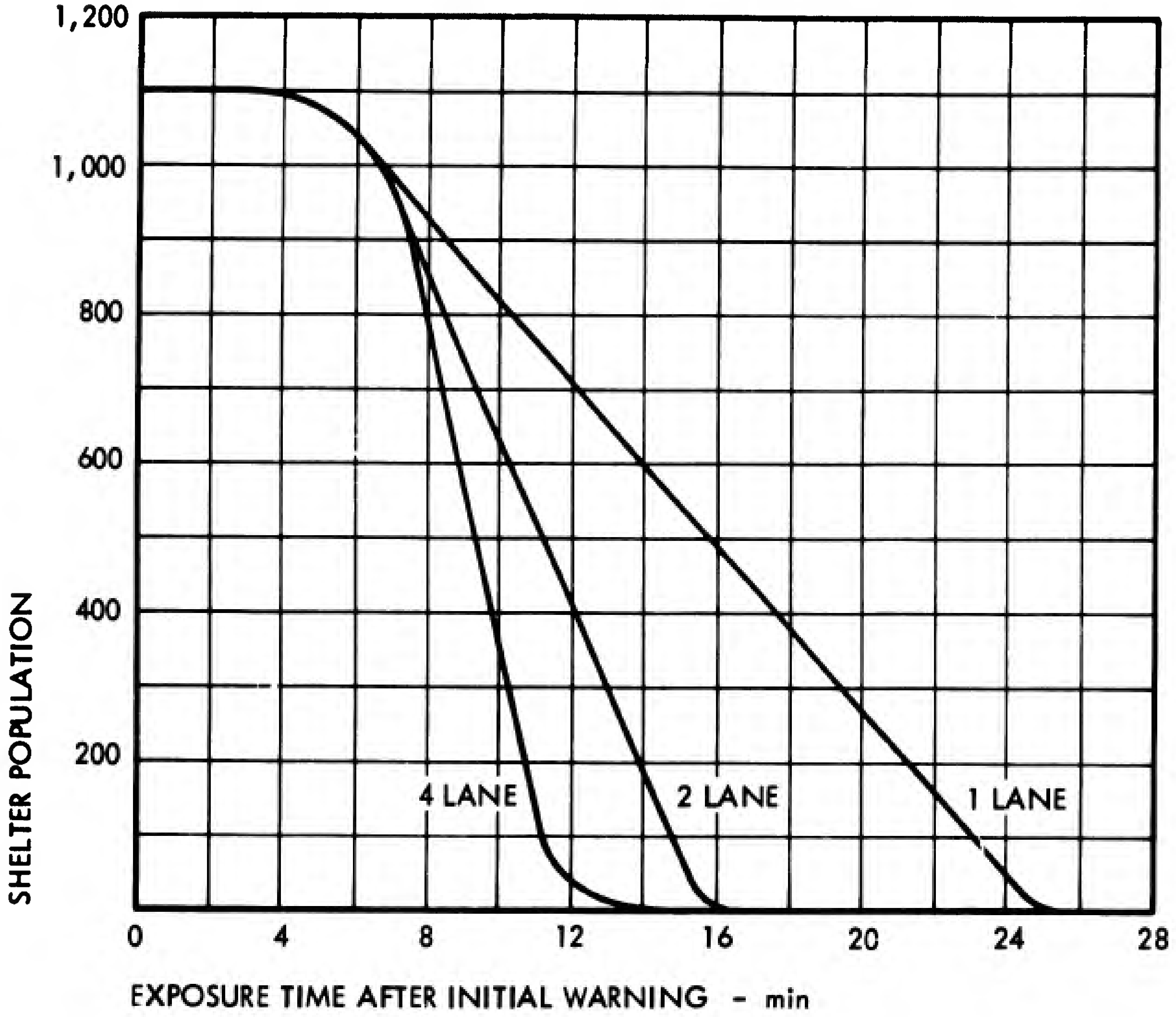

Figure 3

TIME OF EXPOSURE OF SHELTER POPULATION BETWEEN INITIAL WARNING AND TIME TO PASS THROUGH ENTRANCE would seem reasonable to conclude that the difference in cost between the two- and four-lane entranceways would be a more important factor in the final selection than the difference in the exposure time. However, it may well be, for a specific situation, that the risk of the additional exposure may be the controlling factor if the risk inherent in the 15-min arrival time is already at a maximum, and the additional cost of the larger entranceway may therefore be a minor consideration. The resolution of this problem for the particular hypothetical situation is not pertinent to the current study, since its primary purpose was to examine the possible effect of the rate of arrival on the cost of entranceways and to compare this with the usual design assumption based on an arbitrary available loading time. From this limited discussion of the movement of people to shelter, it can be concluded that for a general study of entranceways, meaningful cost information can be obtained by investigating the cost of entranceways with various numbers of traffic lanes and that for realistic rates of arrival, an important factor is the formation and dissipation of a queue in relationship to the time available.

The rate of arrival curves used in this study were developed from the data in Ref. 30 and are based on consideration of the ground level travel time of the population from an initial location to the shelter and an arbitrary departure time distribution. The travel time from the upper floors of buildings to the ground floor is not included explicitly. The importance of this factor is indicated by studies of the effect of population mobility on the location of shelters (Ref. 31). From limited experimental data, it was estimated that the emptying time of a typical multistory office building is approximately 1.3 min for each floor. That is, office buildings 2 to 11 stories high would require approximately 2.6 to 14.3 min to empty.

Other Factors

In addition to the factors discussed previously, there are others that warrant discussion. They were considered to a lesser degree in the study or excluded. These factors are discussed briefly below.

1. Although decontamination areas or equipment rooms are sometimes constructed within the entranceway structure, they were not included in the present study. A requirement for such areas would alter many of the cost estimates. However, the entranceway types such as the closed stairwell have areas beneath the stairs, but still within the stairwell, that could be used for other than storage space. For many of the other reinforced concrete types, areas beneath the stairs could probably be included in the design

at a nominal additional cost, although actual cost estimates were not performed to enable direct comparison.

2. For underground shelters, the entry of water, either rain or runoff, directly into the entranceway structure can be a major problem in some areas. For this study, water entry was not considered directly, except to include in the design and cost estimates a standard type of floor drain and sufficient pipe to connect the drain to an assumed existing shelter drainage system.

3. Site conditions such as location within the city, type and slope of terrain, shelter depth, soil conditions, building density and proximity, and exposure to weapons effects could influence selection, design, and cost of the entranceway system. Many of the values of these factors would be available for specific design problems, but they are difficult to include in an entranceway analysis in a general manner. However, since a number of different types of entranceways were included in this study, the cost information would assist in the selection of an entranceway system appropriate for the site and shelter conditions. A range of site conditions, however, was not considered directly except to assume that a fairly level terrain existed and to include entranceway types for aboveground shelters and underground shelters with a uniform depth of burial of 12 ft to the shelter floor line.

4. Another factor not considered in this study that could affect the cost of an individual entranceway would be the size of the shelter equipment and supplies that must be transported through the entranceway. Although this could affect the cost for a single entranceway system, it probably would not increase the cost of a multiple entranceway system for which an appropriate combination of entranceway sizes could be selected.

IV COST ANALYSIS

Introduction

Because of the lack of definitive cost data for entranceways of the type examined in this study and because detailed cost information was required to determine the cost differential due to variation of the factors discussed in the previous section, it was necessary to prepare detailed designs and cost estimates for individual entranceways. To select the entranceways for further study from among the numerous possible types, emphasis was placed on those types of civil defense shelter entranceways that were appropriate for use by the general public. Although the primary interest was on entranceways for single purpose shelters, the design and cost data are applicable to many dual purpose type shelters, such as schools, community recreation structures, or operational centers, if all applicable codes are considered. The data would not be applicable to such dual purpose structures as underground parking garages or department store basements where large openings exist. However, even in these cases, the cost data would be applicable for situations where separate pedestrian entranceways were provided for emergency use.

In general, the procedure used was to (1) select an appropriate entranceway configuration; (2) perform a preliminary structural design to obtain the approximate size and strength requirements; (3) determine the adequacy of the entranceway for providing fallout radiation protection, or, if required, initial radiation protection; (4) modify the original dimensions if necessary to meet the minimum radiation requirements; and (5) make a detailed construction cost estimate.

Entranceway Design

On the basis of the information presented in the previous section, designs were prepared for 36 individual entranceways and 2 escape exits as shown in Appendix 3. Conventional static design procedures were used in the preliminary design to determine the member size for the fallout shelter entranceways. For the blast shelter entranceways, the dynamic design techniques presented in Refs. 2 and 5 were used. Since the structural designs were required primarily to determine the approximate member size for cost estimating purposes, simplified procedures were employed wherever applicable since the total entranceway cost is not appreciably influenced by small variations in material thickness or the percent of reinforcement steel. After selection of an entranceway configuration, designs were prepared for various capacities to determine the effect on the cost of increasing entranceway capacity, e.g., for Type A, the design capacities ranged from 45 to 180 persons/min and for Type B from 120 to 270 persons/min. To prepare designs for only the entranceway portion of a shelter system required certain assumptions concerning the shelter proper. For convenience, the underground shelters were assumed to be rectangular reinforced concrete structures with 1-ft thick walls, roofs, and floors. With an 8-ft interior height and a 3-ft soil cover, the shelter floor line was 12 ft below grade. For the aboveground shelter, the configuration presented in Ref. 32 for a dual purpose community fallout shelter was used.

After completion of the structural design, a fallout radiation analysis was performed on each entranceway as required, and in accordance with the discussion in Section III and Appendix 2. In general, the PF was found to be in excess of 210 at a detector located 3 ft from the entry door inside the shelter at a height of 3 ft above the floor. For the blast shelter entranceways, it was also necessary to determine the penetration of initial radiation through the entranceway. For this analysis, the method outlined in Appendix 1 was used. The total initial radiation dose at a point located at a height of 3 ft in the plane of the entry into the shelter was found to be a maximum of about 12 rads for a 200 kt weapon yield at the 20 psi overpressure level.

Cost Estimates

After determination of the adequacy of the entranceway for protection against radiation as noted in Appendixes 1 and 2 for each design configuration, a construction cost estimate was prepared for each entranceway. The cost estimates were performed by a single experienced estimator to assure uniformity and consistency among the various entranceway configurations. The cost estimates were prepared by methods usually employed by construction contractors and is referred to as the "Quantity and Cost or Materials and Labor Method" in Ref. 33. The estimates reflect construction costs in the San Francisco Bay Area during the spring of 1967. They include all materials and labor costs, labor burden, and contractors profit. They do not include such costs as the preconstruction costs, finance costs, operating and maintenance costs, or government costs (Ref. 33).* The details

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* Preconstruction costs are defined in Ref. 33 as costs related to program development, preliminary and final design, and site acquisition. The government costs include costs such as administration and supervision of the shelter program, shelter surveys, and purchasing and distribution of shelter supplies, training, and shelter management.

of the cost breakdown for the 36 entranceways and 2 escape exits presented in Appendix 4 are summarized in Tables 8, 9, and 10. For convenience in the cost analysis, the entranceways and exits have been arranged in the 14 categories, or types, noted in the tables. Although it would have been desirable to prepare designs and cost estimates for a range of capacities for all 36 entranceways, it was not possible during this initial program to investigate a range of capacities for entranceway Types F through I.

In the cost estimates, no allowance was made for those entranceways that required additional shelter space or that provided additional storage capacity. For instance, for the cost estimate for the interior covered stairwell, Type C, it was assumed that the costs of exterior walls and the floor of the shelter in the vicinity of the stairwell were basic shelter costs and were not chargeable to the entranceway construction costs. To provide a specified shelter floor area, it would be necessary to increase the shelter area to accommodate the interior stairwell. On the other hand, no cost consideration was given to the additional storage or equipment space provided beneath the stairs.

Cost Analysis

The information presented in Tables 8 to 10, although limited, illustrates several important factors concerning the value of valid cost data for entranceways for civil defense shelters. First, the data permit a designer or systems analyst to make a rapid comparison between the relative costs of a fairly wide selection of basic types of entranceway configurations. For example, for an underground fallout shelter, a reinforced concrete single stair entranceway (No. A-1) is considerably less expensive than a circular steel pipe single stair (No. H-1) for an entranceway capacity of 67 persons/min. Although cost estimates were not obtained for a complete range of capacities for every type of entranceway shown in the tables, the relative costs of entranceways does not generally change significantly with increasing capacity. That is, for the above example, the circular steel pipe type of entranceway would probably be more expensive than the reinforced concrete entranceway for all capacities.

In addition, where cost estimates were developed for a wide range of capacities for a specific entranceway configuration, the data can be used to obtain information on the total cost of an entranceway system for any required capacity. The importance of such information was apparent from the review in the previous section of the influence of the movement of people on the required entranceway capacity. In this study, where only one component of the shelter system was investigated, it was not possible to

Table 8

SUMMARY OF CONSTRUCTION COST ESTIMATES FOR UNDERGROUND FALLOUT SHELTER ENTRANCEWAYS

Number	Description	Capacity (persons/ min)	Total Cost (dollars)	Cost/ Person/ Min (dollars)
A-1	Reinforced concrete, single stair	67	$3,429	$ 51.18
A-2	Reinforced concrete, single stair	90	3,814	42.38
A-3	Reinforced concrete, single stair	112	4,175	37.28
A-4	Reinforced concrete, single stair	120	4,375	36.46
A-5	Reinforced concrete, single stair	180	5,559	30.88
A-6	Reinforced concrete, single stair	45	2,575	57.22
A-7	Reinforced concrete, single stair	90	3,046	33.84
B-1	Reinforced concrete, dual stair	120	5,812	48.43
B-2	Reinforced concrete, dual stair	135	6,363	47.13
B-3	Reinforced concrete, dual stair	180	6,633	36.85
B-4	Reinforced concrete, dual stair	225	6,970	30.98
B-5	Reinforced concrete, dual stair	270	7,888	29.21
C-1	Reinforced concrete, covered stairwell, interior location	90	3,590	39.89
C-2	Reinforced concrete, covered stairwell, interior location	120	4,438	36.98
C-3	Reinforced concrete, covered stairwell, interior location	180	6,250	34.72
D-1	Reinforced concrete, open stairwell, precast concrete stairs	67	3,099	46.25
D-2	Reinforced concrete, open stairwell, precast concrete stairs	90	3,451	38.34
D-3	Reinforced concrete, open stairwell, precast concrete stairs	120	5,043	42.03
D-4	Reinforced concrete, open stairwell, precast concrete stairs	180	7,245	40.25
D-1A	Reinforced concrete, open stairwell, steel stairs	67	4,003	59.75
D-1B	Reinforced concrete, open stairwell, wood stairs	67	2,858	42.66
E-1	Reinforced concrete escape exit	--	774	--
F-1	Reinforced concrete, covered stairwell, exterior location	90	3,952	43.91
G-1	Circular steel pipe, vertical orientation	22	3,774	171.55
G-2	Circular steel pipe, vertical orientation	45	4,432	98.49
H-1	Circular steel pipe, single stair	67	5,249	78.34
I-1	Reinforced concrete class "C" ramp	67	6,383	95.27

Table 9

SUMMARY OF CONSTRUCTION COST ESTIMATES FOR UNDERGROUND BLAST SHELTER ENTRANCEWAYS

Number	Description	Capacity (persons/ min)	Total Cost (dollars)	Cost/ Person/ Min (dollars)
J-1	Reinforced concrete, single stair	90	$4,943	$54.92
J-2	Reinforced concrete, single stair	120	6,478	53.98
J-3	Reinforced concrete, single stair	90	4,869	54.10
J-4	Reinforced concrete, single stair	90	5,883	65.37
K-1	Reinforced concrete, dual stair	180	7,410	41.17
K-2	Reinforced concrete, dual stair	225	8,328	37.01

Table 10

SUMMARY OF CONSTRUCTION COST ESTIMATES FOR ABOVEGROUND FALLOUT SHELTER ENTRANCEWAYS

Number	Description	Capacity (persons/ min)	Total Cost (dollars)	Cost Person/ Min (dollars)
L-1	Reinforced concrete, without basement	120	$1,784	$14.87
L-2	Reinforced concrete, without basement	180	2,420	13.44
L-3	Reinforced concrete, without basement	240	3,031	12.63
M-1	Reinforced concrete, with basement	120	3,579	29.83
M-2	Reinforced concrete, with basement	180	4,254	23.63
M-3	Reinforced concrete, with basement	240	5,439	22.66
N-1	Reinforced concrete escape exit	--	732	--

determine entranceway capacities for specific shelter systems and warning times beforehand. Therefore, the following range of loading capacities was considered: a 1-min 40-sec loading time to conform with the evacuation time in the Building Exits Code (Ref. 26), a 5-min loading time based on an average entranceway capacity, and 15- and 60-min times of arrival based on a more realistic rate of arrival of shelterees. Even though these are representative for many civil defense purposes, it was felt that the development of more general entranceway capacity and cost data would be justified, since such information could be applied to any situation where the design configurations were applicable. Therefore, the data in Tables 8 to 10 for individual entranceways were used to establish the total entranceway cost for capacities up to 1,000 persons/min for the following six types of entranceways:

1. Underground shelter entranceways, reinforced concrete.
    a. Single and dual stair, fallout (Types A and B)
    b. Covered stairwell, interior location, fallout (Type C)
    c. Open stairwell, exterior location, fallout (Type D)
    d. Single and dual stair, fallout plus direct effects (20 psi) (Type J and K)
2. Aboveground shelter entranceways, reinforced concrete.
    a. Surface entranceway, no basement, fallout (Type L)
    b. Surface entranceway, with basement, fallout (Type M)

As shown in Tables 8 to 10 for any particular type of entranceway, cost of an entranceway, on a dollars/person/min basis, generally decreases with increasing size. As shown in Appendix 4, for the entranceway types considered, this trend reaches a minimum at entranceway capacities of approximately 200 to 250 persons/min. This indicates that although larger entranceways are less expensive on a cost per unit capacity basis, <u>there is a capacity for a single type beyond which there is no further cost advantage for increasing size</u>. This information was useful in establishing the maximum size for design purposes and in the construction of the total entranceway cost-capacity curves shown in Figure 4 for the above six types of entranceways. The limitations of these data and the method used to develop the cost curves are explained in detail in Appendix 4. Briefly, however, to obtain the curves shown in the figure, an examination was made of the total cost of numerous combinations of entranceways for each type. From this information, it was possible to select the combination of entranceways that yielded the minimum cost for any particular entranceway capacity. Also, the entranceway cost data shown in the tables increase in finite steps because of the requirement for a minimum change in entranceway width of one-half the exit unit width. However, since a step function is difficult to use in most analytical procedures, and because of the probable differences inherent in estimating construction costs, it was felt that the information would be more meaningful if an averaging technique was used to obtain a continuous function. This was accomplished by employing a standard SRI computer regression program that yielded the equations presented in Table 11, which were then plotted on Figure 4. The equations shown

Table 11

ENTRANCEWAY COST EQUATIONS

Type	Description	Equation
Underground fallout shelter entranceway		
A & B	Reinforced concrete, single and dual stair	$C = 28.5R + 1680$
C	Reinforced concrete, covered stairwell, interior location	$C = 34.3R + 1320$
D	Reinforced concrete, open stairwell, exterior location	$C = 39.9R + 640$
Underground blast shelter entranceway		
J & K	Reinforced concrete, single and dual stair	$C = 37.1R + 2270$
Aboveground fallout shelter entranceway		
L	Reinforced concrete, without basement	$C = 12.0R + 1020$
M	Reinforced concrete, with basement	$C = 21.1R + 2080$

Notes: C = Total cost entranceway in dollars.
R = Capacity in persons/min through the entranceway.
See Appendix 4 for development of entranceway cost data.

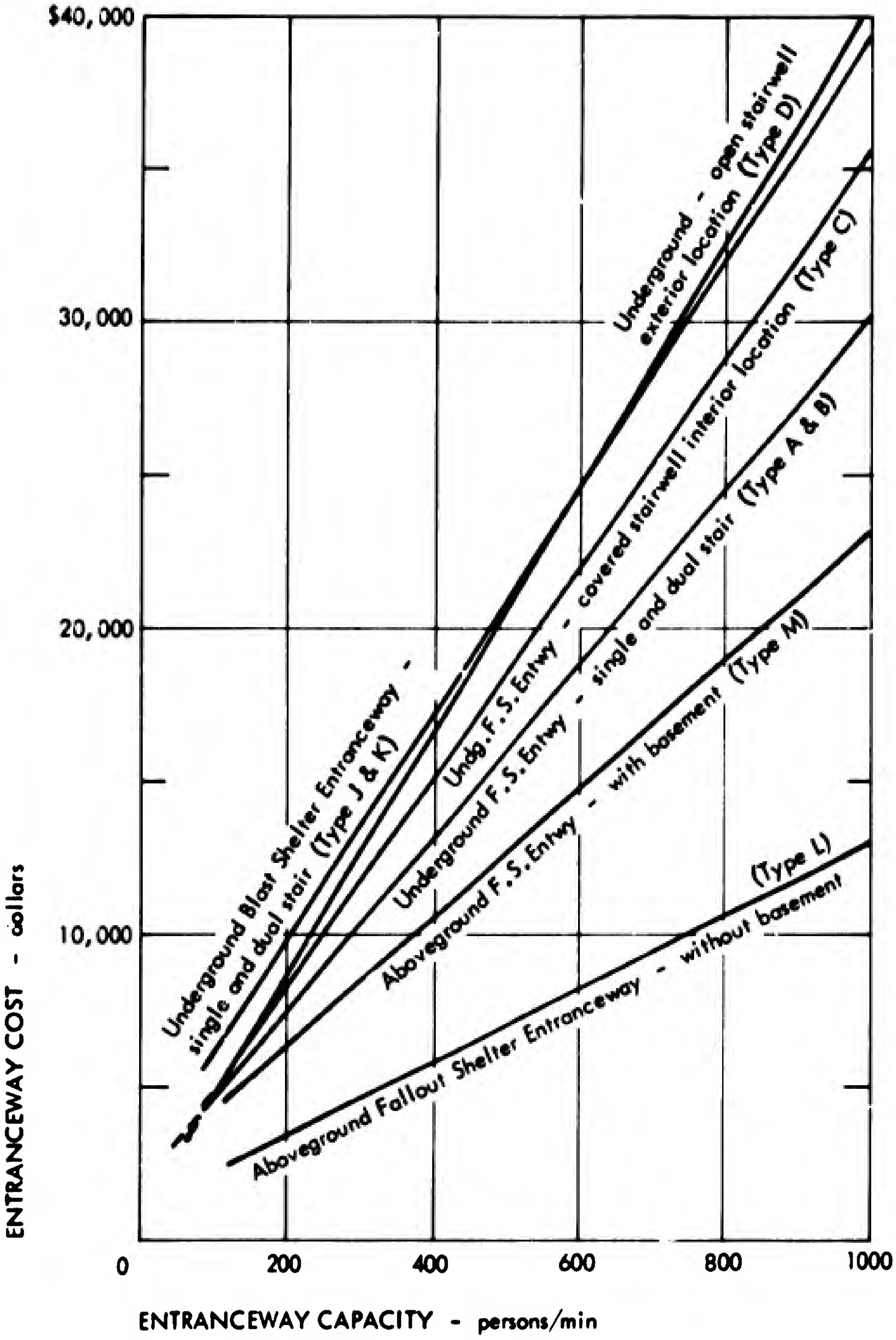

Figure 4

ENTRANCEWAY TOTAL COST VERSUS CAPACITY FOR REINFORCED CONCRETE ENTRANCEWAYS represent the best least squares fit to the straight line through all the data, and therefore, the sum of a combination of entranceways shown in Tables 8 to 10 may not necessarily be equal to that from the equations. However, this error is probably much less than the error in the original cost estimates. As a matter of interest, the best fit to the quadratic equation through all the data was also obtained, but the slight improvement in fit does not warrant the use of the more complex functions (see Appendix 4, Figure 4-4).

Before an investigation of the influence of the four assumed entranceway loading capacity conditions on the cost of the entranceways for 500 and 1,000 person shelters, it was first necessary to determine a realistic rate of arrival of the shelterees, as noted in the previous section on the movement of people to shelter. Since this investigation was not actually concerned with the movement of people, the arrival time curves were developed from the available published information. For this purpose, the data from Ref. 30 for a 30-min time of arrival was replotted assuming a directly proportional relationship between the 30-min and the selected 15- and 60-min arrival times. The percent cumulative arrivals, calculated in this manner, are shown in Figure 5 for both arrival times. To develop these curves, it was assumed for the 15-min arrival time that no shelterees arrived for the first 2 min and that all had arrived by the end of 14 min. For the 60-min arrival time, it was assumed that no shelterees arrived for 5 min and that all had arrived by the end of 55 min. The percent cumulative arrival figures were then used to obtain the number of persons arriving each min after the alert for both a 500- and a 1,000-person shelter. Figure 6 shows that the maximum rate of arrivals for the 1,000 person shelter is 250 persons/min for the 15-min arrival time and 62 persons/min for the 60-min arrival time. For the 500 person shelter, these rates would be 125 and 31 persons/min, respectively.

It was not within the scope of this investigation to determine the validity of the above method; however, the method is based on a rational approach to the problem of the arrival of shelterees and the generic shape of the curves appear realistic. In fact, when the curves were compared on a common basis with the data in Ref. 34 for a case study of Albuquerque, it was found that the curves were similar in shape, but that the data from Ref. 30 resulted in a somewhat higher peak rate of arrival due to a higher assumed travel velocity. However, the important factor is not necessarily the peak rate, but rather that the time distribution of the rate of arrival exhibit a behavior similar to that indicated on Figure 5. As noted in the hypothetical example in the previous section, this would permit an entranceway to be designed for a capacity less than the peak rate of arrival, and still dissipate the queue within the assumed available warning time. It is apparent that various assumptions on movement of people would result in different rates of queue formation and dissipation within any

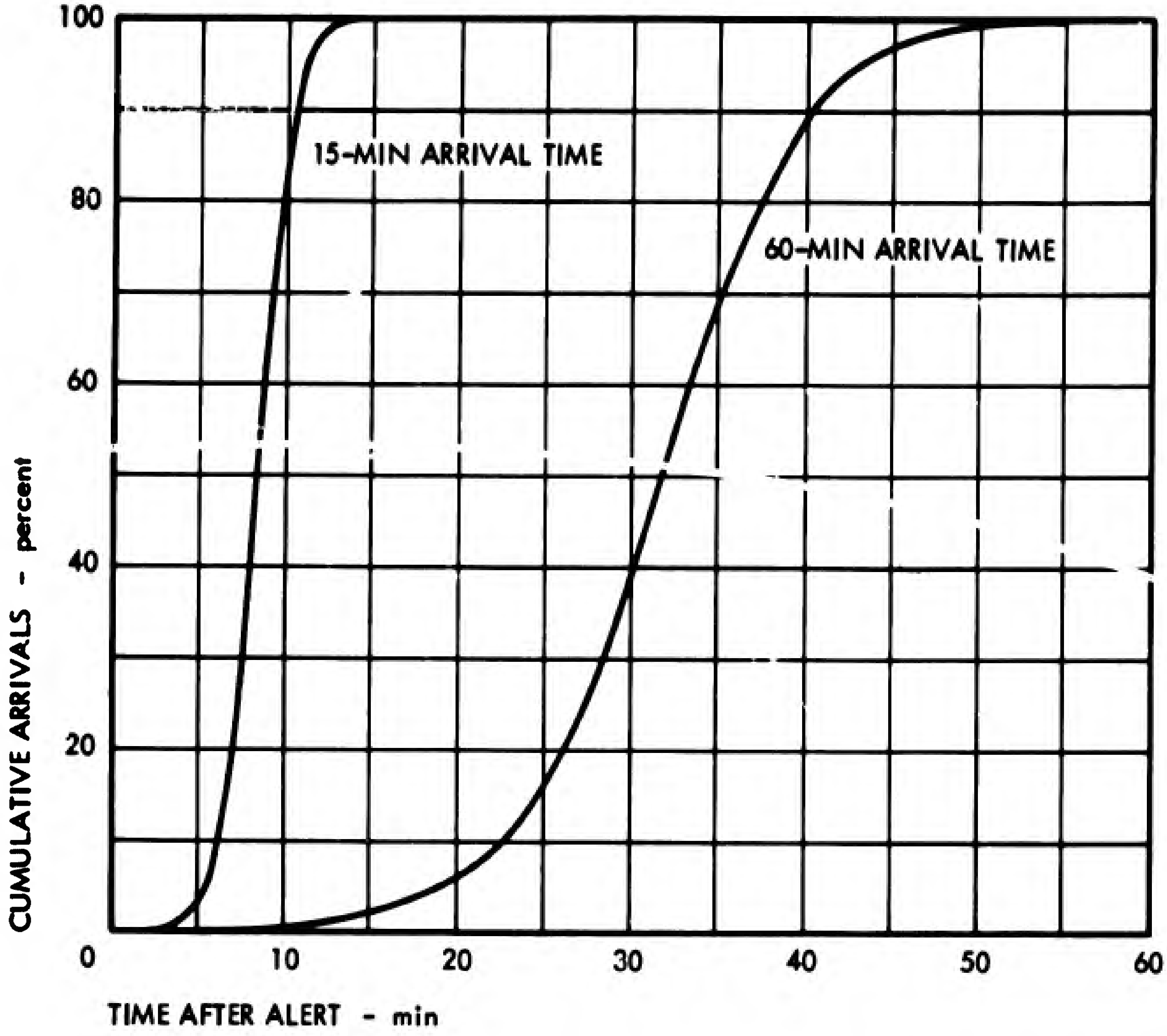

Figure 5

PERCENT CUMULATIVE ARRIVALS VERSUS TIME

SOURCE: Ref. 30.

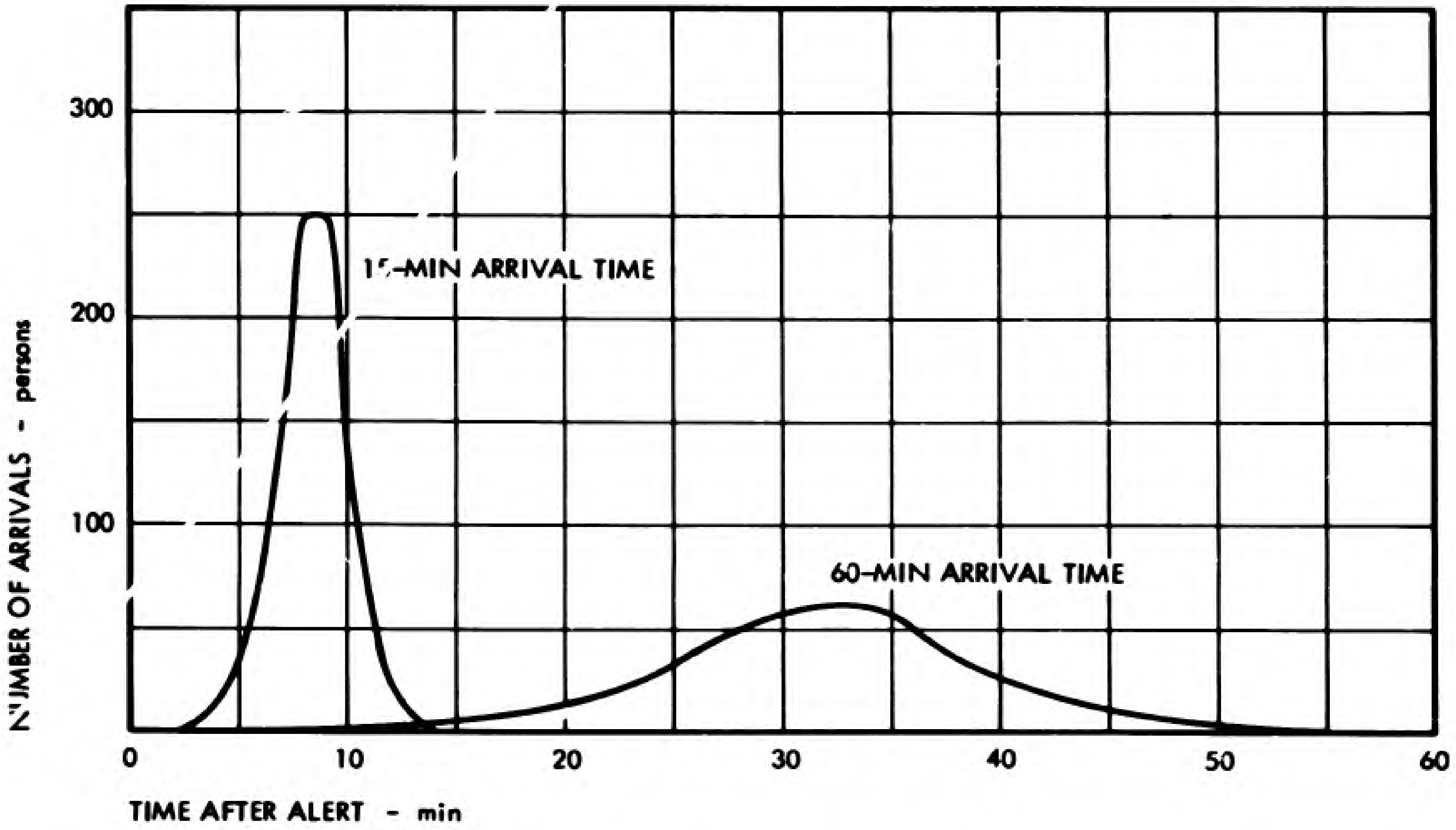

Figure 6

ARRIVAL OF SHELTEREES FOR 1,000-PERSON SHELTER FOR WARNING TIMES OF 15 MIN AND 60 MIN selected time interval. However, even though the effect of a range of time rate of arrivals on the dissipation of the queue was not analyzed, it would appear that its effect on the entranceway would be more a matter of degree than magnitude.

It was not necessary in this study to consider a specific current or proposed shelter posture since the primary reason for considering movement of people was to ascertain its effect on entranceway cost regardless of the actual situation. Therefore, it was sufficient to examine representative cases.

If the entranceway were designed for the peak rate of arrivals for the 15-min arrival time determined above, the capacity would be greater than for a 5-min average loading time. For instance, for a no queue situation for a 1,000 person shelter, the 15-min arrival time would require an entranceway capacity of 250 persons/min, whereas a 5-min average loading time would require a capacity of only 200 persons/min. It is interesting, therefore, to examine the influence of the entranceway capacity on the queue formation for capacities 67, 134, and 200 persons/min as shown on Table 12. For the entranceway with a capacity of 67 persons/min, a large queue would form and would not dissipate for 18 min after the alert, whereas the much smaller queue for the 134 persons/min entranceway would dissipate in about 12 min. With the latter capacity, there could be considerable modification in the arrival time curves on Figure 6 and the shelterees could still pass into the entranceway within a 15-min time period.

Although many factors influence the selection of the entranceway capacity for design purposes, for many civil defense shelter situations, the 5-min loading time frequently assumed for the total shelter population to enter the shelter is probably too conservative and leads to entranceway systems more expensive than necessary. Therefore, unless definite requirements are specified on which to base the design capacity for short warning times such as 15 min, it is recommended that the entranceway be designed for a capacity based on an average loading time of about seven min for the total shelter population. From a cost standpoint, the difference in capacity can be significant. For instance, the construction cost for an underground fallout shelter entranceway, Type A and B, from Figure 4 would be approximately $8,800 for a capacity of 250 persons/min, $7,400 for 200 persons/min, and $5,500 for 134 persons/min. This is a cost differential between the 134 and 200 persons/min capacities of almost $2 per person for the 1,000 person shelter.

The above cost data are primarily for the purpose of illustrating the effect of various entranceway capacity assumptions on the total entranceway cost. Because of the method of constructing the cost curves, as noted in Appendix 4, certain anomalies occur when the total cost obtained from

Table 12

QUEUE FORMATION FOR A 1,000-PERSON SHELTER FOR A 15-MIN WARNING TIME AND VARIOUS ENTRANCEWAY CAPACITIES

Time After Alert (min)	Arrivals at Shelter* (no. each min)	Population in Queue for Entranceway Capacities: 67 Persons/Min	134 Persons/Min	200 Persons/Min
1	0	0	0	0
2	0	0	0	0
3	2	0	0	0
4	8	0	0	0
5	22	0	0	0
6	49	0	0	0
7	110	43	0	0
8	204	180	70	4
9	250	363	186	54
10	199	495	251	53
11	101	529	218	0
12	37	499	121	0
13	14	446	1	0
14	4	383	0	0
15	0	316		
16	0	249		
17	0	182		
18	0	115		
19	0	48		
20	0	0		

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* From Figure 6.

the curves in Figure 4 is compared with individual entranceway costs on Tables 8 to 10. For example, consider the total cost of individual entranceways for the above capacities for an underground fallout shelter with Type A and B entranceways. From an examination of the cost data in Table 8, it can be seen that the least expensive entranceway to meet the 250 persons/min capacity requirement would be one B-5 entranceway and an escape exit, E-1, for a total cost of $8,660 for a capacity of 270 persons/min. This cost is within 2 percent of that from Figure 4. For the 200 persons/min capacity, it would be necessary, for minimum cost, to select a B-4 entranceway with a capacity of 225 persons/min and a total cost, including an escape exit, of $7,740. This cost is less than 5 percent higher than that determined from Figure 4. For the entranceway capacities shown on Table 8, it is apparent that the cost for two A-1 entranceways would be $6,860 for a capacity of 134 persons/min, or the cost for one A-5 entranceway with a capacity of 180 persons/min would be, including escape exit, $6,330. This is considerably above that shown for a 134 persons/min capacity on Figure 4. As discussed in Appendix 4, it was not necessary for this study to prepare cost estimates for every conceivable capacity for each entranceway type to develop the cost curves. For this particular case, an entranceway with a capacity of 135 persons/min is physically possible within the unit-of-exit-width concept (see Table 5, Section III). The cost for such an entranceway can be approximated by multiplying the $34 cost/person/min from Figure 4-1 in Appendix 4 by 135 for an entranceway cost of $4,590. The total cost for one 135 persons/min entranceway with an escape exit would therefore be $5,400, which is about the same as from Figure 4. On the other hand, if a specific entranceway capacity could not be obtained in this manner, it would be necessary to use either the next larger capacity, or some combination of entranceways to approximate the desired capcity.

The cost curves on Figure 4 and the equations on Table 11 are primarily useful for guidance in the selection of entranceway systems and for input data for system analysis purposes. For specific shelter problems, it may be preferable to use combinations of individual entranceway costs to obtain more realistic total system costs.

It is obvious, for the assumed 60-min arrival time, that only a minimum size entranceway would be required for the peak rate of 62 persons/min for a 1,000 person shelter without the formation of a queue. Therefore, it is not necessary to consider the effect of queue formation for this case, since other factors, such as the minimum permissible size for a single entranceway, would govern the design capacity. For a leisurely rate of entry and for situations where fire codes do not apply, the minimum size entranceway for community-type civil defense shelters should probably be based on an average loading time of about 15 min with a minimum of two entranceways (or one entranceway and one escape exit) with a capacity of

67 persons/min each. That is, for shelters less than 2,000 persons, a minimum entranceway capacity of 134 persons/min would be required, and for a 10,000 person shelter, a capacity of at least 667 persons/min would be required. However, the psychological aspects of minimum entranceways, such as two small entranceways for a 1,000 person shelter, may become a very important factor under a panic situation in the shelter. Also, as mentioned previously, in the design of entranceways, consideration must be given to the size of shelter equipment and supplies that must be transported through the entranceway. Although such factors were not evaluated in this study, they could place a constraint on the minimum size of entranceway regardless of the rate of arrival of shelterees.

On the other hand, there are two Building Exits Code (Ref. 26) requirements, that, if applicable, can influence the entranceway cost by limiting the minimum size of the entranceway permitted for shelters. First, the minimum size width of an exit for new construction is 44 in.,* for a minimum stair capacity of 90 persons/min. The other is that a minimum of two widely separated exits are required for emergency shelters of occupancy greater than 10 persons, which could result in a minimum entranceway capacity of 180 persons/min for most civil defense shelters. For a 1,000 person shelter, this capacity is only 10 percent less than that determined by assuming a 5-min average loading time for the total shelter population to enter. The greatest cost penalty would be for the smaller shelters, such as a 500 person shelter, where the cost of the 180 persons/min entranceway would be identical to that for a 1,000 person shelter, or twice as much per shelteree.

The determination of a loading capacity for the design of shelter entranceways is a complex problem that depends on a number of factors that cannot be generalized to account for all situations beforehand. However, to indicate the influence on the entranceway cost of a range of possible design capacities, the entranceway cost/person was calculated for shelter capacities up to 10,000 persons and various average loading times. The results are shown on Figures 7 to 12 for the six entranceway types for which cost data were developed. The 7-min average loading time corresponds approximately to the 15-min arrival time determined from an examination of the movement of the people to shelter, and the 15-min average loading time corresponds to the 60-min arrival time. In addition, the diagonal lines on the curves are the limiting minimum costs for the entranceway capacities indicated. The loading time curves are shown on the figures as dashed lines for entranceway capacities greater than 1,000 persons/min, since this was the upper limit of capacities for which cost data were calculated in this study. However, if better data are not available, extrapolation of the data to capacities of about 2,000 persons/min would be justified and would not introduce significant error.

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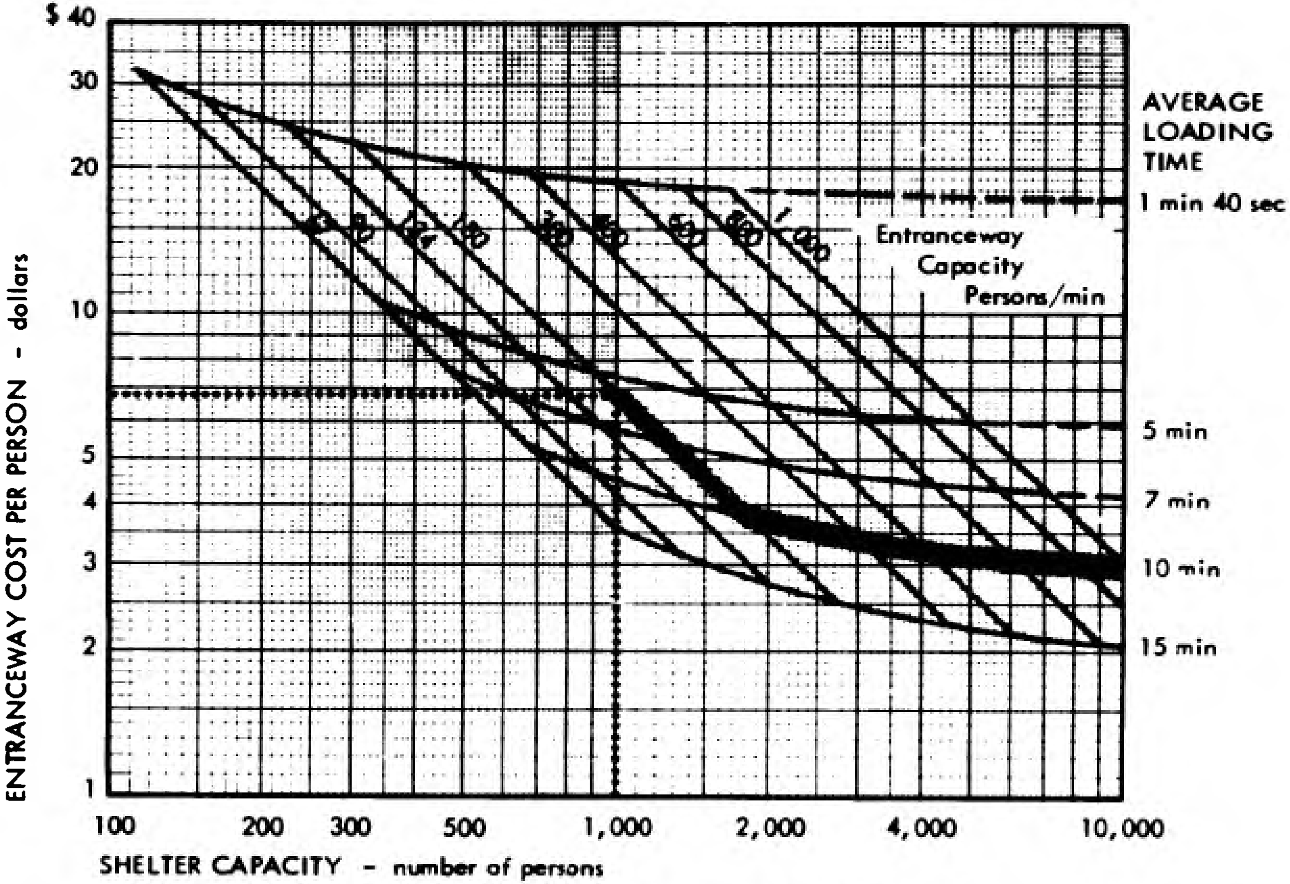
* Except that a 36-in. wide stairway is permissible where the total occupancy of all floors served by the exit stairway is less than 50.



NOTE: For a 1,000-person shelter capacity with a 10-min average loading time and a minimum entranceway capacity of 180 persons min, an entranceway cost of $6.80 is indicated by the intersection of the shaded curve and the 1,000-person shelter capacity coordinate.

Figure 7

ENTRANCEWAY COST/PERSON VERSUS SHELTER CAPACITY
Underground Fallout Shelter, Reinforced Concrete
Single and Dual Stair, Types A and B

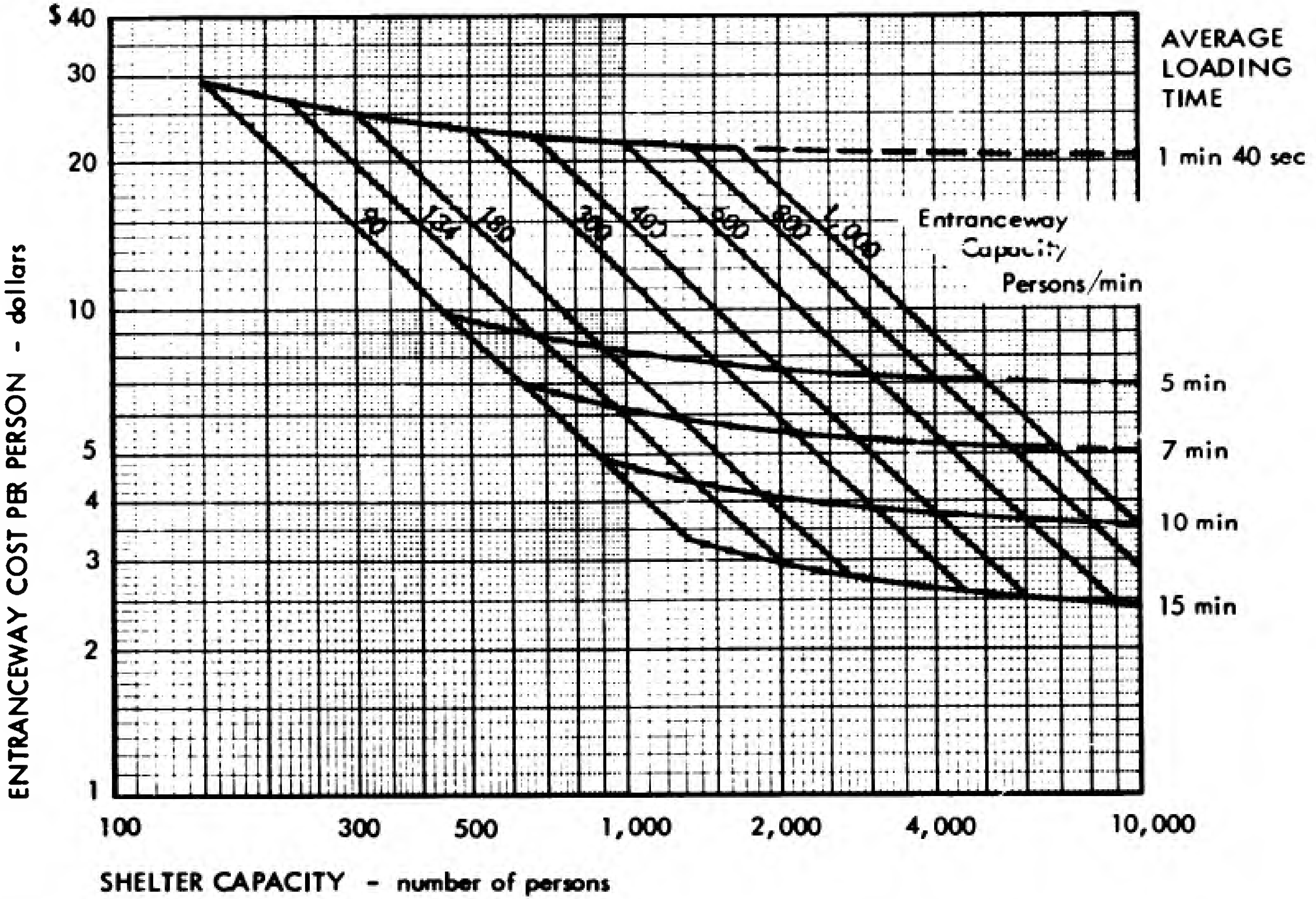


Figure 8

ENTRANCEWAY COST/PERSON VERSUS SHELTER CAPACITY
Underground Fallout Shelter, Reinforced Concrete
Covered Stairwell, Interior Location, Type C

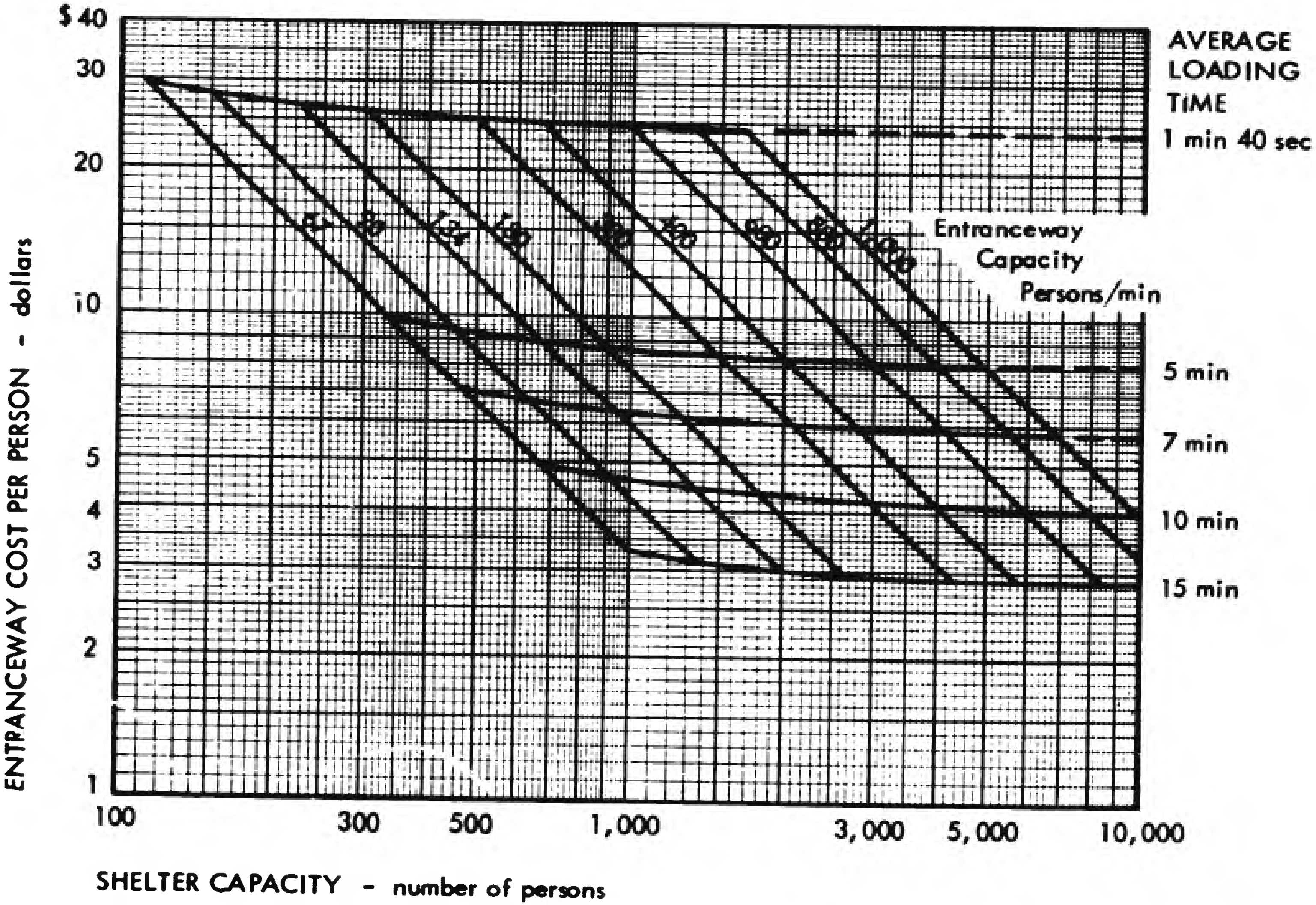


Figure 9

ENTRANCEWAY COST/PERSON VERSUS SHELTER CAPACITY
Underground Fallout Shelter, Reinforced Concrete
Open Stairwell, Exterior Location, Type D

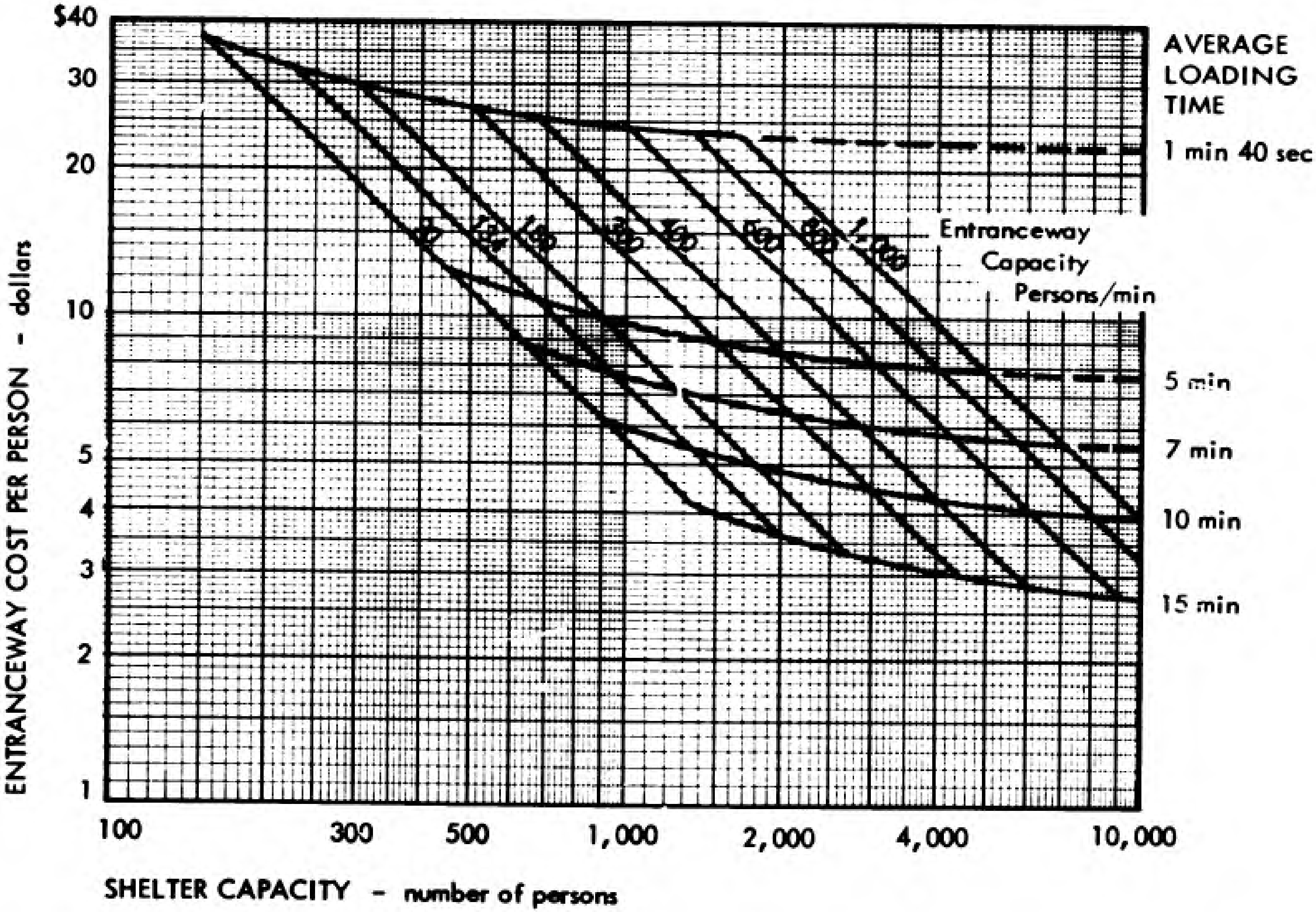


Figure 10

ENTRANCEWAY COST/PERSON VERSUS SHELTER CAPACITY
Underground Blast Shelter, Reinforced Concrete
Single and Dual Stair, Types J and K

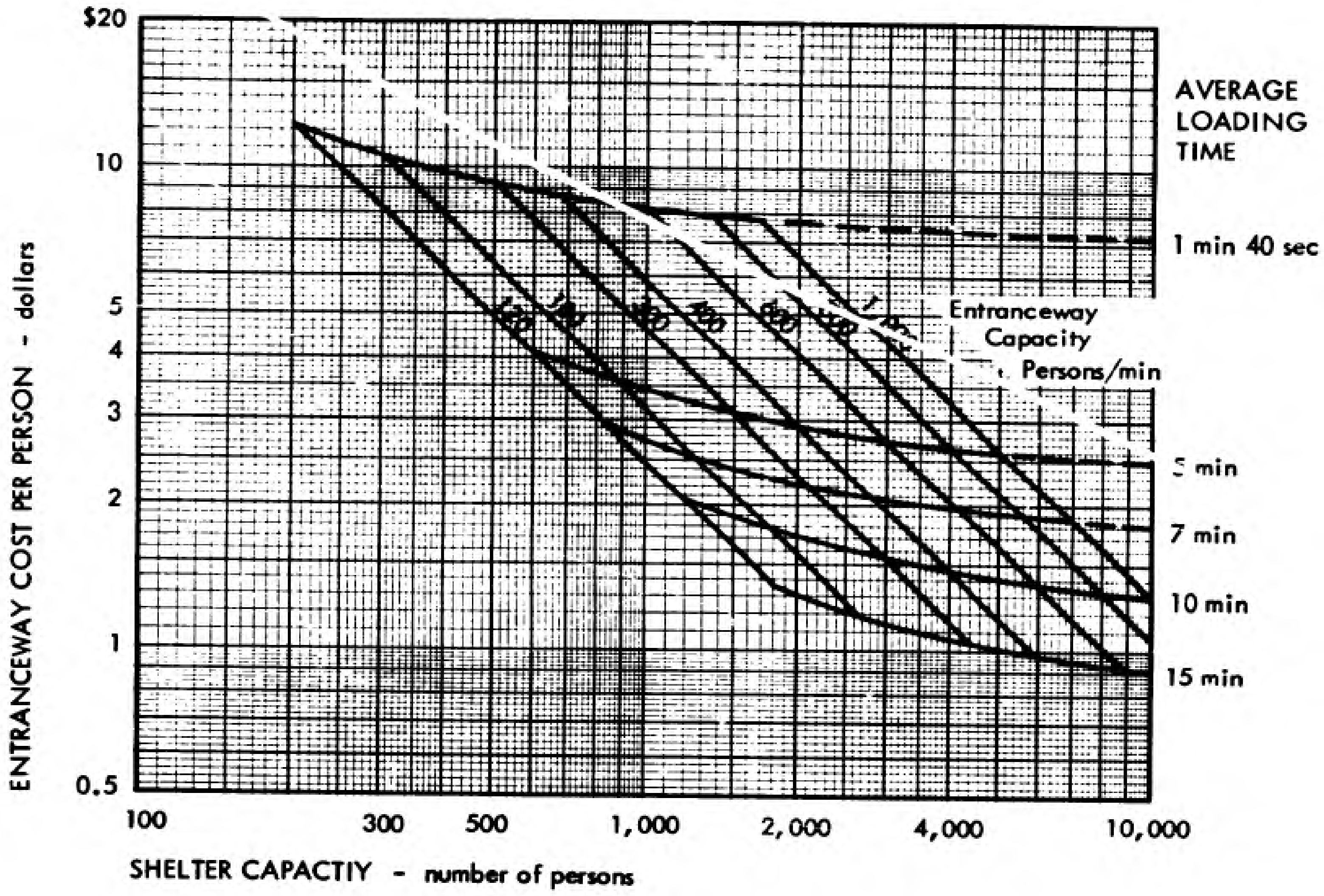


Figure 11

ENTRANCEWAY COST/PERSON VERSUS SHELTER CAPACITY
Aboveground Fallout Shelter, Reinforced Concrete
Without Basement, Type L

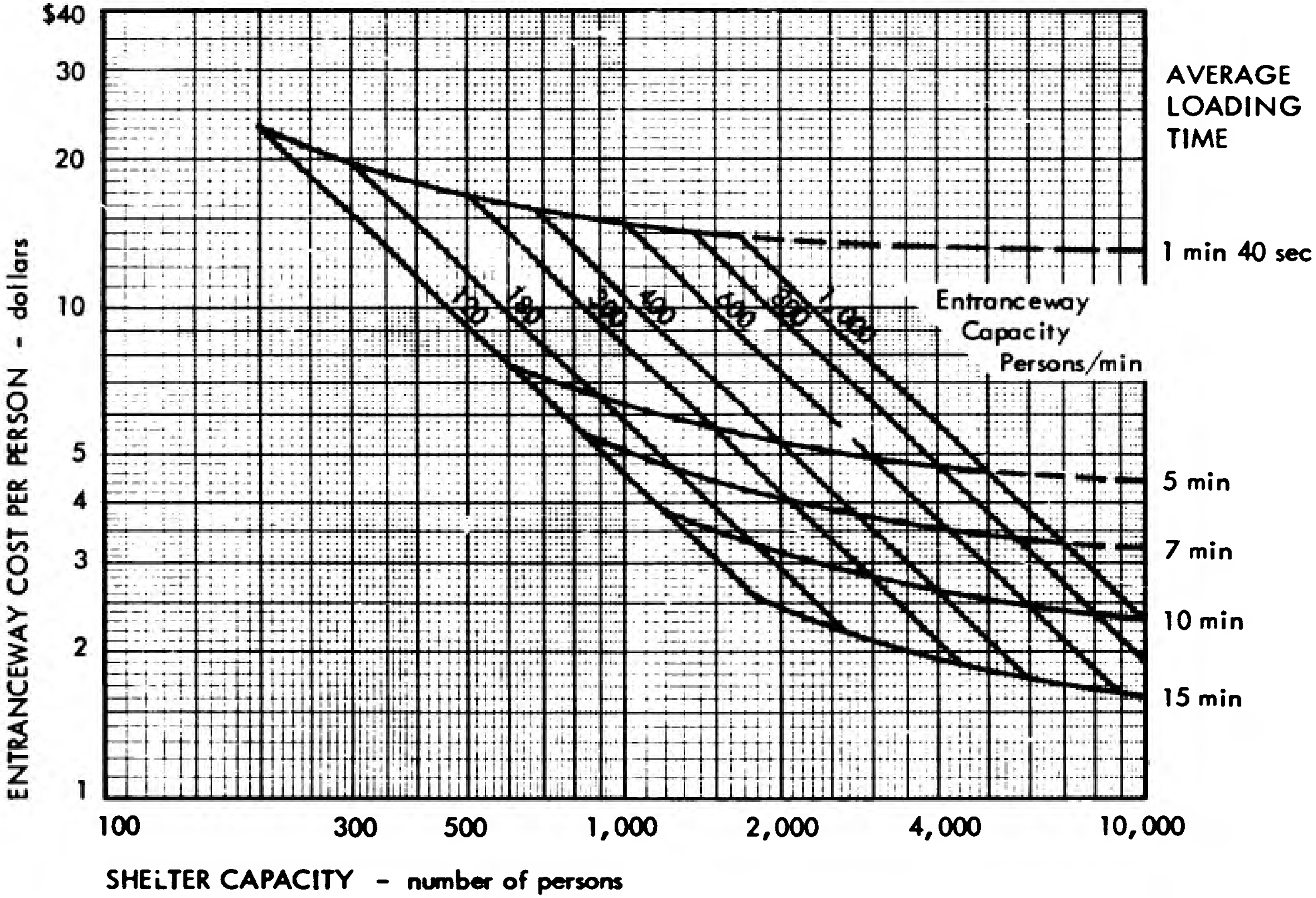


Figure 12

ENTRANCEWAY COST/PERSON VERSUS SHELTER CAPACITY
Aboveground Fallout Shelter, Reinforced Concrete
With Basement, Type M

The use of the figures can be demonstrated by considering the cost of the Type A and B entranceways on Figure 7 for a 1,000 person shelter population and a 10-min average loading time for two different minimum entranceway capacities. For the first case, if no minimum size entranceway is specified, an entranceway cost of $4.50/person is indicated by the intersection of the 10-min loading time curve and the 1,000 person shelter capacity coordinate. The required entranceway capacity would be 100 persons/min. However, for the second case, where the minimum entranceway capacity is specified as 180 persons/min, an entranceway cost of $6.80 is indicated by the intersection of the 180 persons/min entranceway capacity curve and the 1,000 person shelter capacity coordinate. For the latter case, the 180 persons/min entranceway capacity criterion was the controlling cost parameter, even though a 10-min average loading time was specified.

The code requirement to provide exits sufficient to permit an evacuation time of 1 min, 40 sec, could result in very expensive entranceway systems relative to the other loading capacity criteria. However, one possible compromise, which could prevent unreasonable entranceway costs for dual purpose shelters, such as community recreation centers, could be a dual population designation for the structure. The entranceway system could be designed to meet the emergency civil defense requirements, and a restriction could be placed on the total permissible population during normal community use, conforming to the code. For instance, a 1,000 person shelter with a 180 persons/min capacity entranceway system would be limited to 300 persons to satisfy the 1 min, 40 sec evacuation criterion for nonemergency use.

Austerity in entranceways is a relative term. Except for entranceways such as the underground escape exit, Type E, the cost of entranceways for civil defense shelters is fundamentally a result of the rate of loading desired by the planner or designer or required by the code. Therefore, within certain limits for permanent type entranceways, the construction cost is a controllable parameter, which must be evaluated for each particular situation as a compromise or trade-off between such factors as total cost, ease of entry, and the risk inherent in the formation of a queue under the attack environment assumed.

Design Alternatives

Although a number of alternative entranceway configurations or construction techniques became apparent during this study, it was possible to make only a limited investigation of design alternatives for a few of the entranceways. For the Type [illegible] entranceway, there were two entranceways included to investigate the effect on cost of design modifications. First, entranceway A-6 was considered as one with minimum size and cost for entranceways constructed with a reinforced concrete box section. As can be seen in the sketches in Appendix 3, A-6 was designed as a straight-through entranceway for an underground fallout shelter to minimize excavation and backfill costs without regard for the available surface area. As noted in Table 4-1, although the total construction cost is a minimum, on a cost/person/min basis, it is the most expensive of the A type. In addition, although the PF for entranceway A-6 was adequate*, the straight corridor design for larger sizes would probably require the construction of a barrier wall in the shelter at the entry door. Because of these factors, entranceway configurations similar to A-6 probably should not be considered further if cost is a criterion. The second design modification considered is indicated by entranceway A-7, which includes a 90° turn in the corridor, but was constructed to use a common wall with the shelter. The total cost of this entranceway was about $800 less than for the box-section design of the same capacity, i.e., A-2, which is separated from the shelter by a soil layer. Since the fallout protection afforded by entranceway A-7 is almost equal to A-2 (PF of 200 compared with 270), it is apparent that entranceways of the A-7 design should be considered for fallout shelters where the Type A configuration was generally applicable.

The only other design alternative considered was for the Type D entranceway, where the cost of various types of stair construction was investigated. Entranceways D-1, D-1A, and D-1B were identical except for the stairs, which were, respectively, precast concrete, steel, and treated wood. As noted on Table 4-3, the cost of the entranceway with steel stairs is approximately 30 percent higher than for one with concrete stairs, while the cost of the entranceway with treated wood stairs is about 8 percent less. Because of the permanence of the concrete stairs and their greater mass thickness for better radiation protection, they are probably preferable to both the steel and wood for most permanent civil defense shelters.

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* The PF was 210 at a detector located 3 ft inside the entry door at a height of 3 ft above the floor.

V CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This investigation shows that many individual and interacting factors control or influence the design and cost of entranceways for civil defense shelters. Because of the many conceivable types of shelters and the diversity of entranceway requirements, it is difficult to form definite conclusions without prior knowledge of a specific shelter program. However, certain factors influence the final construction costs for an entranceway system to a large degree. These include the type of shelter program, the warning time available, the attack environment, the rate of arrival of shelterees at the entranceway, the type and size of the entranceway, the size of the shelter, and code requirements.

From a design standpoint, it would be sufficient if the time available for the shelterees to enter the shelter, the average entranceway loading capacity, and the shelter population were known. The difficulty arises, however, in the establishment of realistic limits on the various factors that have an important bearing on the entranceway design and cost. For any particular situation where code requirements govern, it is relatively simple to design an entranceway, since both the size and number of entranceways in relationship to the shelter size can be determined in a straightforward manner. The entranceway so designed could then be checked for the actual civil defense environment; however, for the cases considered here, fire code requirements resulted in the most expensive system. Although minor savings could probably be implemented in the design and construction phases, code requirements would generally be the primary factor in determining the entranceway system cost. On the other hand, if cost is an important factor in a national shelter program and relaxing of code requirements can be anticipated for emergency shelters, consideration must be given to such influencing factors as the movement and distribution of people, their rate of arrival at the shelter, the risks of queue formation relative to the total cost, the actual traffic flow through entranceways during emergency conditions, and psychological factors inherent in the use of small entranceways for large shelters. However, the following conclusions apply in general to the design of personnel entranceways for civil defense shelters, when consideration is given to the many complex influencing factors:

- If the entranceways for dual purpose or other civil defense shelters are required to meet fire codes equivalent to the Building Exits Code (Ref. 26), there are two factors that will usually control the total cost. These are (1) the requirement that the minimum width of any entranceway be 44 inches and (2) the requirement to provide entranceway capacity sufficient to permit the entire shelter population to evacuate in 1 min, 40 sec.

- For short warning times such as 15 min, a reasonable design entranceway capacity can be determined by assuming an average loading time of 7 min for the entire shelter population to enter the shelter. Although this results in a queue larger than for the usual 5-min loading time, the queue would probably be dissipated within the 15-min time available after the alert for any assumed realistic rate of arrival of shelterees.

- For longer rates of arrival such as 60 min, it appears reasonable to determine the design entranceway capacity by assuming an average time of 15 min for the entire shelter population to enter the shelter. However, since this leads to minimum size entranceways, factors such as the psychological problems of entranceways that are small in relation to the shelter size and population should be considered. Also, for shelters with capacities smaller than 1,000 persons, the width of the entranceway determined in this manner is narrower than that permissible by the Building Exits Code.

- On the basis of the entranceway cost/person, the narrower the width of the entranceway, the greater the cost/person for a particular type of entranceway. This implies that if minimum entranceway cost is a criterion for a national shelter program, for situations where the cost/person is meaningful, consideration should be given to the minimum size of shelter. As shown in Figures 7 to 12, for all average loading times and shelter sizes considered in this study, the entranceway cost/person increases with decreasing shelter size. Also, for any specific entranceway capacity, there is a shelter size below which there is a relatively rapid increase in entranceway cost/person.

- For the permanent type of entranceways considered in this study, it was found that for underground shelters, a reinforced concrete box section was the most economical when consideration was given to the loading rate through the entranceway.

Recommendations

Although this study identifies the many factors that influence the design of entranceways for civil defense shelters and shows the influence of many of these on system cost, before rational design procedures can be developed it will be necessary to investigate a number of specific problem areas. These include:

- The air blast entering and propagating through entranceways and into the shelter proper should be examined to establish (1) the loading criterion for blast doors and entranceway structures and (2) the maximum peak pressure and pressure build-up in a shelter for various free-field pressure-time functions and entranceways without blast doors. For the various entranceway configurations, the overpressure level at which blast doors are required to prevent excessive pressure within the shelter should be determined. Also, the feasibility of concepts such as blast attenuator doors should be investigated to determine the range of overpressure levels where such doors would be applicable and their cost relative to the cost of the more conventional type of blast doors.

- In view of the current lack of design recommendations for initial radiation analysis for entranceways, a study is needed that will result in the establishment of acceptable design procedures for civil defense shelters. Currently, a shelter designer assumes a "worst case" for both the initial free-field radiation intensity and for the radiation streaming into the entranceway for a specified overpressure level and weapon yield. Relative to the structural design, this appears inconsistent and overly conservative, especially from the viewpoint of a national shelter program in which consideration is given to the number of survivors for fixed dollar investments. For example, if a shelter was designed for a specific overpressure, say 20 psi, and specified radiation dose, say 40 rads, what would be the increase in mortality for an actual case where 40, 50, or 60 psi may cause structural failure, or where the radiation dose was increased to 80, 120, or 200 rads? For a fixed dollar investment, is it better to provide more radiation protection, blast protection, ventilation, and so forth. Because of the many unknowns, the recommended procedure may contain conservative assumptions. However, the probability of occurrence of the various assumptions should be considered to prevent overconservatism. For instance, what is the probability of an actual weapon being detonated on the line-of-sight of the longitudinal axis of an entranceway in relationship to cost?

- An investigation of warning concepts and the movement of people to shelter should be made to establish rates of arrival at the entranceway that are more realistic for civil defense purposes than those currently available. Also, the study should examine the risks in queue formation and dissipation and their relationship to the design capacity of entranceways.

- Because of the conflicting information available on the movement of people through entranceways, the design capacities for traffic flow through the elements of the entranceways in this study were obtained from the Buildings Exits Code (Ref. 26) for the exit of people from buildings. Implicit in the use of fire code capacities for entranceway design is that the exit discharges into a large, relatively uncongested area. However, an entranceway corridor exits into a finite area that may be both congested and unfamiliar to the shelterees. Therefore, a study should be made of the ingress of people into shelter to establish realistic design traffic rates for people entering civil defense shelters under emergency warning conditions. The study should include the applicability of various building codes to the size of entranceway elements and the permissible traffic rates for various categories of emergency civil defense shelters. A requirement to meet the applicable sections of codes such as the Building Exits Codes for both size of individual entranceways and the total number of entranceways would probably control the entranceway cost regardless of other factors. However, narrower corridors and doors and steeper steps than recommended by fire codes may be a better solution when economic and use factors are properly evaluated. Also included should be an investigation of the influence on the entranceway design capacity of the egress of shelterees due to an emergency, such as fire, within the shelter during occupation.

- Implicit in the assumption of the movement of people to shelter through the entranceway and into the shelter is the degree of training of the general population. A supplementary study is needed to examine the influence of training on the entranceway design problem and to establish limits for various degrees of training to assist in the selection of realistic assumptions for the rate of arrivals and traffic rates through entranceways.

- Although the cost information developed here permits a relative estimate to be made for many different types of entranceways for civil defense, a study of permanent-type austere entranceways was not included. Such entranceways may give excellent blast protection and good initial radiation protection and have attractive cost advantages for certain types of shelters. One such type for underground shelters is a modification of the escape exit, Type E, used in this study. The traffic rate through such an entranceway could be increased by substituting a sloping ladder with solid treads and side handrails for the vertical wall mounted ladder rungs. For fallout radiation, a simple fireproofed surface door would be required to prevent ingress of fallout particles. A blast door for such a small opening would be relatively inexpensive for the higher overpressures. To reduce the initial radiation through the entranceway, the vertical shaft could be offset from the entry door into the shelter, and interior barrier walls could be added as necessary. Although such entranceways may have limited use for large dual purpose shelters where codes may control the design capacity, they may present worthwhile cost advantages for small shelters, where they could be used as the sole type of entranceway or in conjunction with more conventional entranceways.

- The influence of the entranceway opening on the transmission of heat and noxious fumes from fire in the vicinity of the shelter should be examined in conjunction with studies to determine the transmission of heat into the shelter proper.

- Although a number of desirable entranceway configurations or construction techniques became apparent during this study, many could be investigated only superficially or not at all. For instance, only a single capacity was examined for the configuration represented by entranceway A-7. Also, the influence on cost and use was not investigated for design modifications that would use storage space under entranceway stairs. Such entranceways, together with the effect of various design modifications, should be examined to determine the type of entranceways and the construction techniques that would result in minimum cost.

Appendix 1

INITIAL RADIATION CALCULATIONS FOR ENTRANCEWAYS

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Appendix 1

INITIAL RADIATION CALCULATIONS FOR ENTRANCEWAYS

Introduction

Although there are many unknowns concerning both the attenuation of radiation through entranceways and its distribution within the structure, the simplified procedures presented in Refs. 5 and 6 were felt to be adequate for the designs prepared here. Basically, there are three problems associated with the analysis of an entranceway for the initial nuclear radiations. These are the determination of the free-field initial radiation intensities, the maximum permissible dose, and the entranceway attenuation of the radiation. The methods used to calculate these quantities, together with an illustrative example, are given in the following subsections.

Initial Nuclear Radiation

The initial nuclear radiation is defined in Ref. 1 as the radiation emitted within one minute after the detonation of a nuclear weapon, including the prompt radiation. For the purpose of this study, Ref. 1 was used to obtain the intensities of the free-field gamma and neutron radiation at the entranceway opening. Because of the yield-range-dose relationships, it is necessary to specify a yield, range, and HOB (height of burst) before the radiation intensity in the free-field can be calculated. However, even with precise yield-range data, Ref. 1 cautions that any calculation of radiation exposure dose is subject to wide fluctuation in reliability due to variation in weapon design and characteristics. Only the 20 psi overpressure level from a 200-kt weapon yield was considered for the radiation intensity calculations in this study.

Maximum Permissible Radiation Dose

The establishment of a total permissible dose for shelter occupants, although beyond the scope of this study, is a primary factor in the design and cost of entranceways. Even at the modest overpressure level of 20 psi examined in this study, the initial radiation requirement increased the cost of the blast shelter entranceways. The total dose in the shelter is composed of the initial radiation and residual fallout radiation that penetrates both the entranceway and the shelter proper. For a specific shelter design problem, the relationship between the contributions of the radiation from these two sources can be studied to obtain an economical compromise for the entranceway and shelter design. However, for a study of only the entranceway portion of the shelter system, it is necessary first to establish a permissible dose and then to estimate the entranceway contribution for both initial and residual radiation. For the purposes of this study, it was sufficient to adopt the criterion presented in Ref. 5. Essentially, this limited the total radiation dose in the shelter to 40 rads, with the assumption that the permissible dose was divided equally at 20 rads each for the entranceway and the shelter proper. Further, the entranceway portion was divided equally between initial and fallout radiation, which resulted in a permissible initial radiation dose of 10 rads through the entranceway. To adhere to the criterion mentioned above for a specific shelter would require assuming an accumulated total dose for the free-field fallout radiation and determining its attenuation through the entranceway. However, as noted in the fallout radiation analysis in Appendix 2, for a study of entranceways only, it was believed sufficient to determine the PF for the blast entranceways in the usual manner (Ref. 20) at a detector point 3 ft inside the shelter entry without calculating the actual radiation dose.

Another factor that is important in describing the permissible radiation dose received by shelterees is the exposed and absorbed dose of nuclear radiation. To describe the effects of nuclear radiation on a biological system adequately, it is necessary to express the free-field radiation exposure dose as an absorbed dose. This has been accomplished by introduction of the rad, which is defined as the absorbed dose of any nuclear radiation that is accompanied by the liberation of 100 ergs of of energy/gram of absorbing material (Ref. 1). Because of the uncertainty of determining the biological effect of nuclear weapons and to simplify the radiation analysis, the absorbed dose in rads was used in this study to judge the adequacy of the entranceways for providing initial radiation protection.

Entranceway Radiation Attenuation

The attenuation of the free-field nuclear radiation intensities through an entranceway can conveniently be separated into three phases for purposes of analysis: the entrance reduction factor, entranceway bend and corridor attenuation, and barrier attenuation.

Entrance Reduction Factor

The important factors in determining the initial radiation dose within the entranceway are the orientation of the entrance opening relative to the burst point, the entranceway geometry, and the free-field radiation intensity. In general, Refs. 5 and 6 both conclude that the hazard from radiation streaming into the entrance opening would be maximum for a line-of-sight direction along the longitudinal axis of the entrance section between a detector located in the entranceway, usually at the first bend, and the burst point. This would result from the fact that the higher energy gamma rays and neutron particles are more likely to come from a line-of-sight direction than from a scattered direction. Although the effect on radiation dose of the angle between the line-of-sight and the burst point was not investigated, it was possible to examine limited burst positions on the vertical plane through the longitudinal axis of the entrance section. The locations were on the line-of-sight from the detector approximately along the longitudinal axis of the entrance section, on the grazing line-of-sight between the detector and the first step of the entranceway, and for a surface burst location. It was found that the most critical location was for the grazing line-of-sight. In general, as the HOB is increased, the range for a given yield and overpressure also increases to a maximum for some optimum HOB. Since the initial radiation dose is range dependent, it would decrease to a minimum at the optimum HOB for a given yield and overpressure. Although the magnitude of the entrance reduction factor is dependent on the angular deviation from the line-of-sight orientation, the reduction of this factor for the grazing line-of-sight is more than offset by the increase in free-field radiation intensity due to the decreased range; this was not the case for the surface burst location. It may well be that some intermediate angle between those selected may produce a greater entrance section radiation dose, but it was felt sufficient for the purposes of the entranceway designs and cost estimates in this study to use the grazing line-of-sight for the initial radiation analysis.

To determine the fraction of the free-field radiation that would penetrate the entrance section, it is necessary to compute the solid angle fraction subtended by the entrance opening and the detector location. Figure 1-1, obtained from Ref. 20, can be used to calculate the solid angle fraction for rectangular openings. To calculate the entrance reduction factor, R_{fe} for both gamma and neutron radiation, the solid angle fraction is used to enter Figure 1-2, which was obtained from Ref. 6.

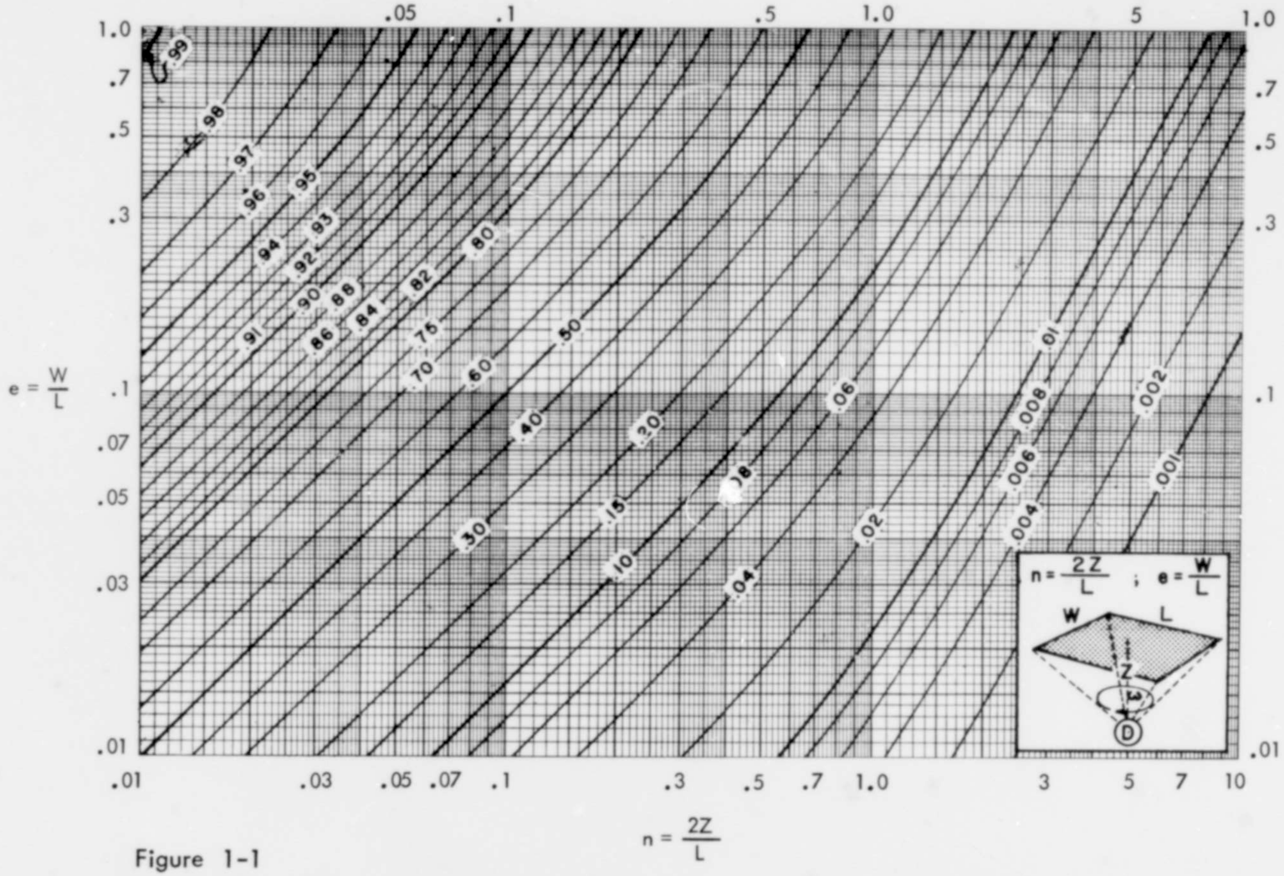


Figure 1-1

VALUES OF SOLID ANGLE FRACTION, ω

SOURCE: Ref.20

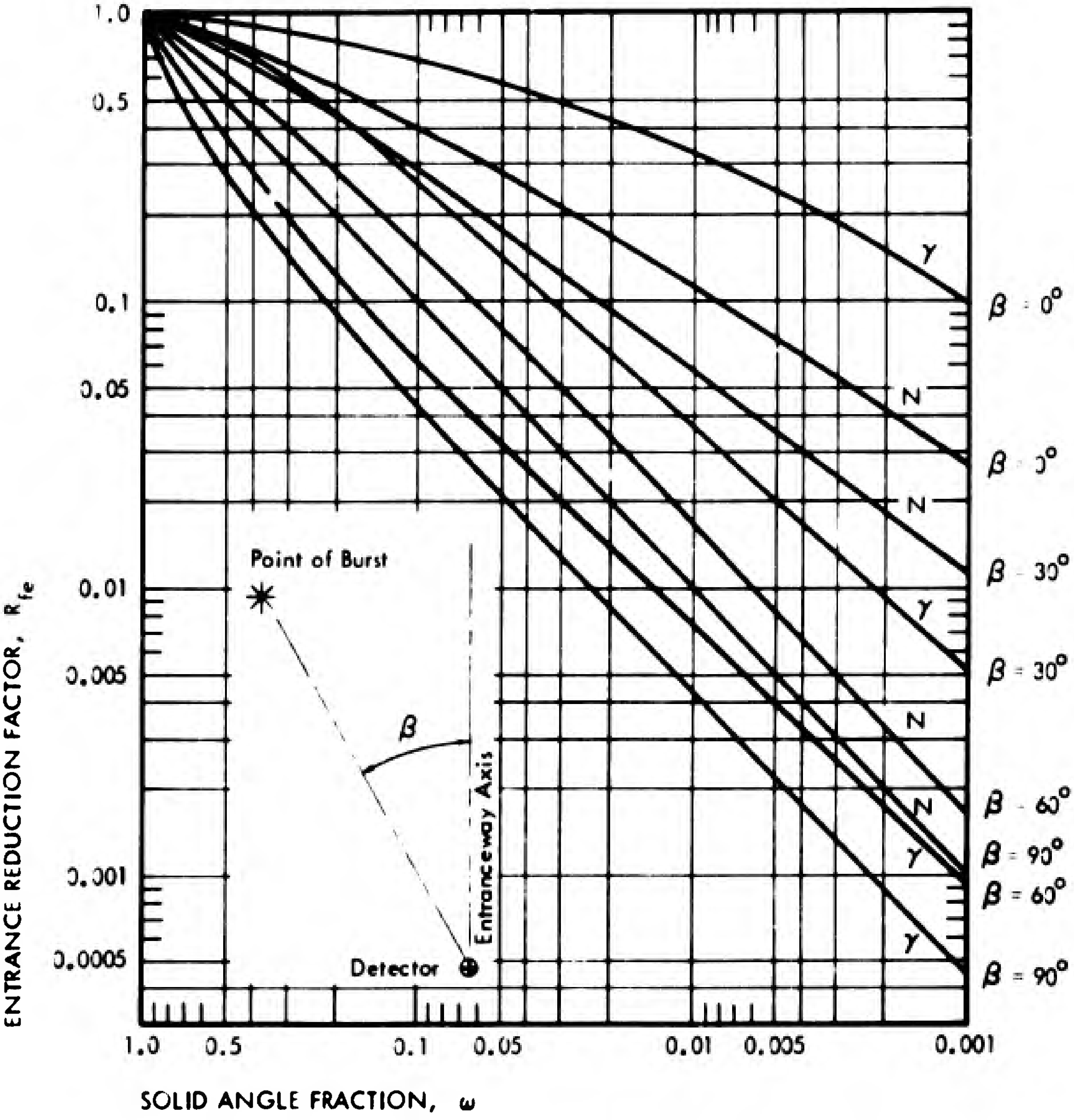


Figure 1-2

ENTRANCE REDUCTION FACTOR FOR INITIAL NUCLEAR RADIATION VERSUS SOLID ANGLE FRACTION AND BURST POINT

SOURCE: Ref. 6.

Entranceway Bend and Corridor Attenuation

Gamma Radiation

As noted in Refs. 15-19, even though considerable analytical and experimental effort has been expended in recent years to study the transmission of gamma radiation through tunnels and bends, detailed calculations for the initial nuclear gamma radiations are both tedious and of uncertain accuracy. For the purposes of this project, the following simplified method presented in Ref. 5 was therefore felt to be adequate. The reduction factor, R_f, for the first 90° bend beyond the entrance section is given by

$$R_{f_1} = 0.1\omega_1$$

where ω_1 = solid angle fraction subtended by the corridor section at the next point of interest

For the second and subsequent 90° bends, the reduction factor is given by

$$R_{f_n} = 0.5\omega_n$$

for n = 2, 3...

Neutron Radiation

Because of the lack of theoretical and experimental information on neutron attenuation in entranceways, it was sufficient for this study to use the simplified procedures presented in Refs. 5 and 6 to determine the length of corridor required for neutron radiation attenuation. The method is based on the concept of the length of corridor required to reduce the neutron dose by one-half. Since neutron attenuation occurs by neutron collision with the corridor walls, it is assumed that the attenuation is a function of the average cross-sectional dimensions of the corridor and not of the bends in the corridor. The experimental evidence indicates that the corridor half-length increases with the neutron energy, although information is lacking for the higher energy levels associated with nuclear weapons. This is accounted for in the method by neglecting any neutron radiation attenuation by wall interaction in the first section of the entranceway and by assuming that most of the higher energy neutrons are not transmitted past the first corridor bend.

It is assumed that the neutron half-length for the corridor beyond the first bend is given by

$$L_{1/2} = 1/2\ K\ (H + W) = 0.366\ (H + W)$$

where $L_{1/2}$ = half length of entranceway corridor, ft

K = 0.732, experimentally determined ratio

H = height of corridor, ft

W = width of corridor, ft

The number of neutron half-lengths for the corridor is given by

$$n = \frac{L}{L_{1/2}}$$

n = number of corridor half-lengths

L = total length of corridor beyond first bend to point of interest, ft

The reduction factor, R_{fc}, for neutron radiation for the corridor beyond the first bend is given by

$$R_{fc} = \frac{1}{(2)^n}$$

Because of a lack of adequate information, the method above does not specifically include a factor for secondary gamma rays resulting from the absorption of thermal neutrons in the corridor walls. In Ref. 5, it is stated that the present degree of conservatism in design should help reduce this hazard.

Barrier Attenuation

Barrier at Entrance

To determine the barrier reduction factor, B, at the outside entrance, Figures 1-3 through 1-5 have been reproduced from Ref. 5. Figure 1-3 shows the barrier reduction factor in relationship to the mass thickness of the shielding material and the angle of incidence for nitrogen capture gamma radiation. The use of nitrogen capture gamma

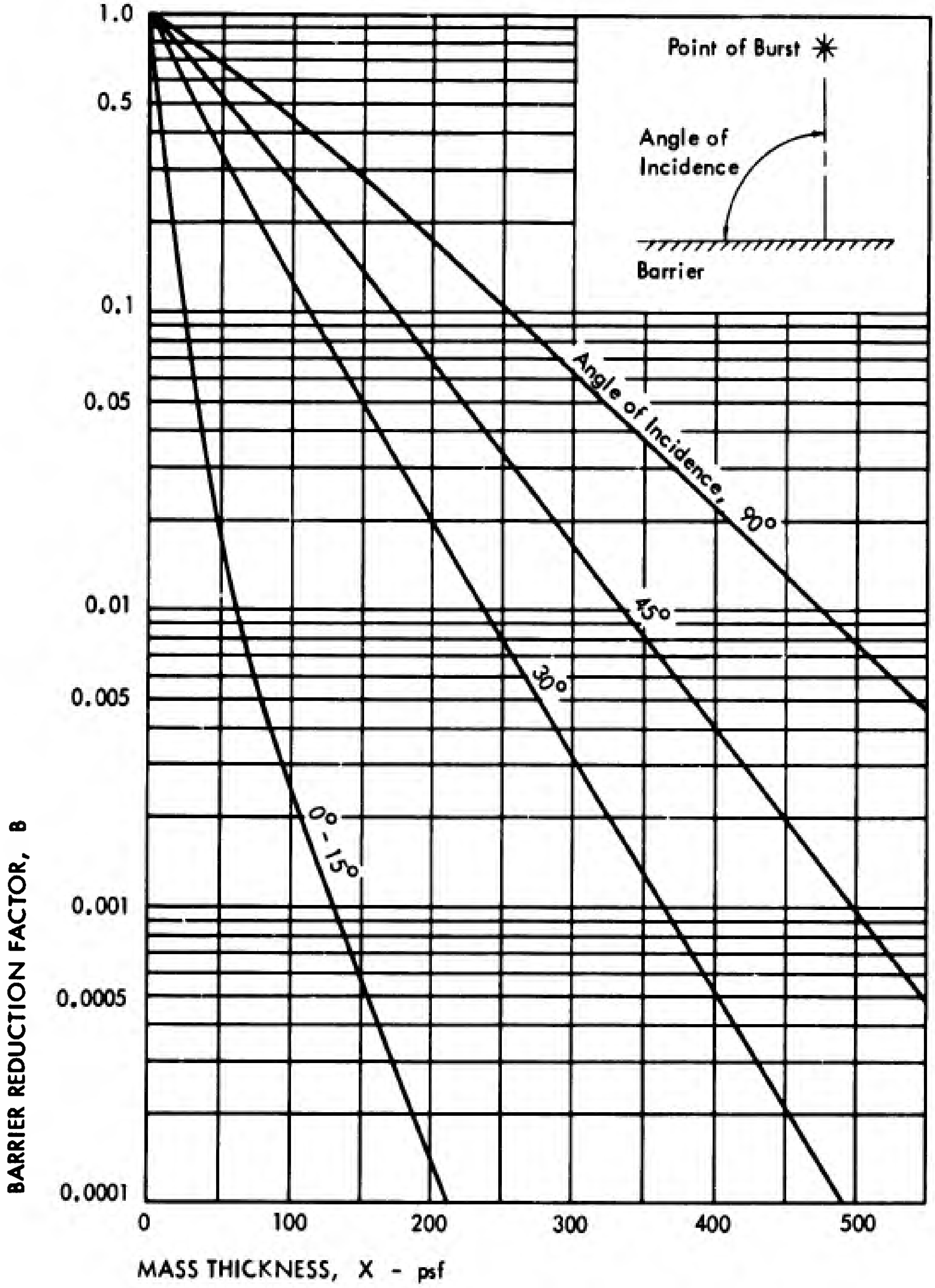


Figure 1-3

BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR NITROGEN-CAPTURE GAMMA RADIATION

SOURCE: Ref. 5

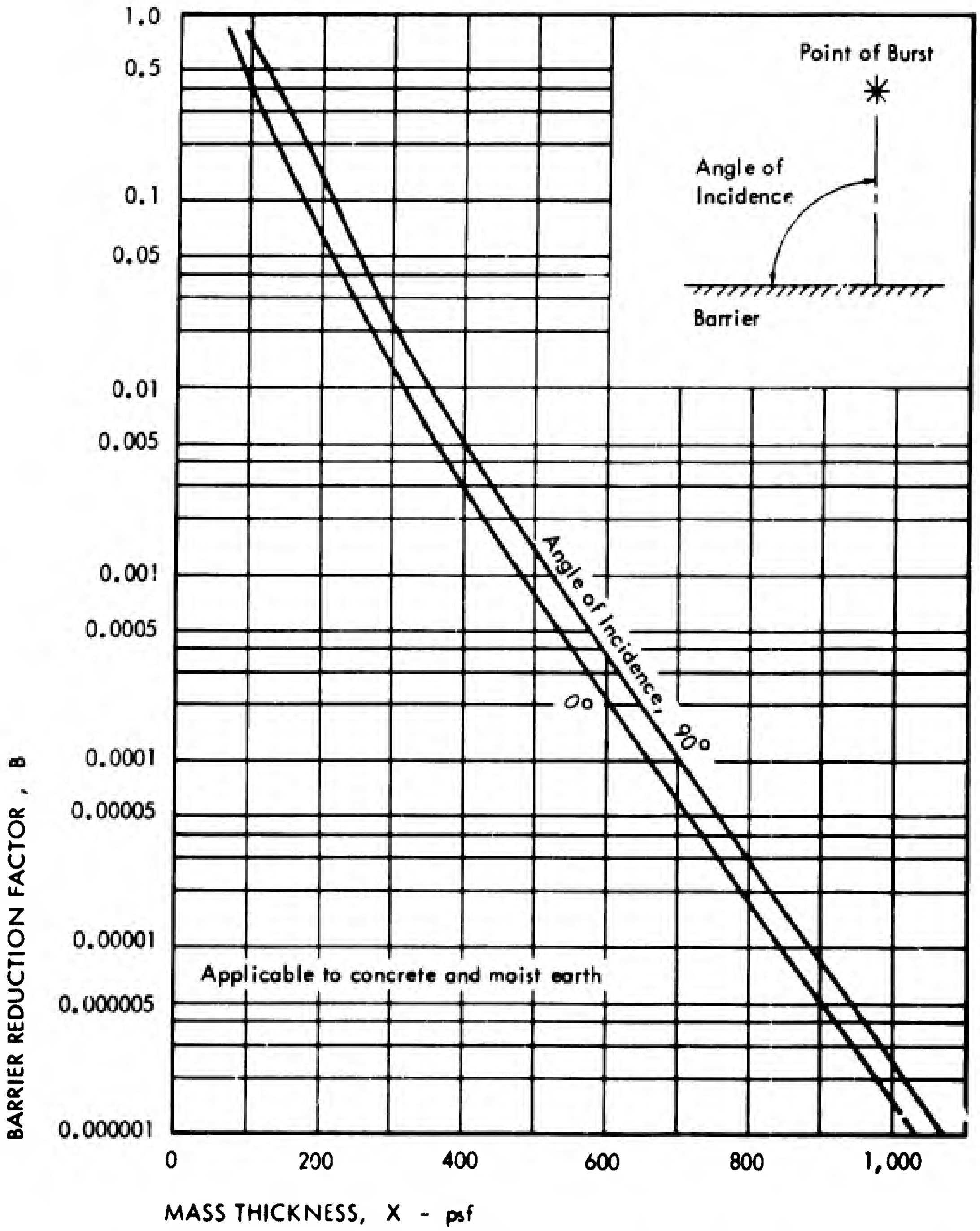


Figure 1-4

BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR 14 Mev NEUTRONS

SOURCE: Ref. 5.

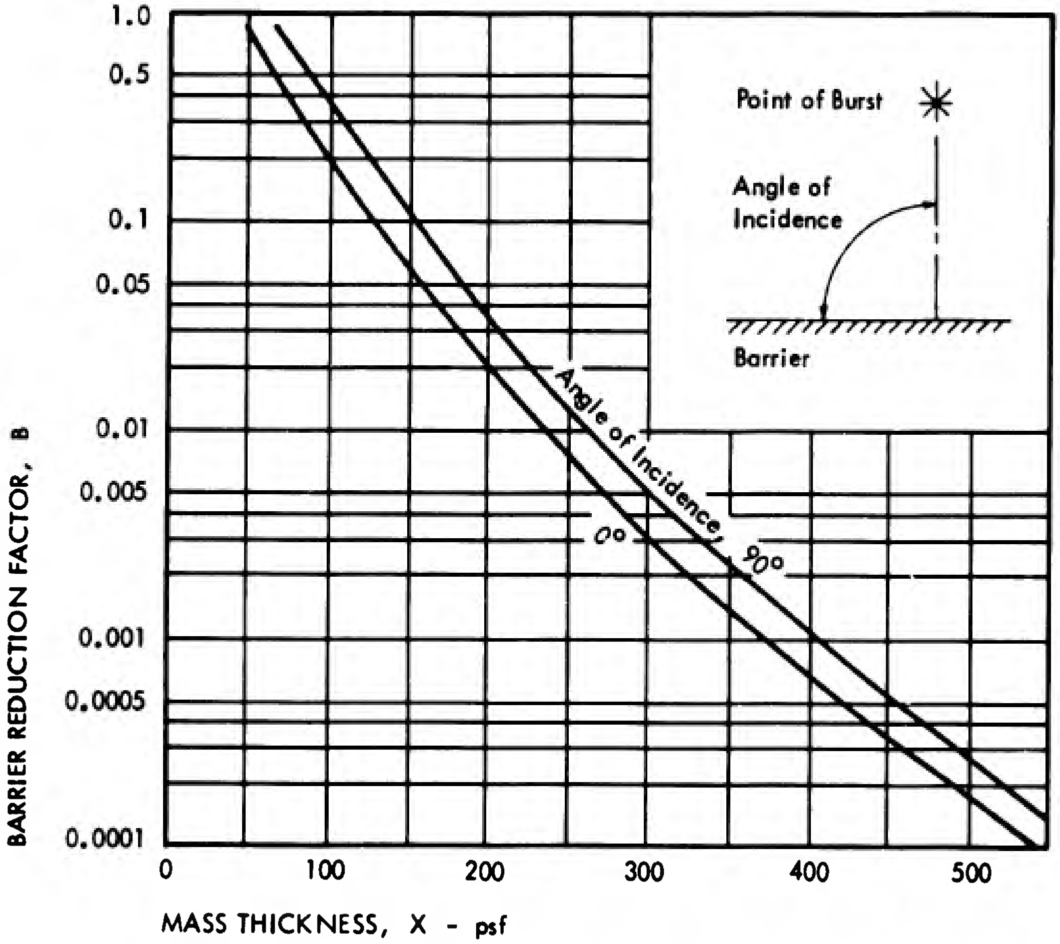


Figure 1-5

BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR 2.5 Mev NEUTRONS

SOURCE: Ref. 5.

radiation for shielding analyses is justified since it is the primary component of the initial gamma radiation at the ranges of interest in this study, and it is recommended as being on the conservative side in Ref. 1. A degree of conservatism for the barrier reduction factor is probably warranted for entranceways due to the previously mentioned neglect of the secondary gamma rays. Figures 1-4 and 1-5 show the barrier reduction factors for fusion yield neutrons (~ 14 Mev) and fission yield neutrons (~ 2.5 Mev), respectively.

Barriers Beyond First Corridor Bend

Gamma Radiation. The energy level of gamma radiation, which has been scattered through an angle of 90°, cannot be greater than 0.51 Mev, regardless of the initial energy. Therefore, the recommendation in Ref. 5 that Figure 1-6 be used for gamma ray barrier shielding beyond the first corridor bend, was adopted for this study.

Neutron Radiation. As recommended in Ref. 5, the reduction factors for neutron attenuation through barriers located beyond the first bend were obtained from Figure 1-5 for 2.5 Mev neutrons. The use of the lower average neutron energy level for interior barriers seems justified on the basis of the degradation of the free-field energy level beyond the first 90° corridor bend (Refs. 5 and 19).

Illustrative Example

To obtain the cost data presented in this report, it was necessary to perform an analysis of the attenuation of the initial radiation for the six blast entranceways (Types J and K). To demonstrate the method outlined in the previous sections, a typical initial radiation analysis is presented for entranceway J-1 in Figures 1-7 and 1-8.

Solid Angle Fractions

The solid angle fractions subtended at the various points shown on Figures 1-7 and 1-8 are given in the following tabulation. The values

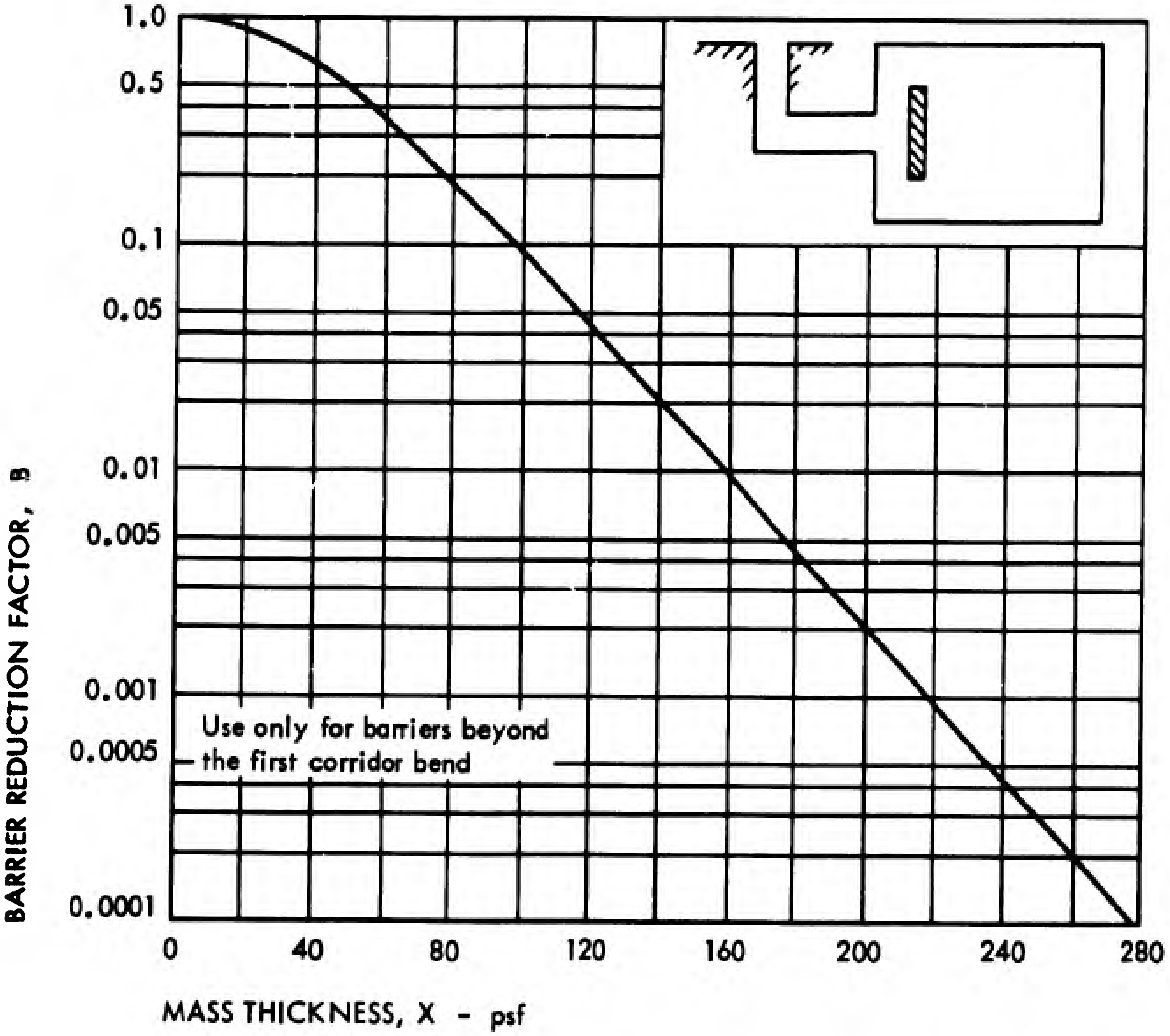
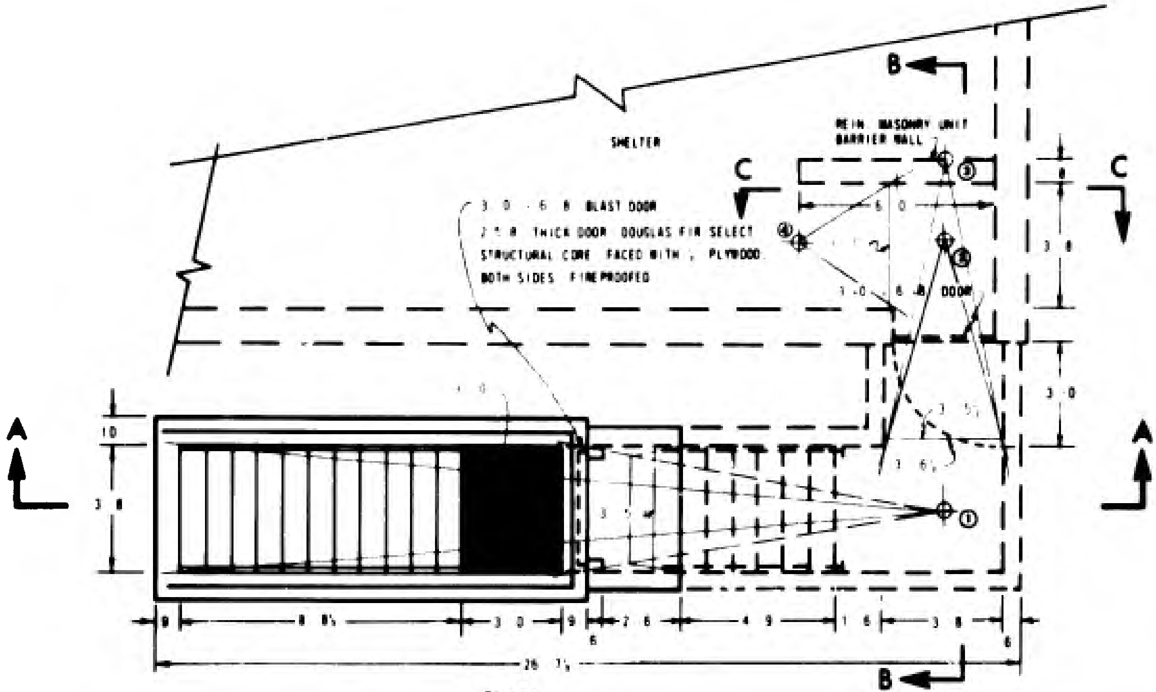


Figure 1-6

BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS
FOR 0.51 Mev GAMMA RAY PHOTON

SOURCE: Ref. 5.



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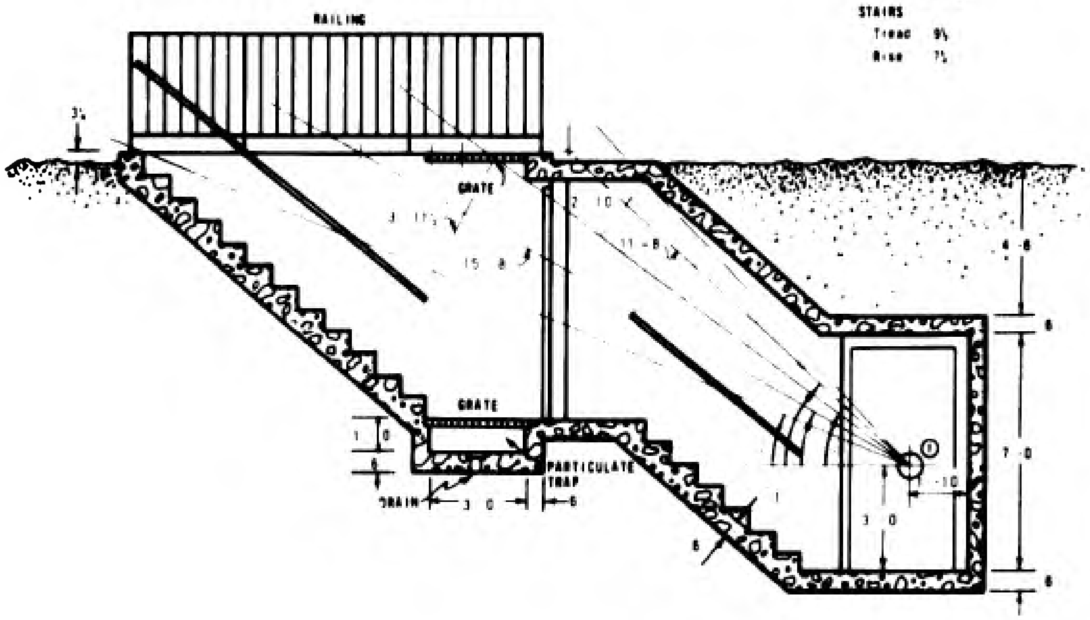
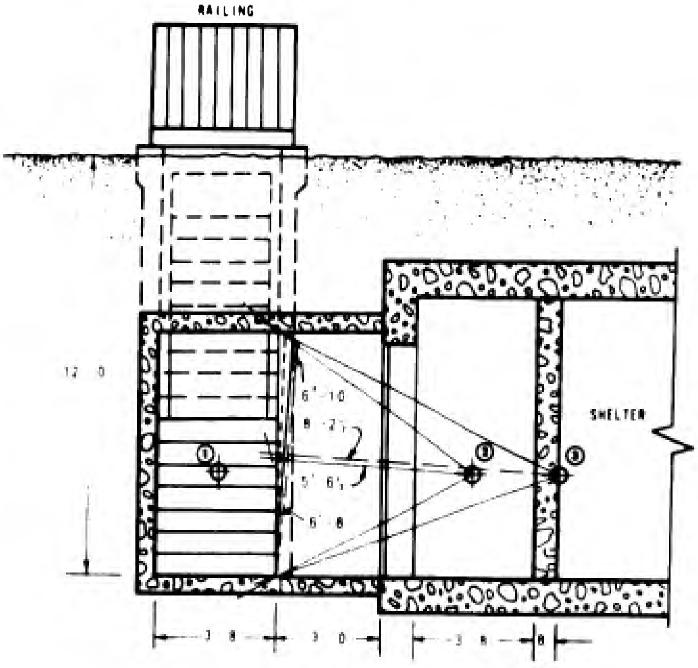


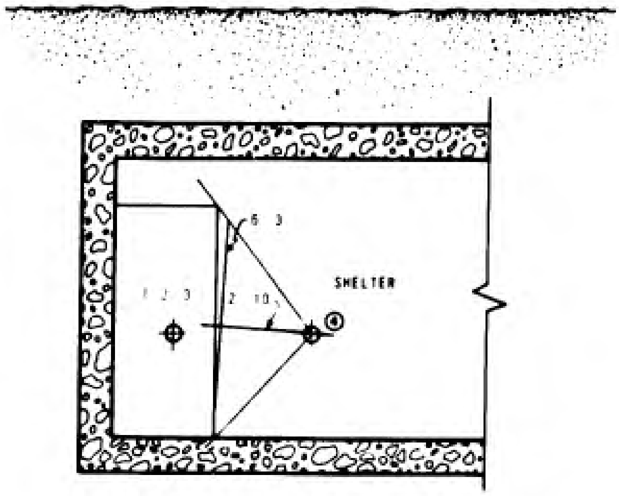
SECTION A-A

Figure 1-7

UNDERGROUND BLAST SHELTER ENTRANCEWAY, J-1



SECTION B-B



SECTION C-C

Figure 1-8
ENTRANCEWAY J-1, SECTIONS B-B AND C-C

of W, L, and Z were determined graphically as noted on the figures and used to obtain the solid angle fractions, ω, from Figure 1-1:

Point	W	L	Z	e	n	ω
1	3.00	3.96	15.67	0.76	7.91	0.008
2	3.46	6.67	5.54	0.52	1.66	0.10
3	3.54	6.83	8.21	0.52	2.40	0.055
4	3.42	6.25	2.83	0.55	0.91	0.25

where W, L = dimensions of the entrance opening projected on the plane normal to the selected line-of-sight, ft

Z = distance from detector to plane of W and L, ft

$$e = \frac{W}{L}$$

$$n = \frac{2Z}{L}$$

Assumed Weapon Parameters

Peak overpressure, P_{so} = 20 psi
Weapon yield, W = 200 kt
$W^{1/3} = 5.85$

Free Field Initial Radiation

As noted previously, the worst case orientation for radiation streaming in the entranceways in this study, was found to be for the grazing line-of-sight ϕ, as shown on Figure 1-7.

Slant Range

Knowing the peak overpressure and the angle ϕ, the horizontal range, R, to the shelter entranceway can be determined from Ref. 1 (Para. 3.67):

$$R = 780\ W^{1/3} = (780)(5.85) = 4560 \text{ ft}$$

and the slant range, R_s, is

$$R_s = \frac{4560}{\cos \phi} = 4900 \text{ ft} = 1630 \text{ yd}$$

Free-Field Initial Radiation

Using the appropriate figures and scaling factors from Ref. 1 (Para. 8.27, 8.61, and 11.90), the free-field initial radiation dose can be determined for a 200 kt weapon yield at the slant range of the entranceway as follows:

Gamma radiation = 4500 rads
Neutron radiation = 580 rads

Entranceway Reduction Factors

Gamma Radiation

At Point 1*

From Figure 1-2, for $\omega_1 = 0.008$ and $\beta = (\theta - \phi) = 7^{\circ}$

$R_{fe} = 0.15$

At Point 2

$R_f = R_{fe}\,(0.1\omega_2)$

$R_f = (0.15)(0.1)(0.10) = 0.0015$

At Point 3

$R_f = R_{fe}\,(0.1\omega_3)B$

From Figure 1-6, for $X = \frac{8}{12}(150) = 100$ psf

$B = 0.1$

$R_f = (0.15)(0.1)(0.055)(0.1) = 0.00008$

At Point 4

$R_f = R_{fe}\,(0.1\omega_2)(0.5\omega_4)$

$= (0.15)(0.1)(0.10)(0.5)(0.25) = 0.00019$

---

* The barrier reduction factor for the wood blast and entry doors is insignificant and is therefore not included.

Neutron Radiation

At Point 1

From Figure 1-2, for $\omega_1 = 0.008$ and $\beta = 7^\circ$

$R_{fe} = 0.08$

At Point 2

$L_{1/2} = 0.366\ (H+W)$

$= 0.366\ (7.00 + 3.67) = 3.90'$

$L = 7.67'$

$$n = \frac{L}{L_{1/2}} = \frac{7.67}{3.90} = 1.97$$

$$R_{fc} = \frac{1}{(2)^n} = 0.255$$

$R_f = R_{fe} \times R_{fc}$

$R_f = (0.08)(0.255) = 0.020$

At Point 3

From Figure 1-5, for X = 100 psf and angle of incidence = 90°

$B = 0.35$

$R_f = (0.08)(0.255)(0.35) = 0.0071$

At Point 4

$L_{1/2} = 0.366\ (7.65 + 3.67)$*

$= 4.14'$

$L = 11.84'$

$$n = \frac{11.84'}{4.14} = 2.86$$

---

* Average for corridor in entranceway and shelter

$R_{fc} = \frac{1}{(2)^n} = 0.138$

$R_f = R_{fe} \times R_{fc}$

$R_f = (0.08)(0.138) = 0.011$

Initial Gamma Radiation Dose

Through Entranceway

Dose at Point 2

$R_f = 0.0015$

$D_2 = R_f \times D_o$

where D_o = outside radiation dose
D_i = inside radiation dose

$D_2 = (0.0015)\ (4500) = 6.8$ rads

Dose at Point 3

$R_f = 0.00008$

$D_3 = (0.00008)(4500) = 0.4$ rad

Dose at Point 4

$R_f = 0.00019$

$D_4 = (0.00019)(4500) = 0.9$ rad

Through Entrance Roof Slab

Dose at Point 2

From Figures 1-7 and 1-8, W = 2.17', L = 3.42', Z = 11.67'

From Figure 1-1, for e = 0.64, n = 6.82

$\omega_{1A} = 0.009$

From Figure 1-2, for $\omega_{1A} = 0.009$ and $\beta = \theta_1 = \phi = 20°$

$R_{fe} = 0.07$

From Figure 1-3, for X = 1/2 150 = 75 psf, and angle of incidence = ϕ = 21°

B = 0.06

$R_f = R_{fc}\ (0.1\omega_2)\ B$

$R_f = (0.07)(0.1)(0.10)(0.06) = 0.000042$

$D_2 = R_f \times D_o$

$D_2 = (0.00004)(4500)$ = negligible

Dose at Point 4

$R_f = R_{fe}\ (0.1\omega_2)(0.5\omega_4)\ B$

$R_f = (0.07)(0.1)(0.10)(0.5)(.25)(0.06) = 0.000005$

D_4 = negligible

Through Roof Slab over Point 1

Dose at Point 2

$X = (\frac{150}{2}) + (4.5 \times 100) = 525$ psf*

From Figure 1-3, for X = 525 psf and angle of incidence = 21°

$B << 0.0001$

$R_f = B\ (0.1\omega_2)$

$R_f << (0.0001)(0.1)(0.10) << 0.000001$

D_2 = negligible

Therefore gamma radiation dose through roof slab over point 1 is negligible at all points of interest

---

* Assumes an infinite plane barrier with no geometry reduction

Through Entranceway Walls

Dose at Point 4

$X = (1.5 \times 150) + (2.5 \times 100) = 475$ psf

From Figure 1-3, for X = 475 psf and angle of incidence = 0 - 15°

D_4 = negligible

Initial Neutron Radiation Dose

Through Entranceway

Dose at Point 2

$R_f = 0.020$

$D_2 = R_f \times D_o$

$D_2 = (0.020)(580) = 11.6$ rads

Dose at Point 3

$R_f = 0.0071$

$D_3 = (0.0071)(580) = 4.1$ rads

Dose at Point 4

$R_f = 0.011$

$D_4 = (0.011)(580) = 6.4$ rads

Through Entrance Roof Slab

Dose at Point 2

From Figure 1-2, for $\omega = 0.009$ and $\phi = 20^\circ$

$R_{fe} = 0.07$

From Figure 1-4, for X = 75 psf and angle of incidence = $\phi = 21^\circ$

$B = 0.8$

$R_f = R_{fe} \times B \times R_{fc}$

$R_f = (0.07)(0.8)(0.255) = 0.014$

$D_2 = R_f \times D_o$

$D_2 = (0.014)(580) = 8.1$ rads

Dose at Point 3

$R_f = R_{fe} \times B \times R_{fc} \times B$

$R_f = (0.07)(0.8)(0.255)(0.35) = 0.0050$

$D_3 = (0.0050)(580) = 2.9$ rads

Dose at Point 4

$R_f = R_{fe} \times B \times R_{fc}$

$R_f = (0.07)(0.8)(0.138) = 0.0077$

$D_4 = (0.0077)(580) = 4.5$ rads

Through Roof Slab Over Point 1

Dose at Point 2

From Figure 1-4, for X = 525 psf and angle of incidence = 21^0

$B = 0.0007$

$R_f = B \times R_{fc}$

$R_f = (0.0007)(0.255) = 0.00018$

$D_2 = (0.00018)(580) =$ negligible

Therefore, neutron radiation dose through roof slab over Point 1 is negligible at all points of interest

Through Entranceway Walls

Dose at Point 4

From Figure 1-4, for X = 475 psf and angle of incidence = 0°*

B = 0.001

D_4 = (0.001)(580) = 0.6 rads

Summary

The tabulation below summarizes the initial radiation dose.

Source	Type of Radiation	Dose in Rads		
		Point 2	Point 3	Point 4
Entranceway	Gamma	6.8	0.4	0.9
Entranceway	Neutron	11.6	4.1	6.4
Entrance roof slab	Gamma	0	0	0
Entrance roof slab	Neutron	8.1	2.9	4.5
Roof slab at Point 1	Gamma	0	0	0
Roof slab at Point 1	Neutron	0	0	0
Entranceway walls	Gamma	--	--	--
Entranceway walls	Neutron	--	--	0.6
Total radiation dose		27	7	12

From the above tabulation, it is apparent that to reduce the 27 rad dose at Point 2 to a tolerable level in the shelter would require either lengthening the corridor or adding a barrier wall at the shelter entrance. The addition of a 6-ft long barrier wall reduces the dose to 7 rads at the interior face of the wall and to 12 rads at the entrance to the shelter proper. In view of the uncertainties in calculating the free-field nuclear radiation quantities and in the radiation analysis method, the entranceway design is considered adequate for the cost analysis performed

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* This assumes the walls are infinite in extent. If the geometry were considered, the reduction factor would be decreased.

in this study. If desired, it would be relatively inexpensive to reduce the radiation dose further by increasing the thickness of the entrance slab, by increasing the length of the barrier wall, or by increasing the length of the corridor between Points 1 and 2. For instance, increasing the thickness of the entrance slab from 6 in. to 9 in. would reduce the radiation dose for Point 4 at the shelter entrance from 12 to approximately 8 rads, but would not significantly increase the total cost of the entranceway.

Appendix 2

FALLOUT SHIELDING ANALYSIS OF ENTRANCEWAYS

By H. L. Murphy

Appendix 2

FALLOUT SHIELDING ANALYSIS OF ENTRANCEWAYS

By H. L. Murphy

The entranceways developed in the project were examined for shielding capability against fallout contaminant from a nuclear detonation, as stated earlier. This somewhat repetitive FSA (fallout shielding analysis) work led to an approach that is presented in this appendix. Entranceways A-2 and C-1 are used for demonstration.

Entranceway pencil drawings to scale were used, since their use permits direct measurement of the many dimensions needed in FSA and thereby saves much working time over a method requiring any calculation of dimensions.

The basic tool was that whose use is currently taught in Office of Civil Defense FSA courses for practicing engineers and architects (Ref. 20). Therein, a careful comparison of Figure 4.6, used for cleared (or contaminated) finite circular areas, with the roof chart (Chart 4) values for a zero mass thickness roof showed identical results for the same solid angle fractions; however, Chart 4 with its entering argument of solid angle fraction (ω) is better suited to entranceway FSA purposes.

Certain assumptions are necessary in entranceway FSA. Some used in this project were:

1. Contamination factors: Fallout contaminant enters the entranceway portal at the "standard" (outdoor) rate per unit (horizontally projected) area, and this is then spread uniformly over all horizontal areas of the entranceway but not beyond the first turn. Using entranceway A-2 (see Figure 2-1) as an example, the contamination factor would be the area of the portal (3.67 X 9.5 ft) divided by the total area of steps and particulate trap under the grating (3.67 X 19.42 ft), or 0.489. To assume that the contaminant would only fall straight down into the entranceway would be nonconservative in PF (protection factor) results and would be assuming zero wind conditions. At the other end, it might be assumed that most if not all of the contaminant would accumulate

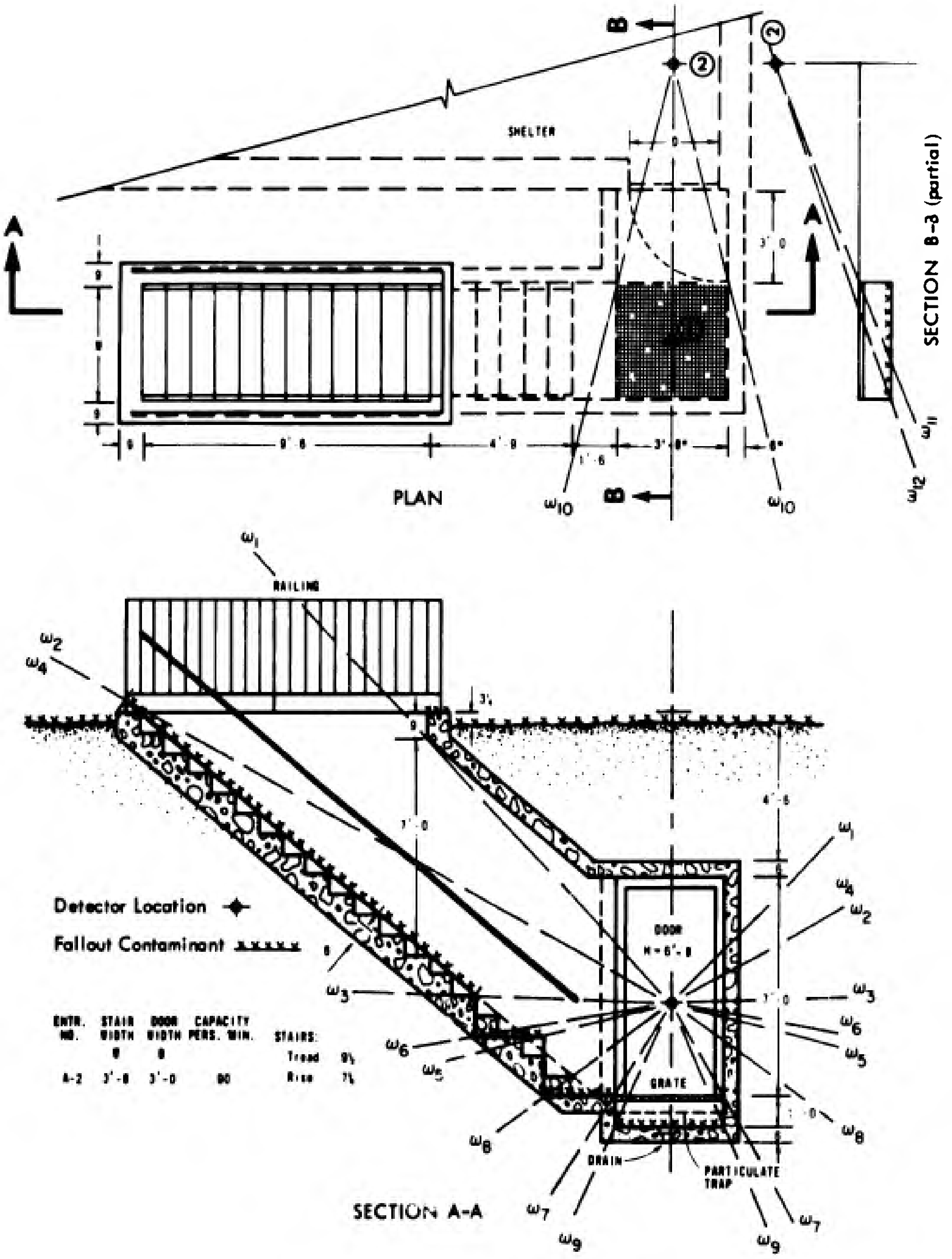


Figure 2-1
WORKED-OUT EXAMPLE 1

on the step at the level of the grating and on the trap under the grating. This assumption is conservative but was not used because shelter occupants could readily sweep the step contaminant through the grating or flush down both step and trap to get rid of the contaminant entirely.

This assumption was modified in entranceways such as B-5 as follows: Each side of the entranceway was separately handled as described for entranceway A-2 down to and including the grating, resulting in a doubling of the assumed contamination under the grating.

Another contamination factor was used in dealing with the steps located above the horizontal plane of the detector; it is discussed in the Worked-Out Example 1.

2. Steel gratings hold no falling contaminant and provide negligible shielding.

3. Doors of ordinary wood or hollow metal construction provide negligible shielding.

4. Detector location is a point although the human body is not.

5. For stairs located above the detector horizontal plane, neither the stairs nor stair nosings, if any, provide significant shielding. This assumption is demonstrated by the examples.

6. Where a contaminated area could both be "seen" (at least partially) by the final detector location and was in a tunnel-like location--for example, the trap under the grating, entranceway A-2--contributions were included for both (a) the contaminated area directly to the final detector location and (b) for the same contaminant being "seen" at a detector location directly above the contaminant, and then through a right-angle (tunnel) turn to the final detector location. This assumption was termed the "tunnel effect" for use in this study. It was sometimes applied as just described; sometimes only the larger of the two contributions (a) and (b) was used; or, for a relatively open entranceway (for example, entranceway D-4), only contribution (b) was used. The rationale was based on the likelihood of gamma radiation scattering off walls in a somewhat long and narrow, relatively confined, tunnel-like situation.

Entranceway A-2 fallout shielding analysis was made using a pencil scale drawing illustrated by Figure 2-1. The computational steps shown in Table 2-1 are explained following the table.

Table 2-1

COMPUTATIONS FOR WORKED-OUT EXAMPLE 1

	ω	W	L	Z	ω	Multipliers	C_o
1.	ω_1	3.67	18	9.3	.0860	-0.5/0.489	-.0036
2.	ω_2	3.67	35.2	9.3	.1095	0.5/0.489	.0046
3.	ω_3	3.67	10.4	3.9	.2213	-0.5 × 0.85	-.0186
4.	ω_4	3.67	40.6	3.9	.2746	0.5 × 0.85	.0238
5.	ω_5	3.67	8.3	1.1	.6223	-0.5	-.0791
6.	ω_6	3.67	13	1.1	.6416	0.5	.0827
7.	ω_7	3.67	3.67	3	.1755	-0.5	-.0169
8.	ω_8	3.67	8.3	3	.2780	0.5	.0284
9.	ω_9	3.67	3.67	4	.1112	1	.0207
10.							C_1 = .0472
11.	ω_{10}	3.67	7	7	.0723	$0.2C_1\omega_{10}$	.0007
12.	ω_{11}	3.67	18.7	4	.2505	-0.5	-.0252
13.	ω_{12}	3.67	21.33	4	.2553	0.5	.0257
							C_t = .0012 × 0.489
							= .0006
							PF ≈ 1700

Lines 1-2: Core and peripheral area of a decontaminated, zero mass roof (Chart 10, Case 3). Dividing this one item by the contamination factor permits applying the factor to the overall total contribution, rather than to each step, because it applies to all other contributions except this one.

Lines 3-on: Roof contributions all taken from Chart 4, zero mass thickness.

Lines 3-4: Steps changed to a plane, which is then treated as if horizontal; second contamination factor enters here, in that the plane used has a greater area than the horizontal area of the steps, thus the 0.85 multiplier.

Lines 5-8: Steps below detector horizontal plane, simplified into two steps.

Line 9: Particulate trap contribution to detector location 1.

Line 11: Converts total contribution to detector location 1 through a turn and solid angle fraction into a contribution to detector location 2.

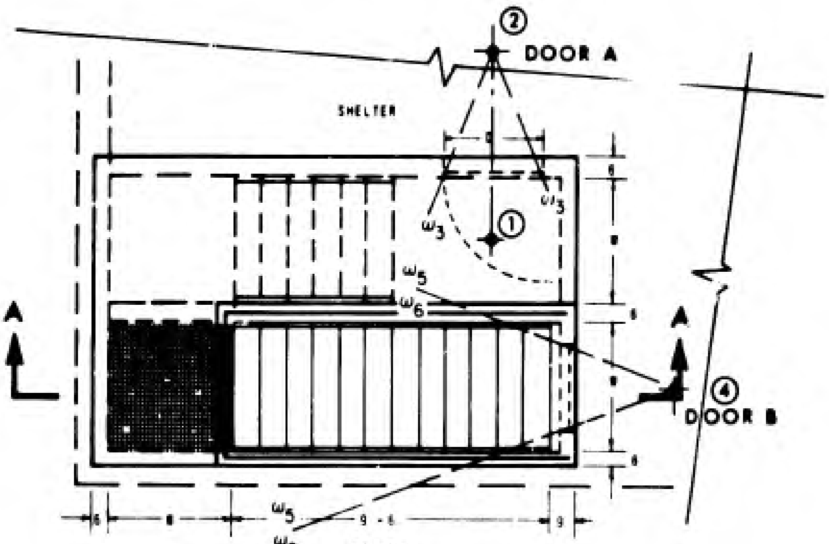
Lines 12-13: Contribution from portion of trap seen from detector location 2.

An entranceway C-1 FSA was made, also using a pencil scale drawing illustrated by Figure 2-2. The computational steps shown in Table 2-2 are explained below.

Table 2-2

COMPUTATIONS FOR WORKED-OUT EXAMPLE 2

	ω	W	L	Z	ω	Multipliers	C_o
1.	ω_1	3.7	4	9	.0278	+0.5 $[X_o=75]$	.0011
2.	ω_2	3.7	23.5	9	.1022	+0.5 $[X_o=75]$	.0040
3.							C_1 = .0051
4.	ω_3	3	6.8	3.5	.1770	$0.2C_1\omega_3$	C_{T_A} = .0002
							$PF_A \approx$ 5000
5.	ω_4	3.67	12	6.4	.1207	$0.7\omega_5$ $[X_o=100]$	.0006
6.	ω_5	2.5	6.67	3.5	.1491		--
7.	ω_6	3.67	17.2	9.3	.0839	0.5 $[X_o= 100]$	.0021
							C_{T_B} = .0027 X 0.571 = .0015
							$PF_B \approx$ 670



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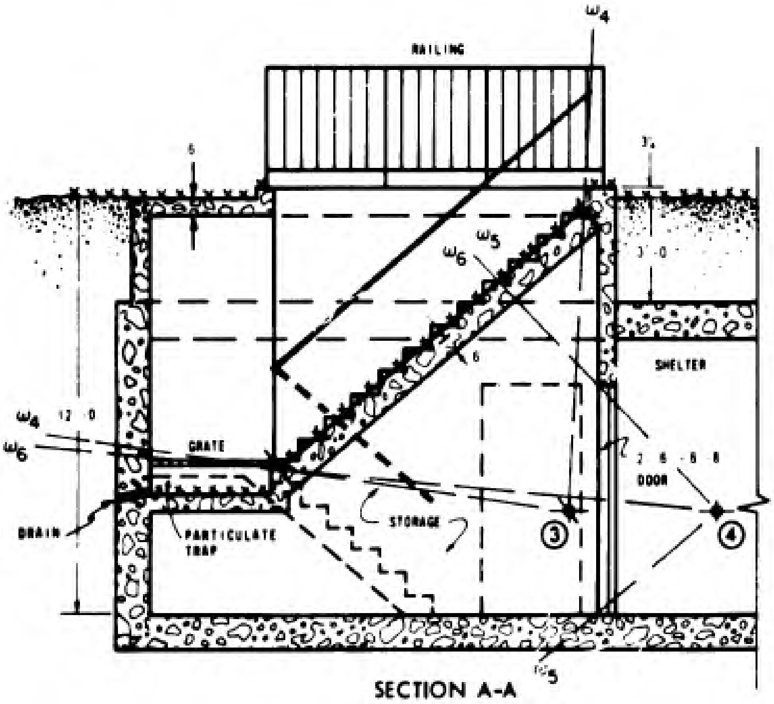


SECTION A-A

ENTR. NO.	STAIR WIDTH W	DOOR SIZE D	CAPACITY PERS./MIN	STAIR
C-1	3'-8	3'-0 x 6'-8	90	TREAD 9½

Figure 2-2

WORKED-OUT EXAMPLE 2

Door A

General: Radiation from contamination on stairs must come through the concrete steps, a 6-in. concrete wall acting like an interior partition, and the doorway restriction, <u>or</u> must be reflected through three turns, in either case making this contribution negligible. Similar thinking may be applied to the trap under the grating. Thus, the only contribution left to be considered is that from the contaminated roof above the room where detector location 1 is shown, an ordinary off-center detector location problem. Contributions were all taken from Chart 4.

Lines 1-2: Roof above off-center detector location 1 (ω_1 and ω_2 not shown in Figure 2-2).

Line 4: Turn and solid angle fraction from 1 to 2.

Door B

General: Stairs simplified as in Worked-Out Example 1. Because of tunnel effect, contributions taken directly to detector location 4, and via 3 to 4; that direct to 4 restricted to portion seen through doorway, because any other must come through concrete stairs (used 8-in. or 100 psf, for mass) and through 6-in. more concrete in lintel, thereby becomes negligible. Any contribution from trap under grating is negligible because of both geometry and barriers. Contribution from roof over detector location 1 must come through several heavy barriers, so it is negligible. Contamination factor for steps and trap under grating amounts to 9.5/13.17 and must be combined with a factor for the simplified stairs amounting to 9.5/12, giving a combined factor of 0.571. Contributions were all taken from Chart 4.

Line 5: First right-angle turn is 0.2 and no turn is 1; for this partial turn, 0.7 was used.

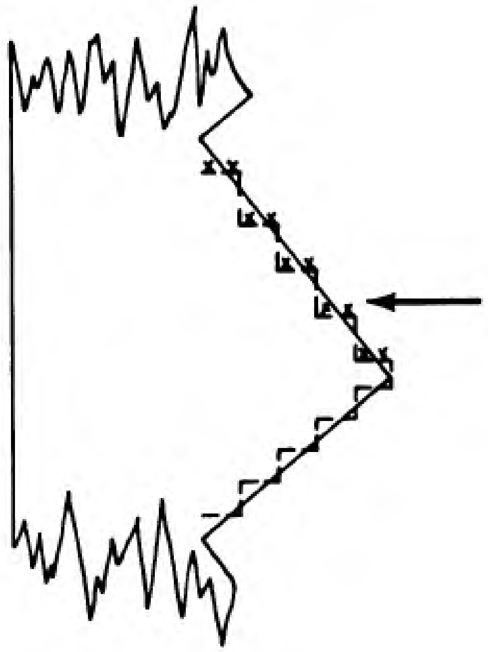
Line 7: Ray from stairs to detector location 4 treated as normal to the simplified stairs, thus solution is for a half-roof.

Some of the values in Tables 2-1 and 2-2 are shown to an unwarranted number of decimal places. They are shown that way, however, because (1) all solid angle fractions and all zero mass roof contributions were computer-calculated so that no extra work was involved and (2) such might be useful to anyone trying to check through the computations, for understanding or other reasons.

Near the end of this work, two simplifications used (as in the first example problem solution herein) were subjected to more detailed examination. Computer programs were used for computing solid angle fractions and for computing radiation contributions, both to save professional working time and, more specifically, to carry values out to several decimal places, take differences, and then round off the total to fewer decimal places, all aimed at reducing round-off values wherein "roof" cores were continually subtracted from larger "roof" values. Simplifications examined were:

1. Simplification of the stairs located below the detector horizontal plane to fewer stairs. In Figure 2-1, the total contribution from the actual steps below the detector horizontal plane, including the step at the level of the grating, amounted to 0.0164.* In Worked-Out Example 1 the contribution based on the simplification amounted to 0.0151,* or an error of -8 percent in this one item In carrying this nonconservative error forward, however, the tunnel turn reduces its effect so much as to leave the overall total contribution unchanged.

2. Simplification of the stairs located above the detector horizontal plane to a sloping, plane, smooth, contaminated surface, then analyzed by rotating the plane of the detector. Each step in Figure 2-1 was analyzed by considering it in five "roof" increments as indicated in the sketch, but the same Z distance was used for each step, as shown by the sketch arrow. The mass thickness of each increment was determined from its scaled thickness (on a scale drawing at 1"=0.1'), using reinforced concrete at 150 pcf. With a core and peripheral roof calculation for each of five increments and for each of 15 steps, 150 roof contributions were calculated. In Worked-Out Example 1, the contribution from the simplification of the stairs above the detector horizontal plane was 0.0052.* The results from the 150 roof calculations was 0.00524,* indicating an error of < 1 percent. Table 2-3 gives



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* Value before applying general contamination factor, 0.489.

values obtained for stair widths of 22, 44, and 66 in., and shows gross errors ranging from -9 percent to +10 percent in using the sloping plane approximation. Such errors would be indeed negligible after the radiation contribution values were multiplied by 0.489 (contamination factor), 0.2 (first tunnel turn), and 0.0723 (tunnel solid angle fraction), or a combined multiplier of 0.00707. Unfortunately, time was not available for detailed calculations varying other parameters than stair width.

Table 2-3

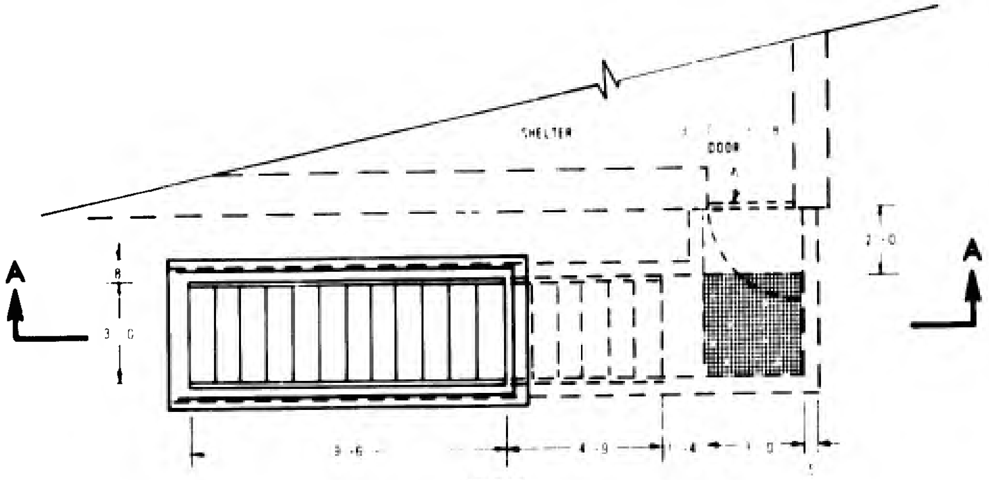
CONTRIBUTIONS FOR VARIOUS STAIR WIDTHS

	Detailed Computations		Sloping Plane Approximation		
Stair Width	C_T	$\left[\frac{9.5''}{6''}\right] C_T$	C_o	$0.85\ C_o$	Error
22"	.00166	.00263	.0028	.0024	-9%
44"	.00331	.00524	.0061	.0052	-1%
66"	.00487	.00771	.0100	.0085	+10%

The matter of stair nosings was reviewed briefly during the work. Nosings are required by some building codes, for the particular tread-rise values used. One standard nosing detail, shown in Ref. 38, is a simple one requiring only the sloping of the riser, the effect of which is to increase the tread by 1 in. Such a change would have only a trivial effect on the computations herein; e.g., use of this nosing in the examples in this appendix would mean only that each nosing would move the contaminant out 1 in. from the back of the tread below, leaving the same amount of tread contaminated as was assumed.

Appendix 3

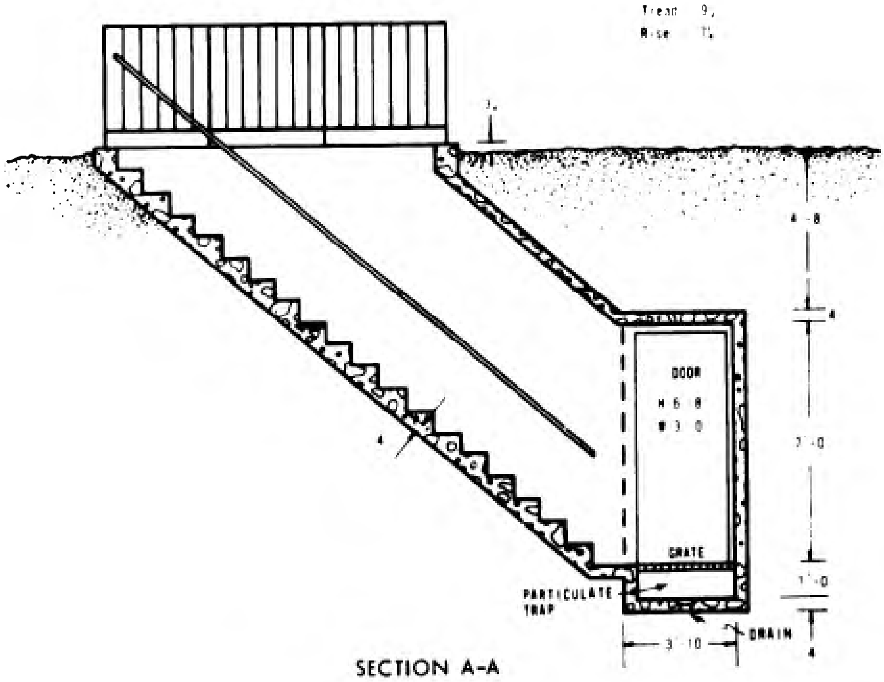
ENTRANCEWAY PLANS



PLAN

CAPACITY
67 persons/min

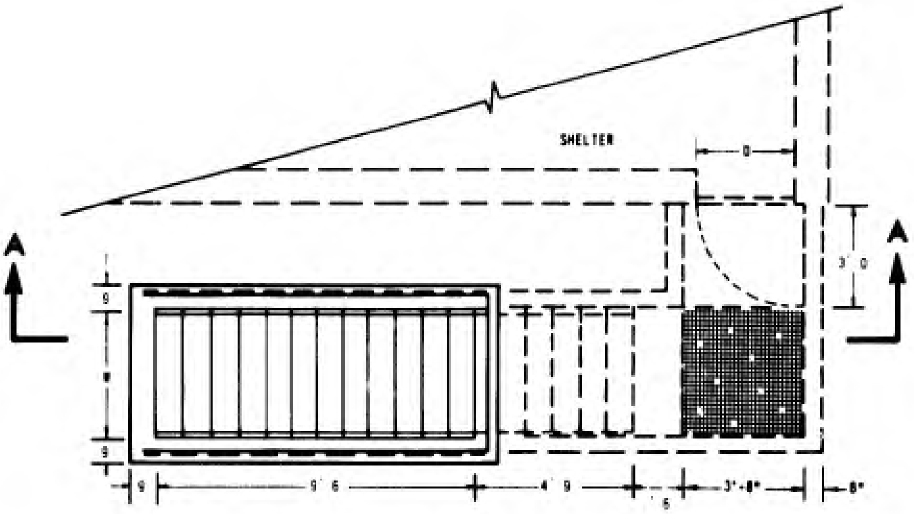
STAIRS
Tread 9½
Rise 7½



SECTION A-A

Figure 3-1

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. A-1
Reinforced Concrete, Single Stair



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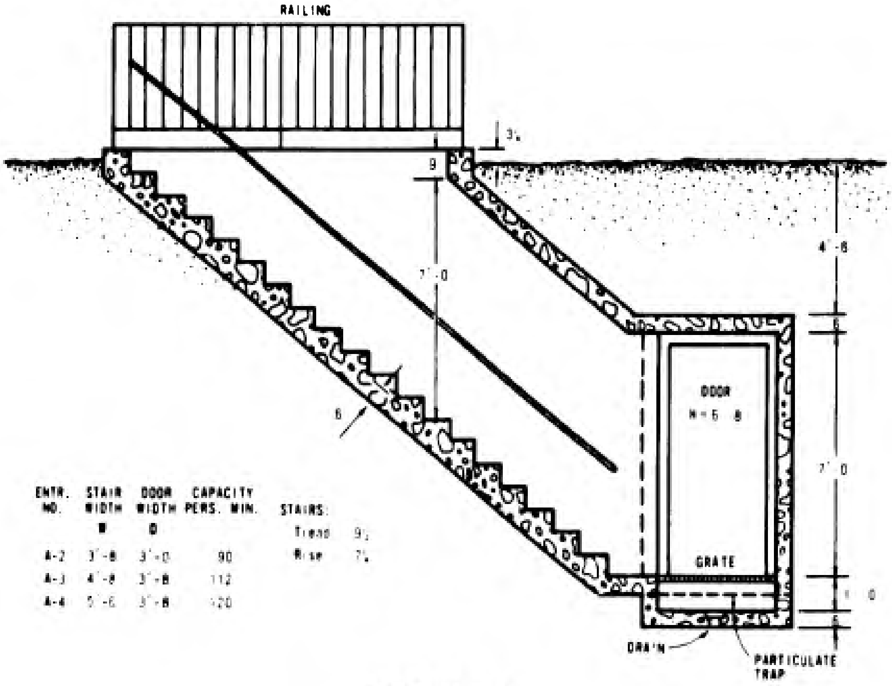


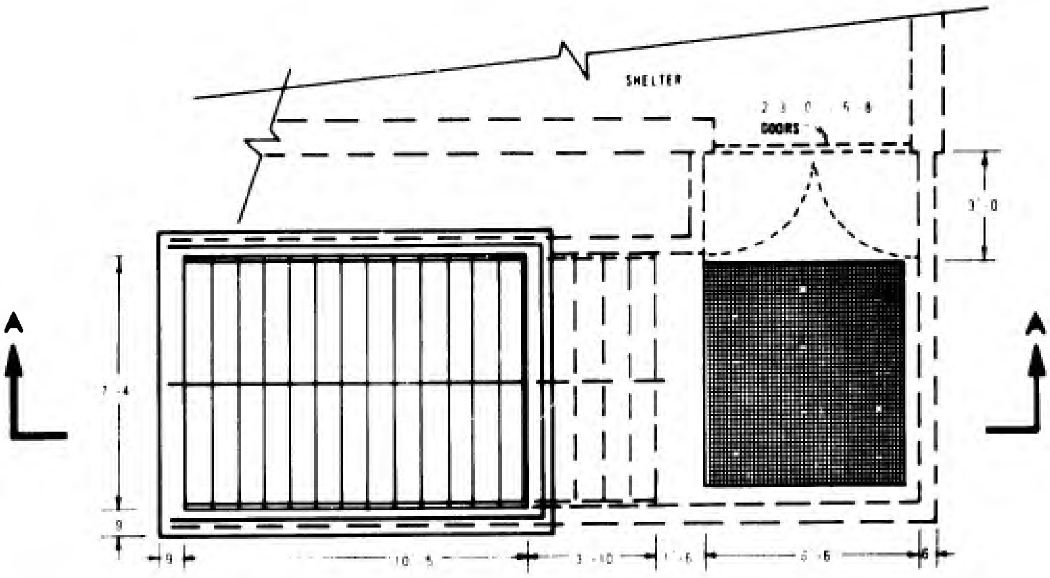
ENTR. NO.	STAIR WIDTH W	DOOR WIDTH D	CAPACITY PERS. MIN.
A-2	3'-8	3'-0	90
A-3	4'-8	3'-8	112
A-4	5'-6	3'-8	120

STAIRS:
Tread 9½
Rise 7½

SECTION A-A

Figure 3-2

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. A-2, A-3, AND A-4
Reinforced Concrete, Single Stair



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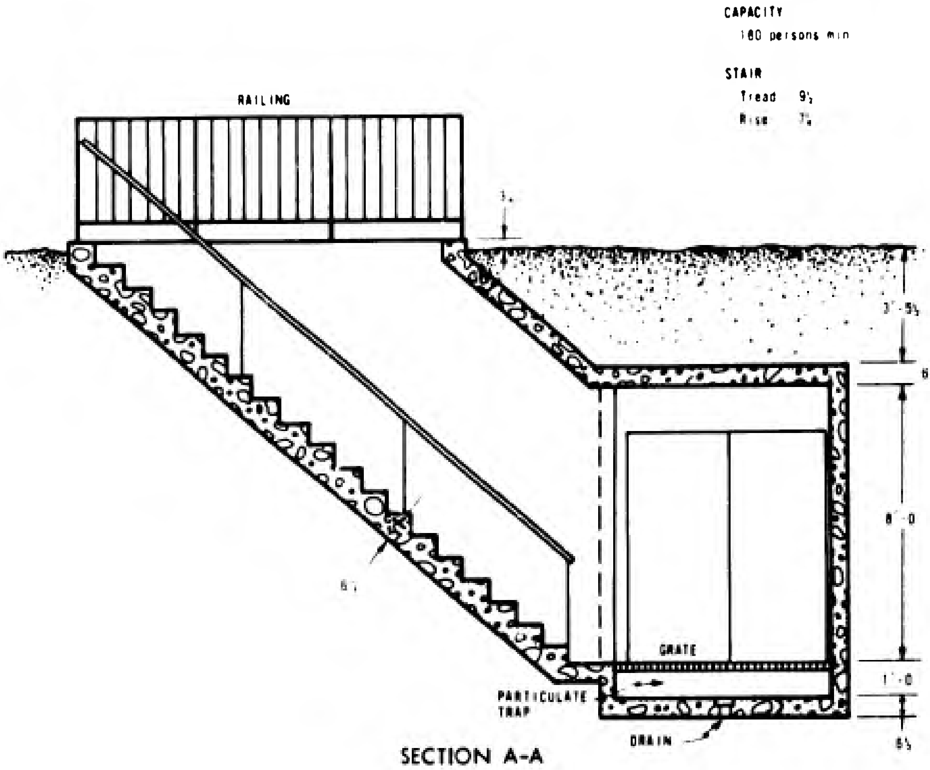
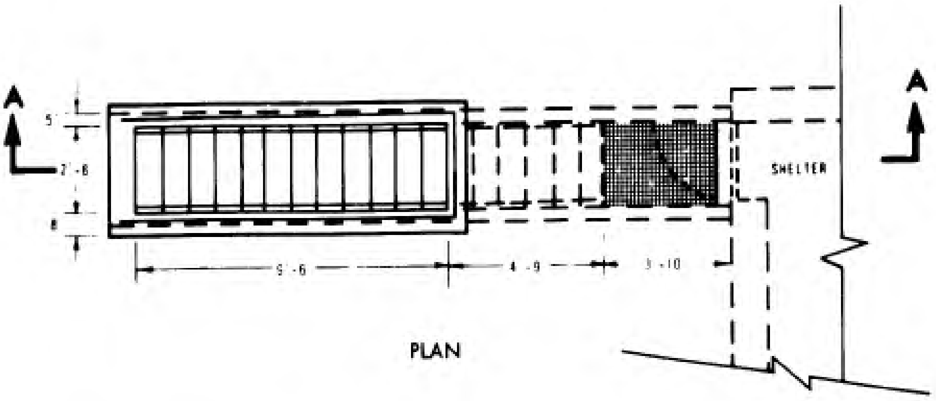

CAPACITY
180 persons min

STAIR
Tread 9½
Rise 7¾

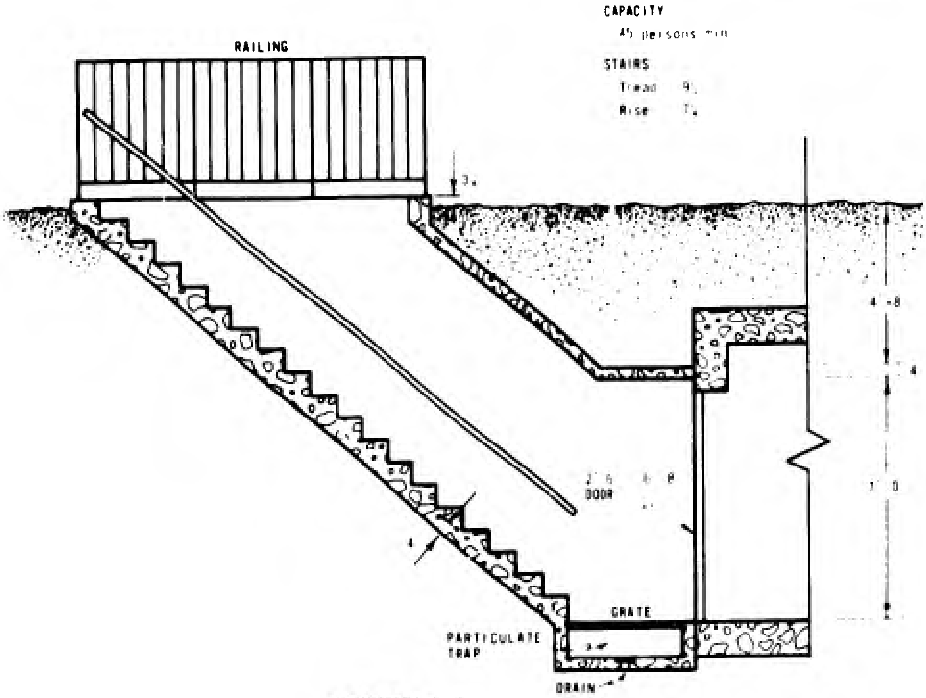
SECTION A-A

Figure 3-3

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. A-5
Reinforced Concrete, Single Stair



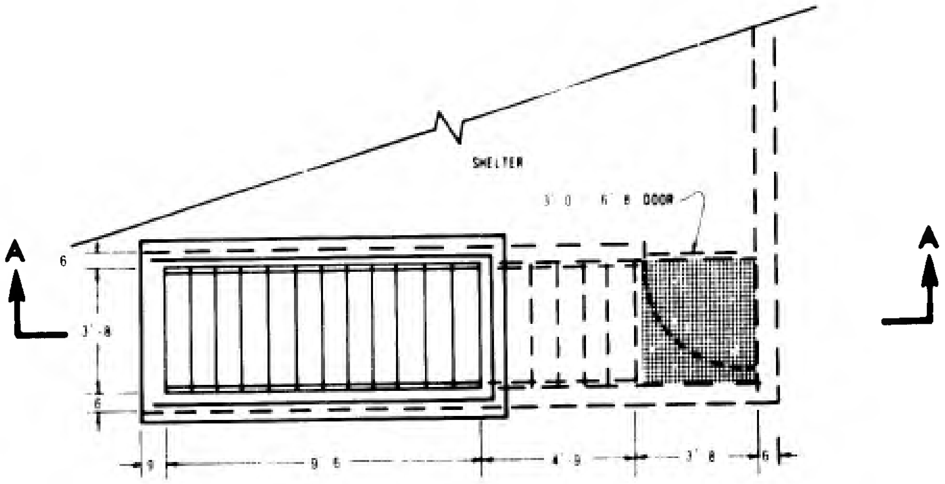
PLAN



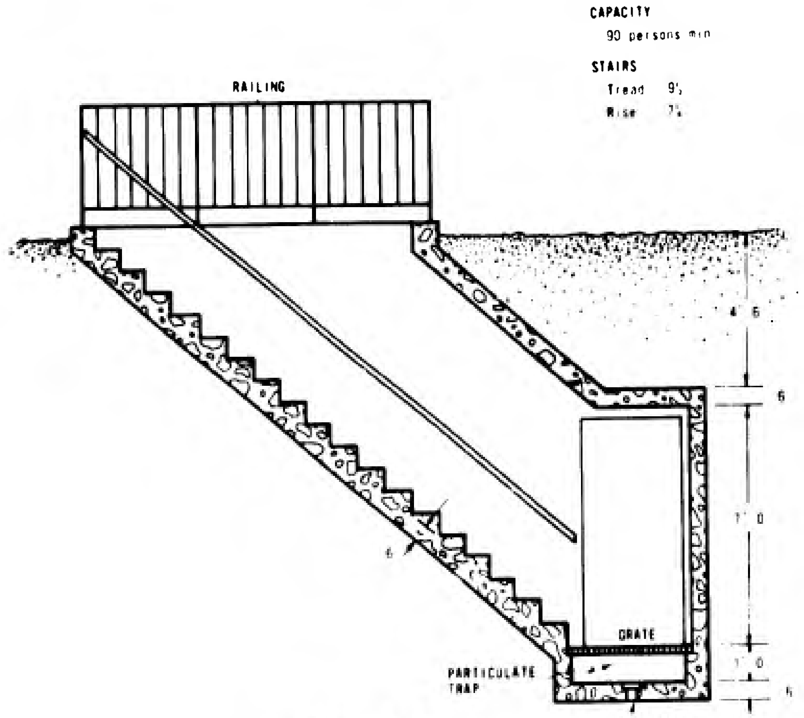
SECTION A-A

Figure 3-4

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. A-6
Reinforced Concrete, Single Stair



PLAN



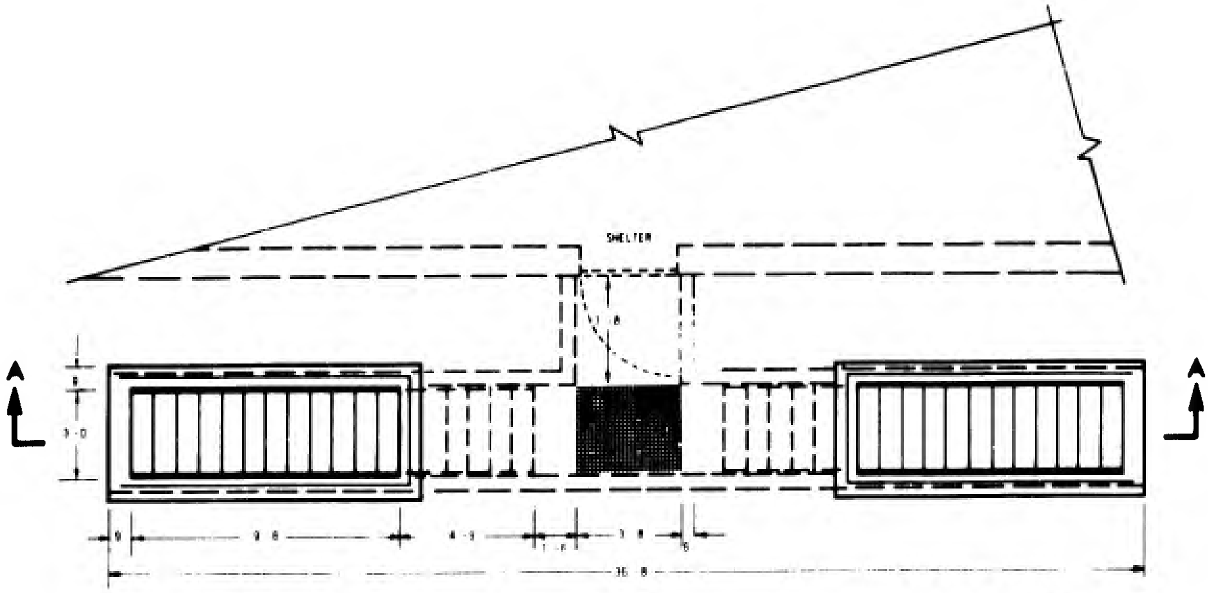
CAPACITY
90 persons min

STAIRS
Tread 9½
Rise 7½

SECTION A-A

Figure 3-5

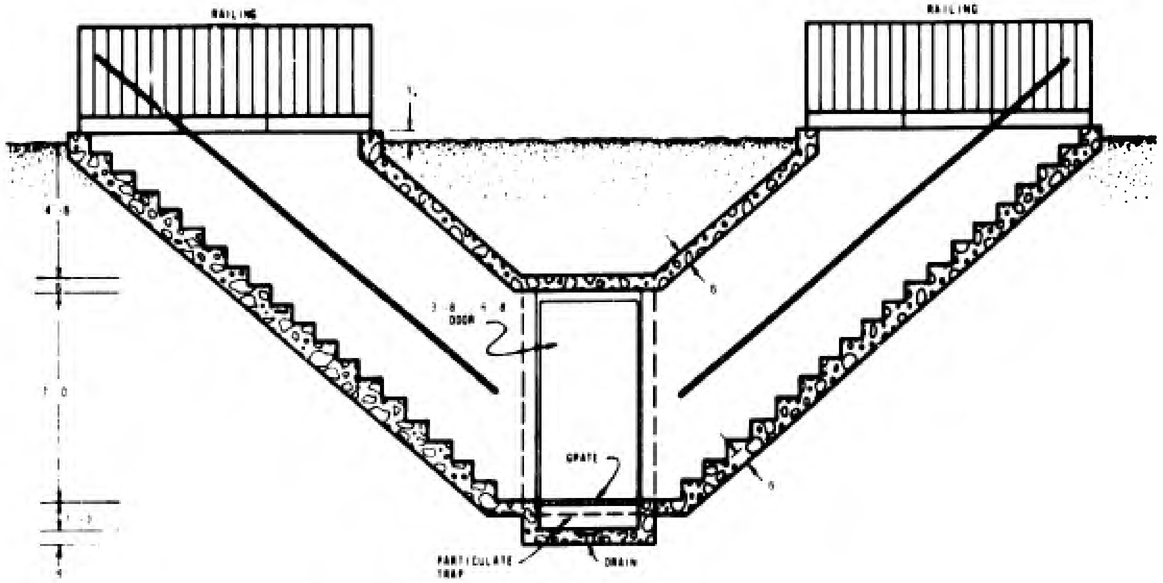
UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. A-7
Reinforced Concrete, Single Stair



PLAN

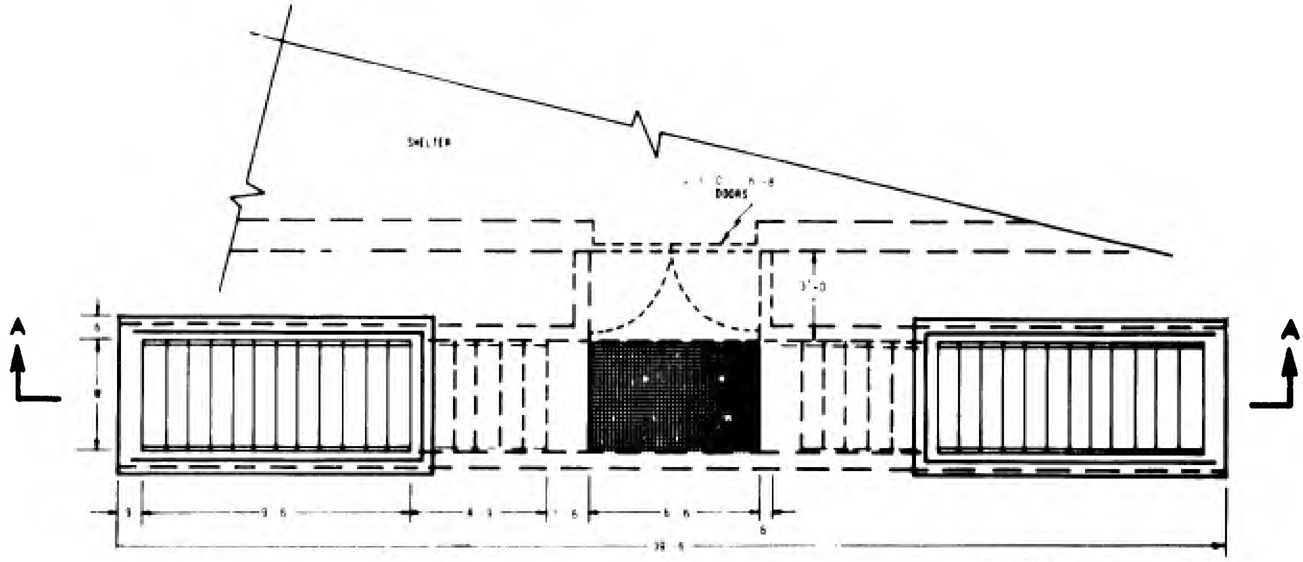
CAPACITY
120 persons min

STAIRS
Tread 9½
Rise 7¼



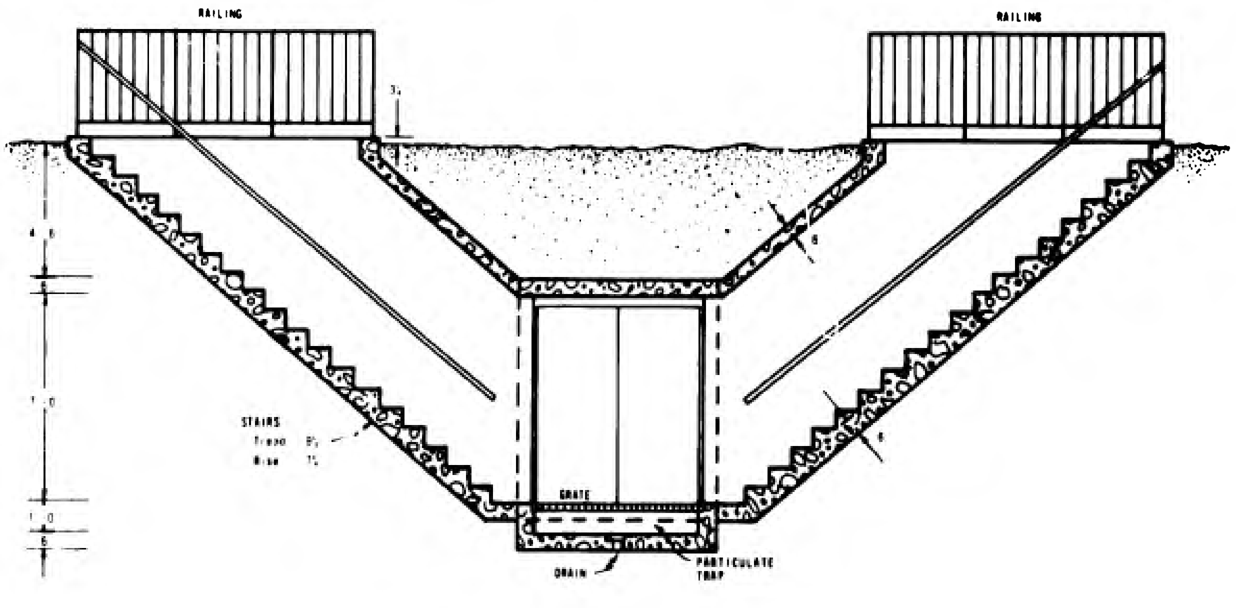
SECTION A-A

Figure 3-6
UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. B-1
Reinforced Concrete, Dual Stair



PLAN

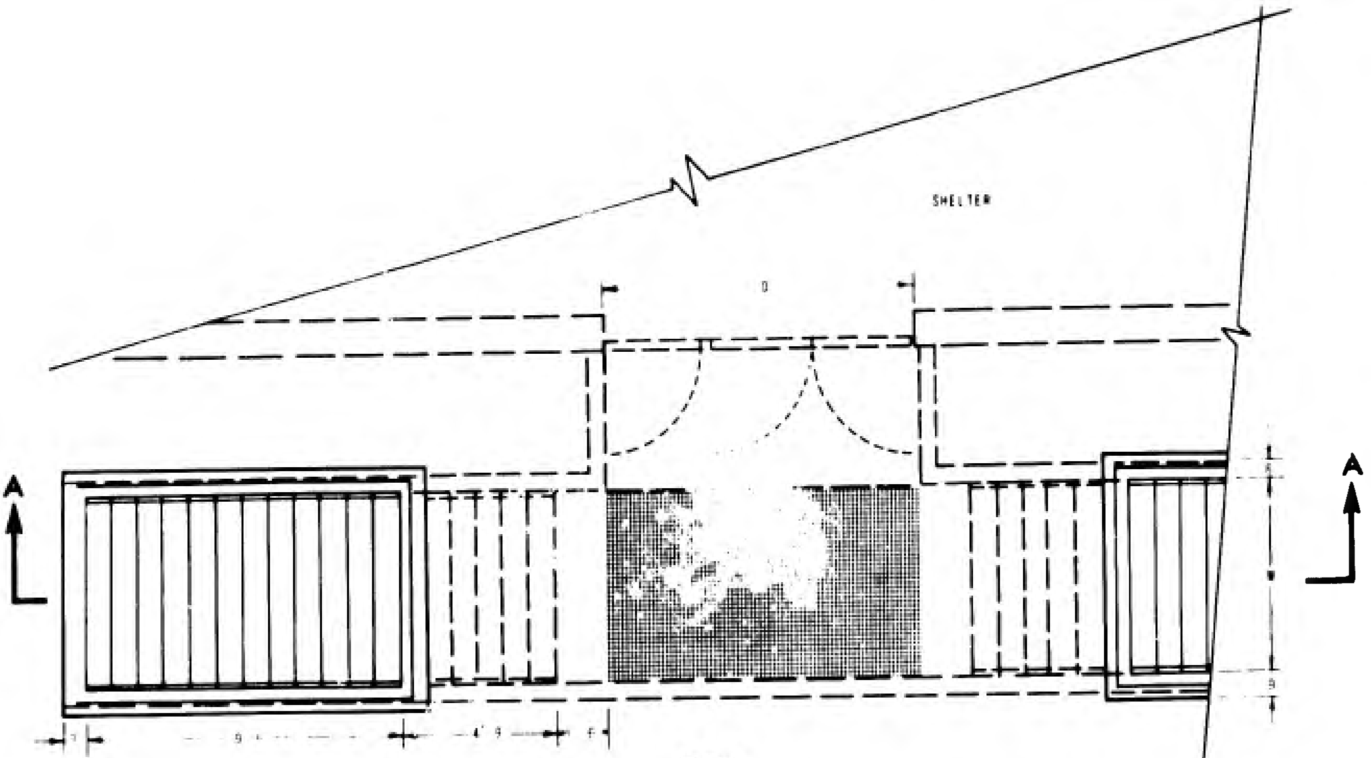
ENTR. NO.	STAIR WIDTH W	DOOR SIZE	CAPACITY PERS. MIN.
B-2	3'-0	2-3'-0 x 6'-8	135
B-3	3'-6	2-3'-0 x 6'-8	180



SECTION A-A

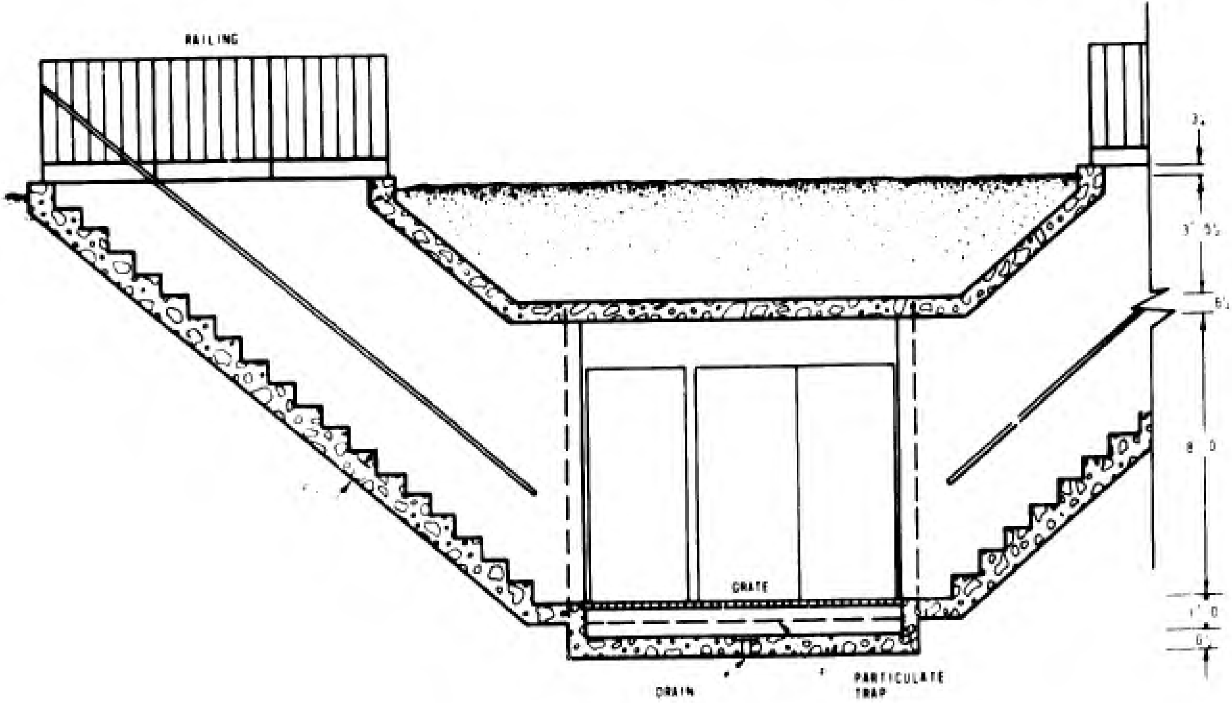
Figure 3-7

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. B-2 AND B-3
Reinforced Concrete, Dual Stair



PLAN

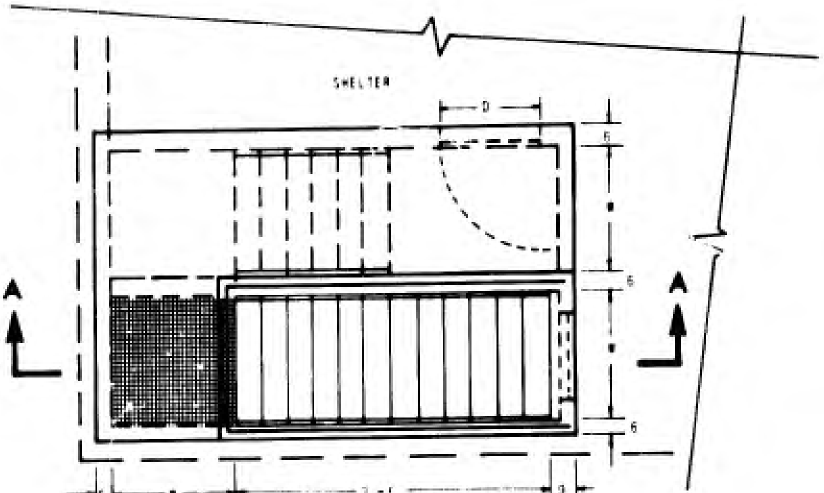
ENTR. NO.	STAIR WIDTH W	DOOR SIZE D	CAPACITY PERS. MIN.	STAIRS
B-4	4 8	2 3 8 6 8	225	Tread [illegible]
B-5	5 6	3 3 0 6 8	270	Rise 7¼



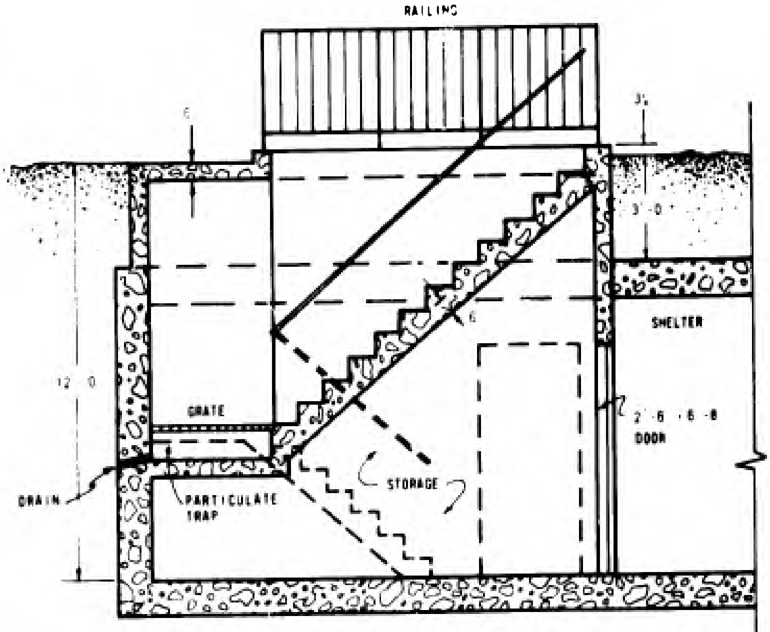
SECTION A-A

Figure 3-8

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. B-4 AND B-5
Reinforced Concrete, Dual Stair



PLAN

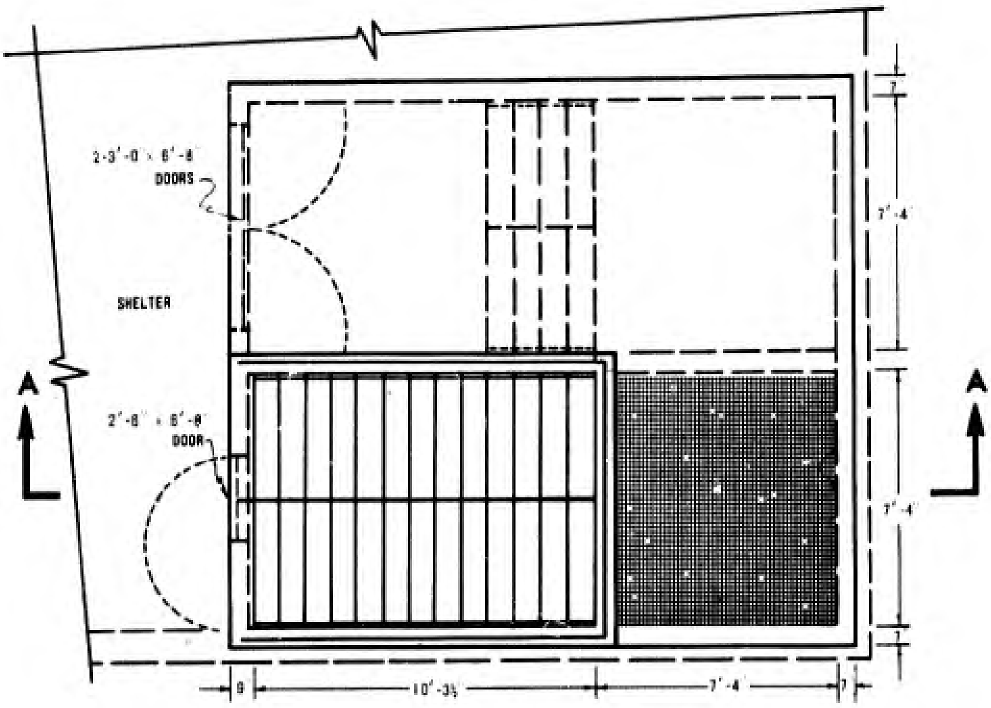


SECTION A-A

ENTR NO.	STAIR WIDTH W	DOOR SIZE D	CAPACITY PERS MIN	STAIR
C-1	3 -8	3 -0 6 8	90	TREAD 9½
C 2	5 -6	3 8 6 8	120	RISE 7¼

Figure 3-9

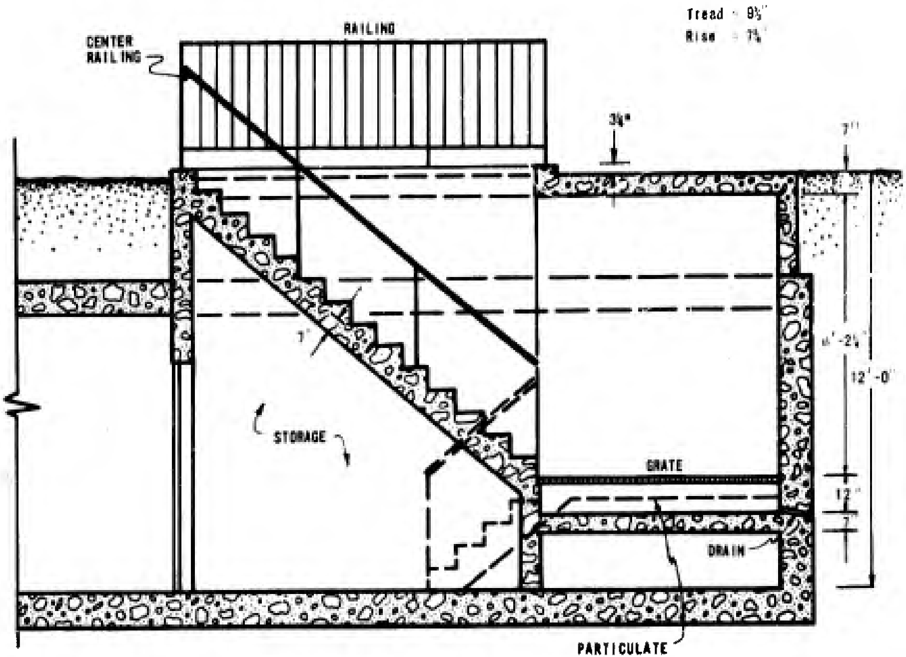
UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. C-1 AND C-2
Reinforced Concrete, Covered Stairwell, Interior Location



PLAN

CAPACITY:
180 persons/min.

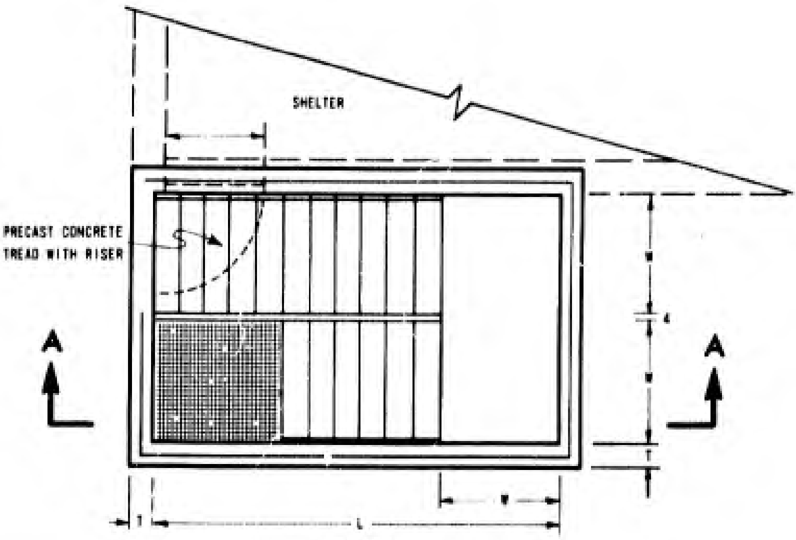
STAIRS:
Tread = 9½"
Rise = 7¾"



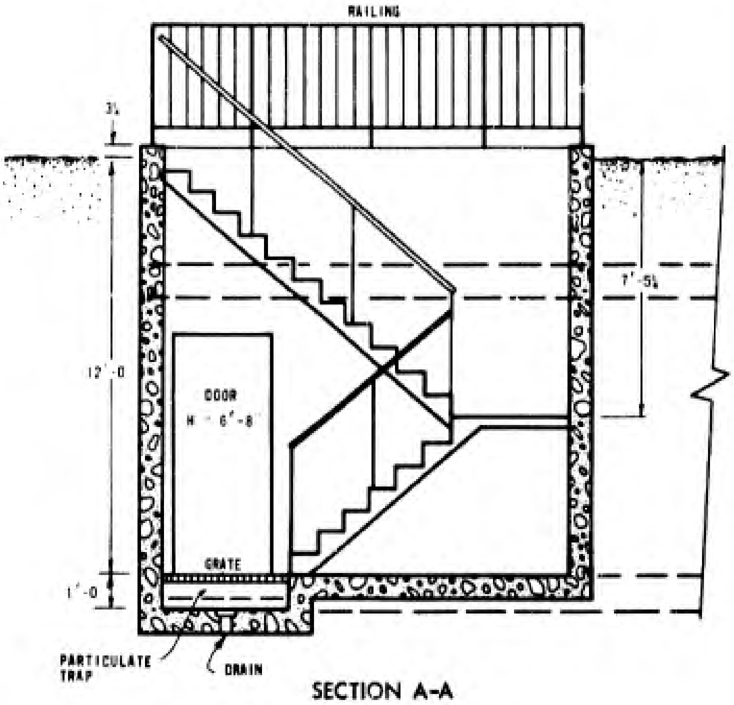
SECTION A-A

Figure 3-10

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. C-3
Reinforced Concrete, Covered Stairwell, Interior Location



PLAN

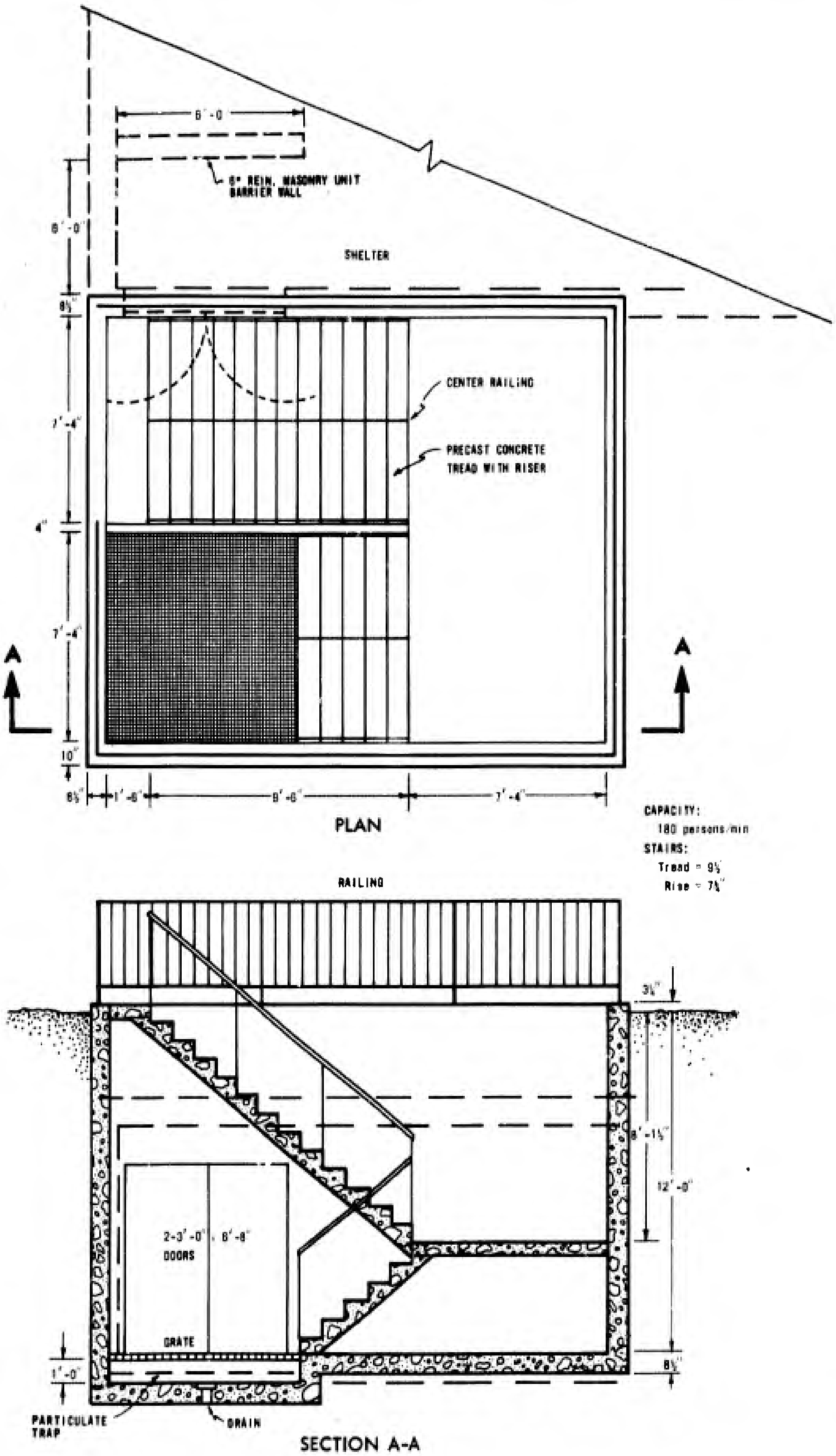


SECTION A-A

ENTR. NO.	STAIR WIDTH W	DOOR WIDTH D	LENGTH L	WALL THICK. T	CAPACITY PERS/MIN.	STAIRS:
D-1	3'-0"	3'-0"	11'-8½"	8"	67	TREAD 9½"
D-2	3'-8"	3'-0"	12'-4½"	8"	80	RISE 7¾"
D-3	5'-6"	3'-8"	15'-0"	8½"	120	

Figure 3-11

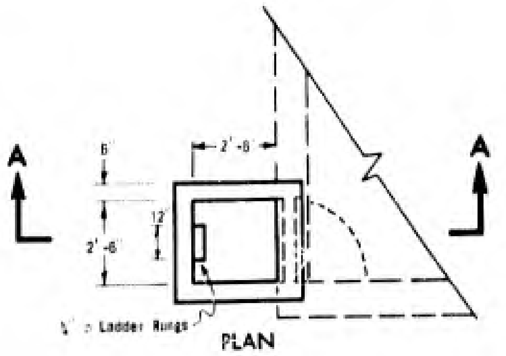
UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. D-1, D-2, AND D-3
Reinforced Concrete, Open Stairwell



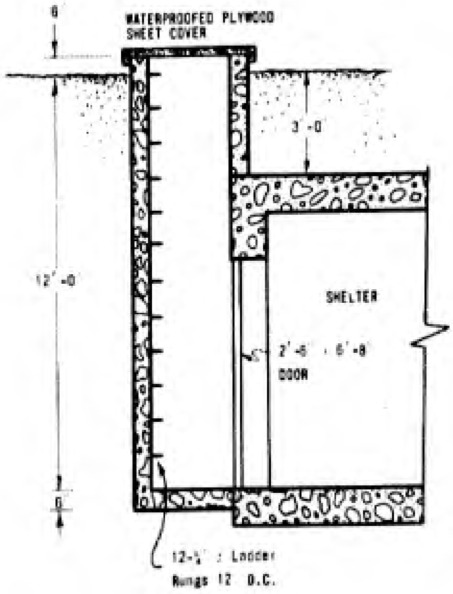
CAPACITY:
180 persons/min
STAIRS:
Tread = 9½"
Rise = 7¾"

Figure 3-12

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. D-4
Reinforced Concrete, Open Stairwell



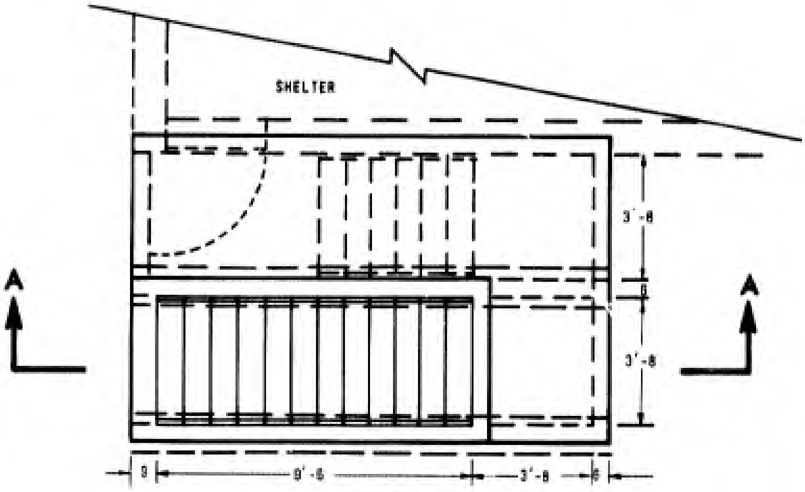
PLAN



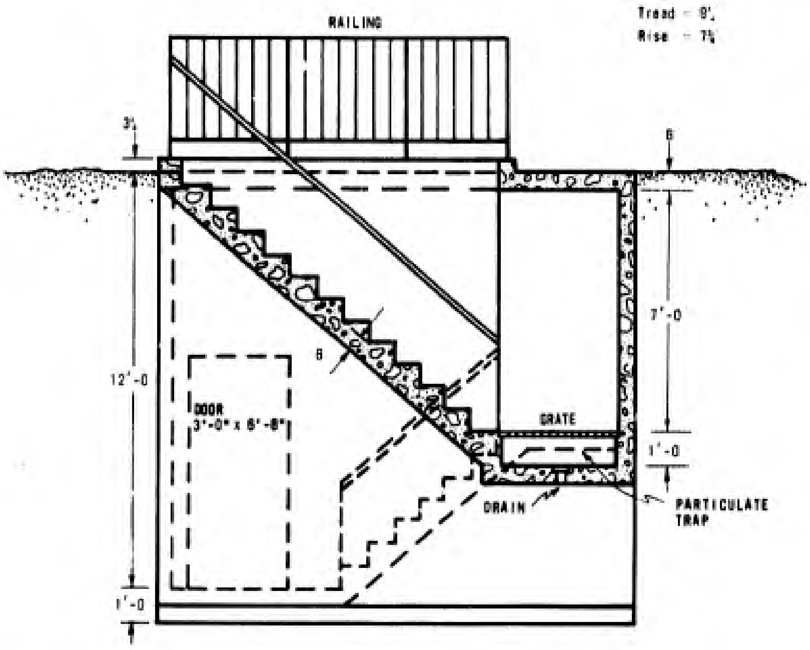
SECTION A-A

Figure 3-13

UNDERGROUND FALLOUT SHELTER ESCAPE EXIT, NO. E-1
Reinforced Concrete



PLAN



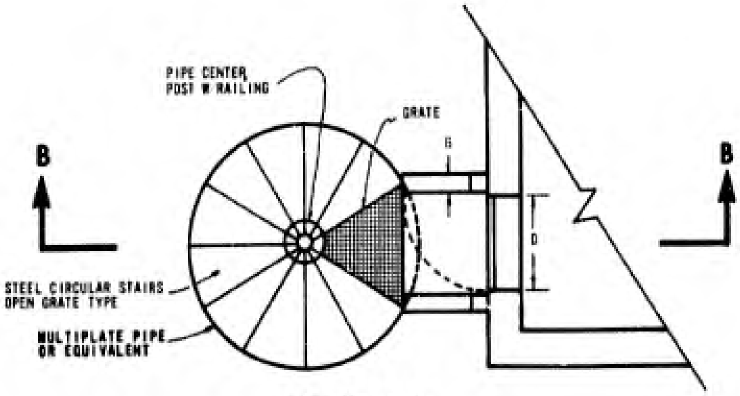
CAPACITY:
90 persons/min

STAIRS:
Tread = 9½
Rise = 7½

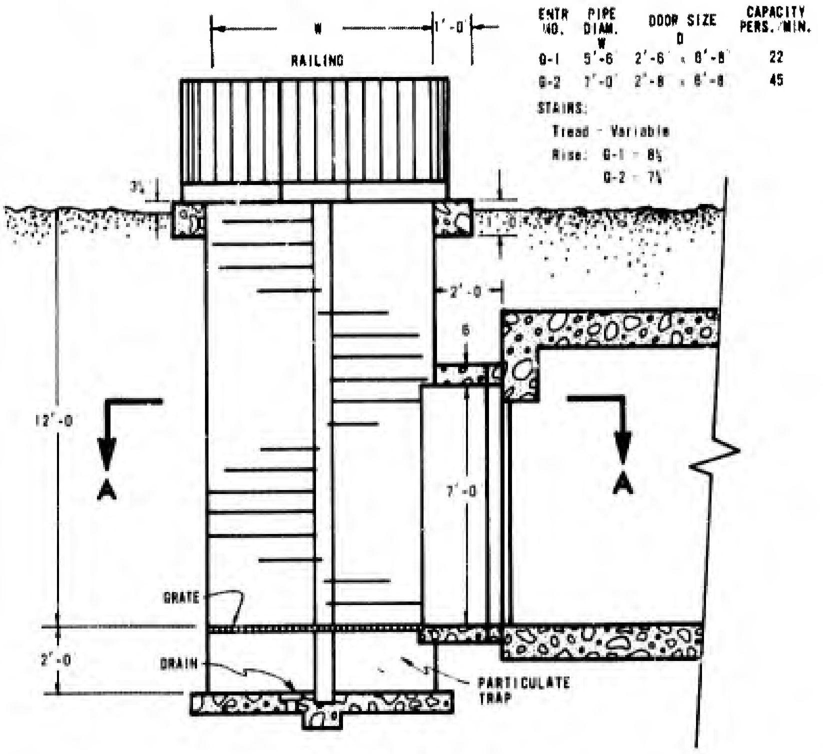
SECTION A-A

Figure 3-14

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. F-1
Reinforced Concrete, Covered Stairwell, Exterior Location



SECTION A-A



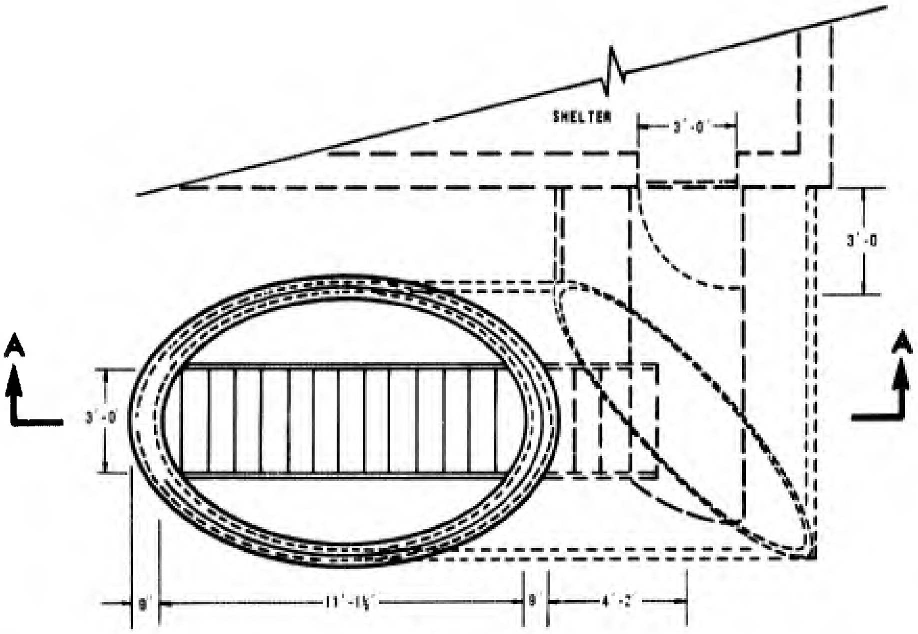
ENTR NO.	PIPE DIAM. W	DOOR SIZE D	CAPACITY PERS./MIN.
G-1	5'-6"	2'-6" x 6'-8"	22
G-2	7'-0"	2'-6" x 6'-8"	45

STAIRS:
Tread – Variable
Rise: G-1 – 8½
G-2 – 7½"

SECTION B-B

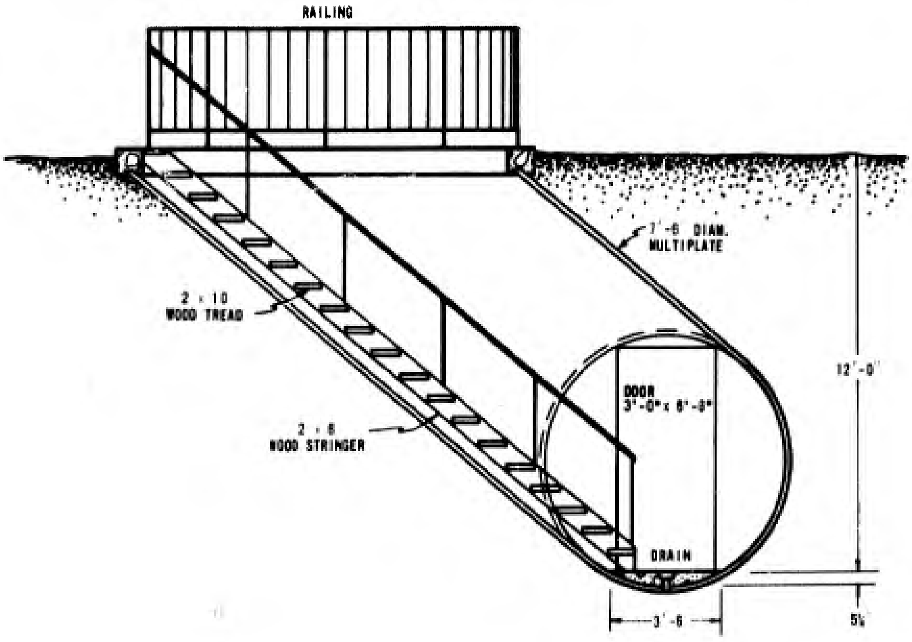
Figure 3-15

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. G-1 AND G-2
Circular Steel Pipe, Vertical Orientation



PLAN

CAPACITY:
67 Persons/Min
STAIRS:
Tread = 9½"
Rise = 7¾"



SECTION A-A

Figure 3-16

UNDERGROUND FALLOUT SHELTER ENTRANCEWAY, NO. H-1
Circular Steel Pipe, Single Stair

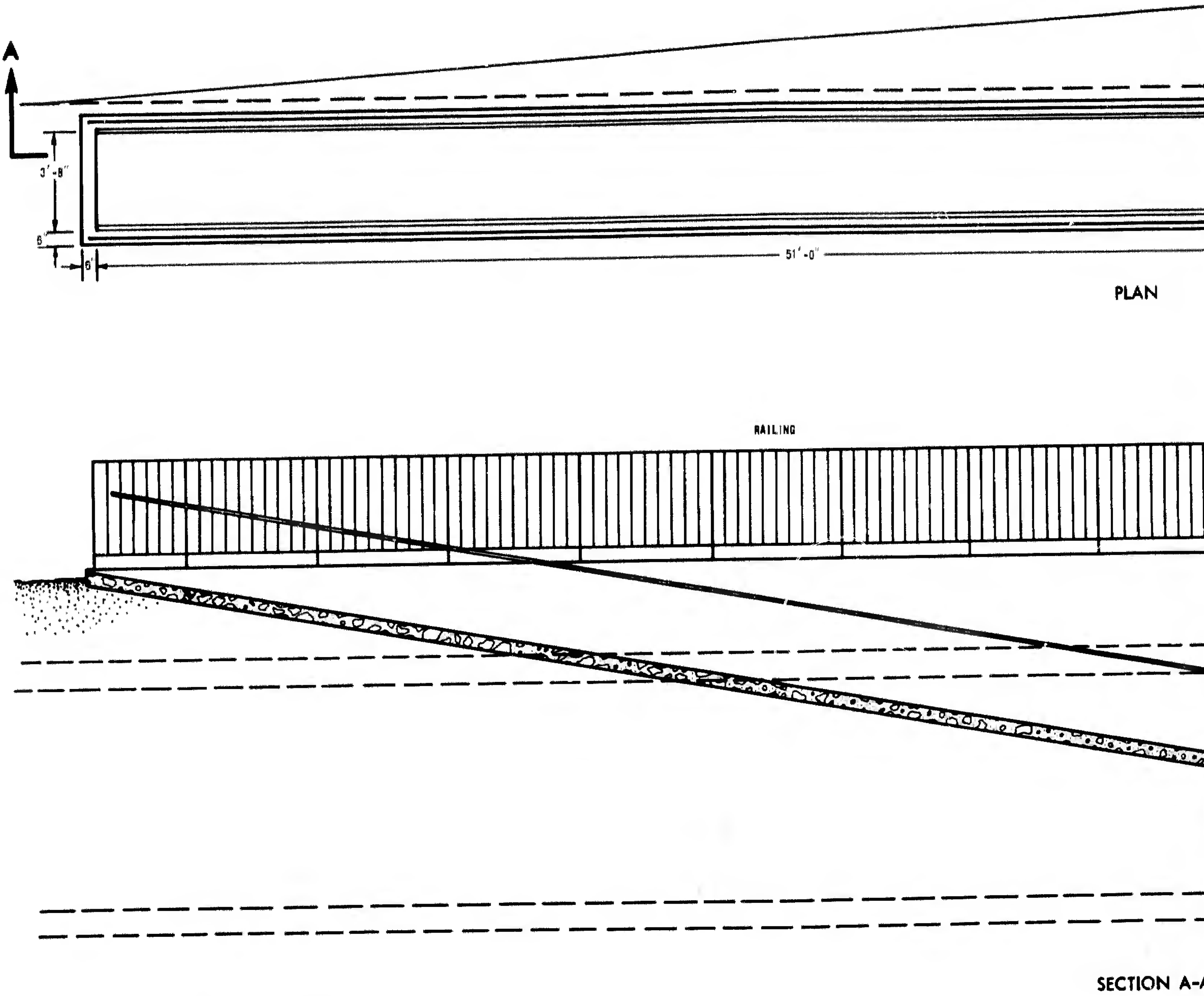
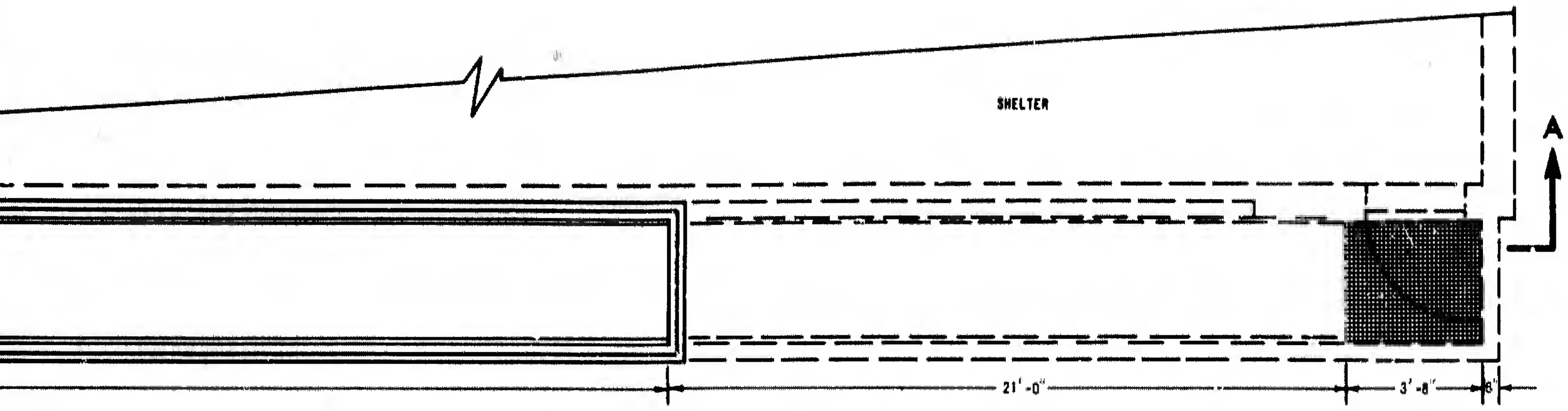


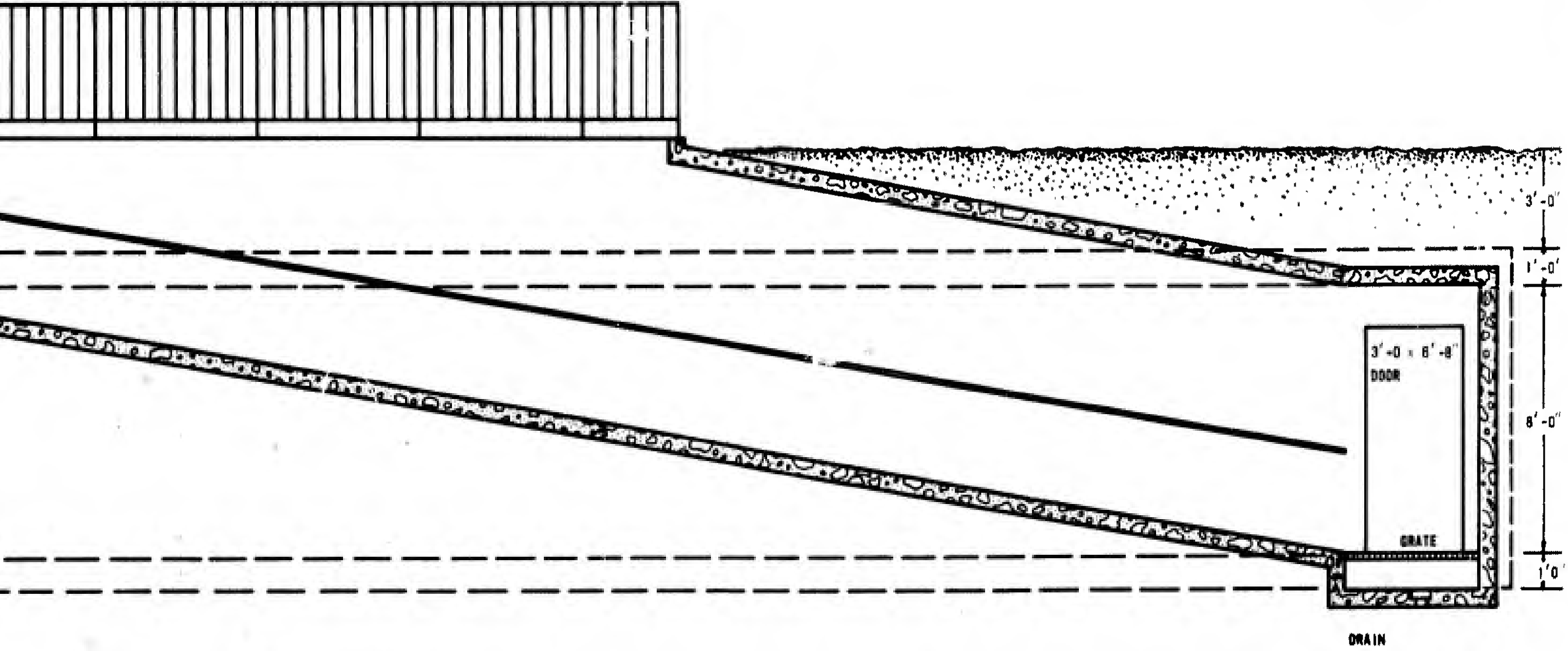
Figure 3-17

UNDERGROUND FALLOUT SHELTER RAMP, NO. 1-1
Reinforced Concrete, Class "C"



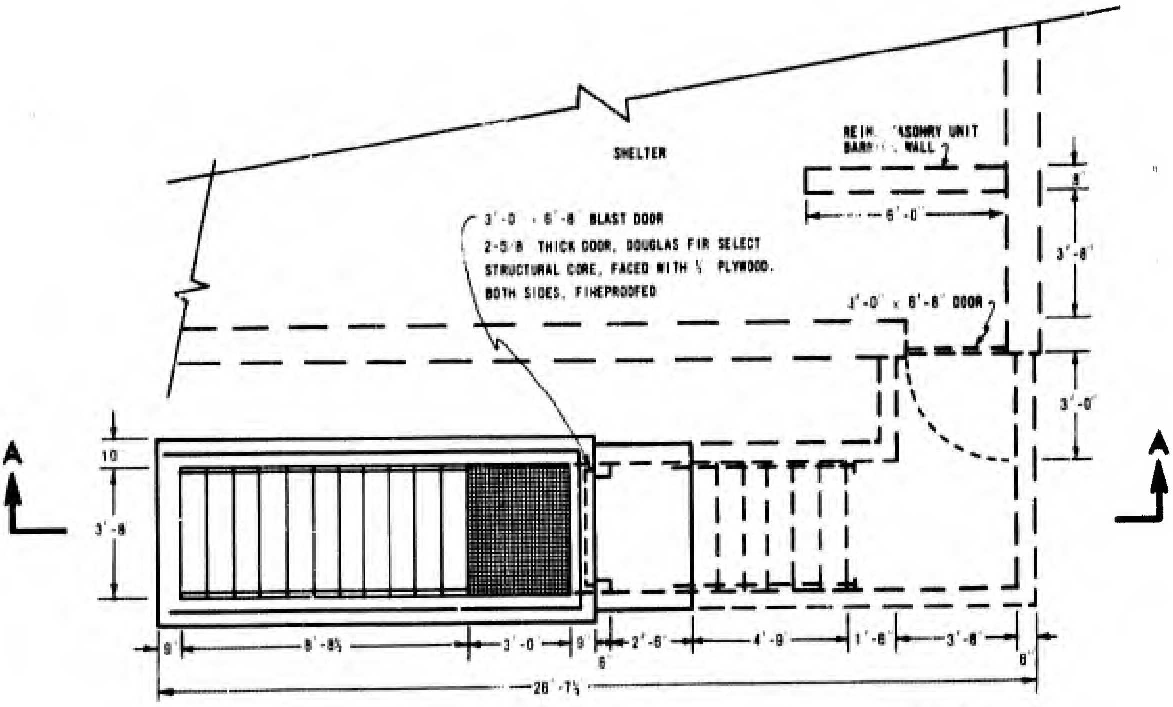
PLAN

CAPACITY:
67 persons/min
RAMP:
CLASS "C", SLOPE 1:6



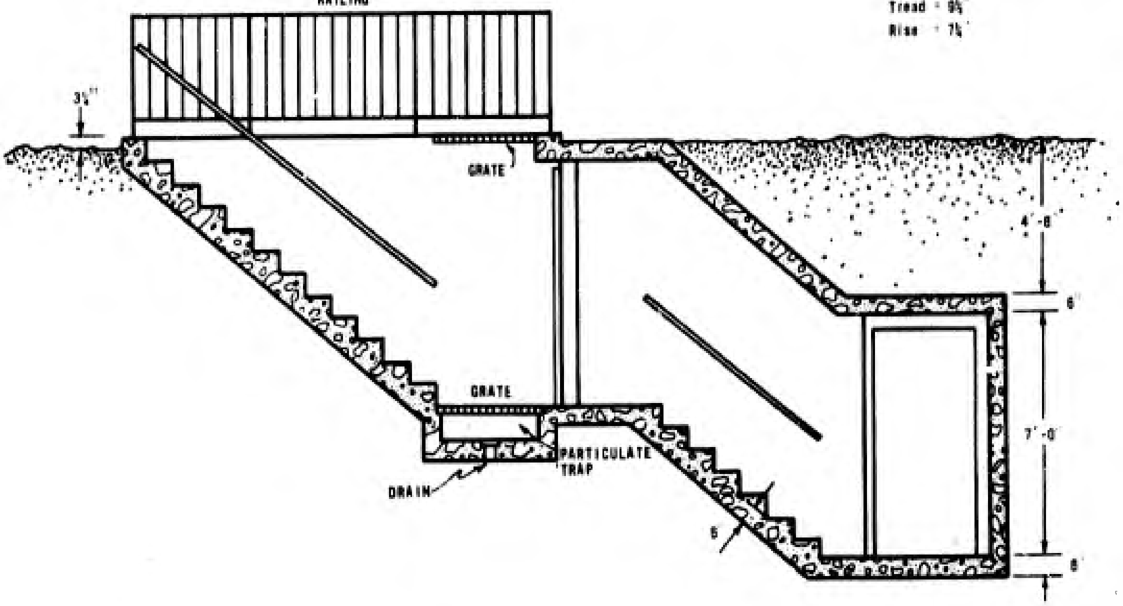
SECTION A-A

B



PLAN

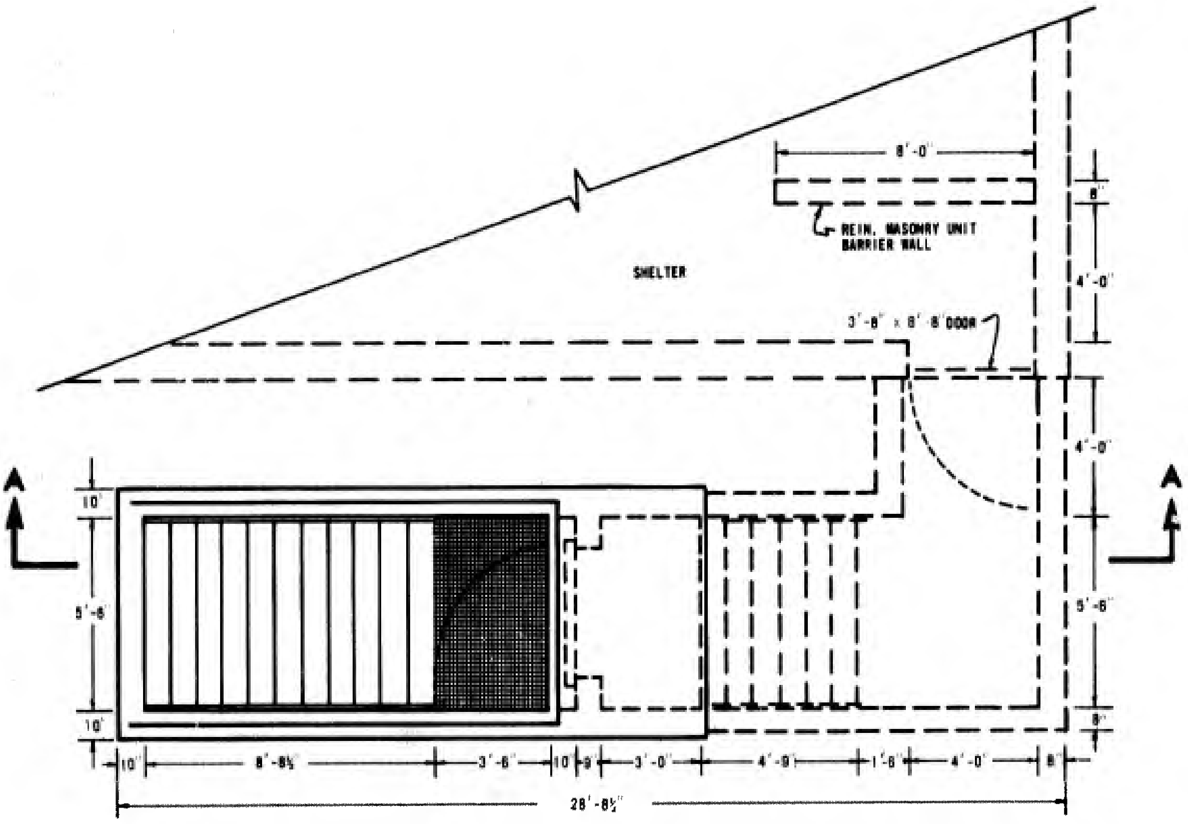
CAPACITY:
90 Persons/min.
STAIRS:
Tread = 9½"
Rise = 7½"



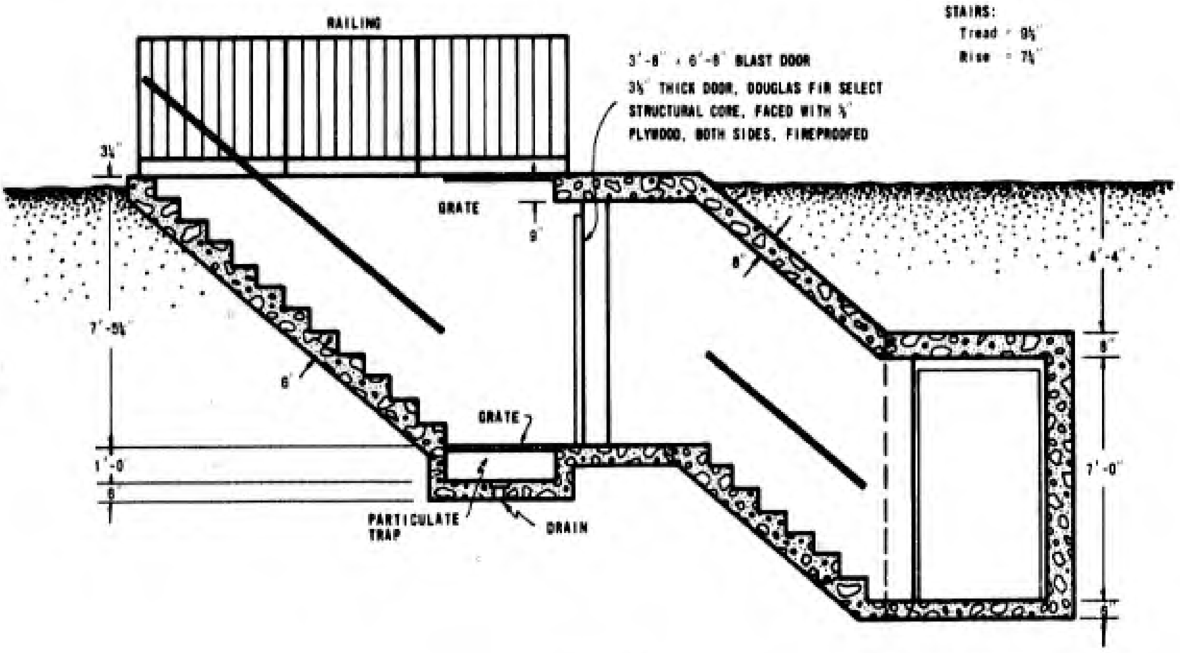
SECTION A-A

Figure 3-18

UNDERGROUND BLAST SHELTER ENTRANCEWAY, NO. J-1
Reinforced Concrete, Single Stair



PLAN

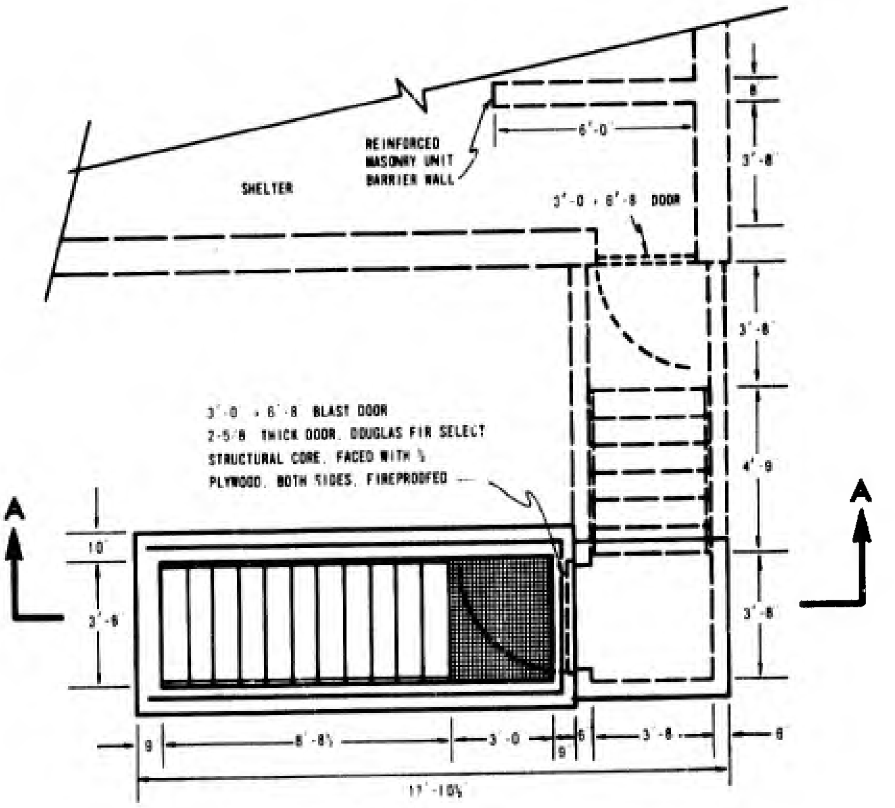


CAPACITY:
120 Persons/Min
STAIRS:
Tread = 9½"
Rise = 7½"

SECTION A-A

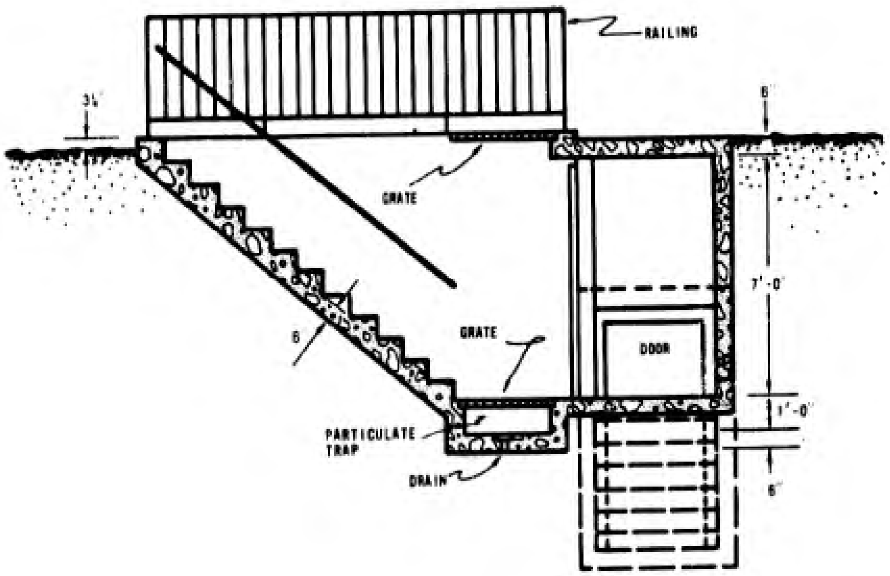
Figure 3-19

UNDERGROUND BLAST SHELTER ENTRANCEWAY, NO. J-2
Reinforced Concrete, Single Stair



PLAN

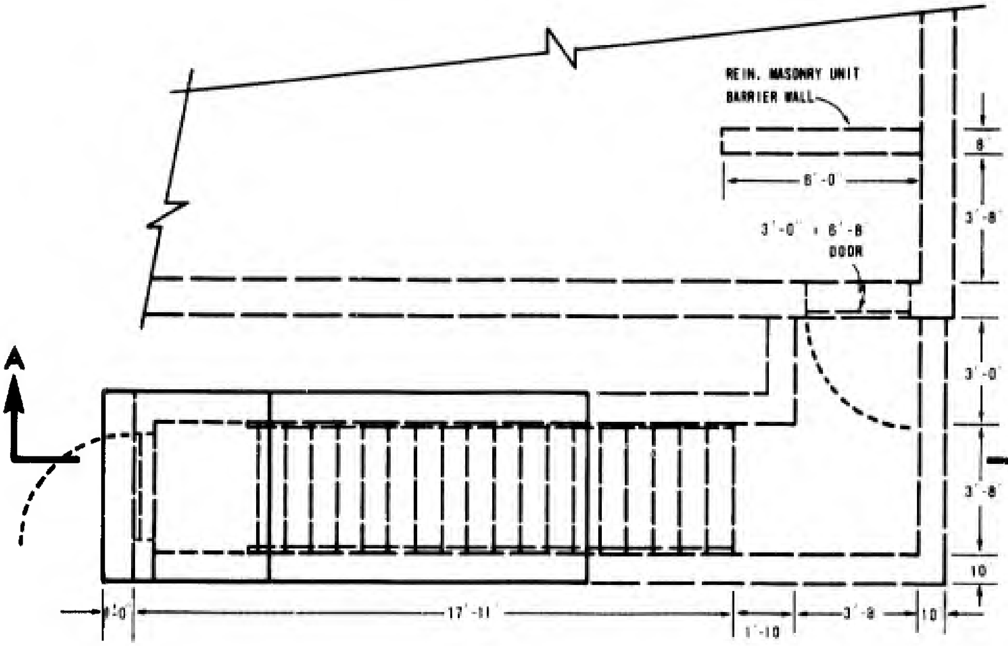
CAPACITY:
80 Persons/Min
STAIRS:
Tread = 9½"
Rise = 7¼"



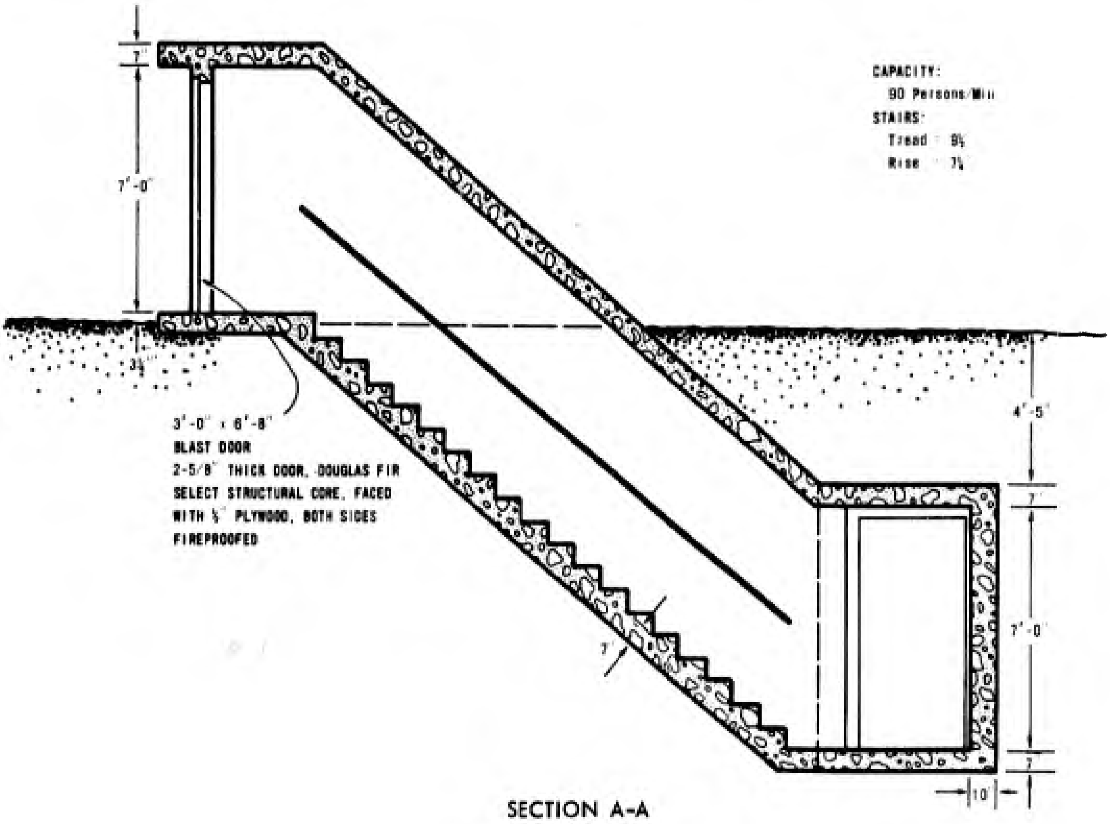
SECTION A-A

Figure 3-20

UNDERGROUND BLAST SHELTER ENTRANCEWAY, NO. J-3
Reinforced Concrete, Single Stair



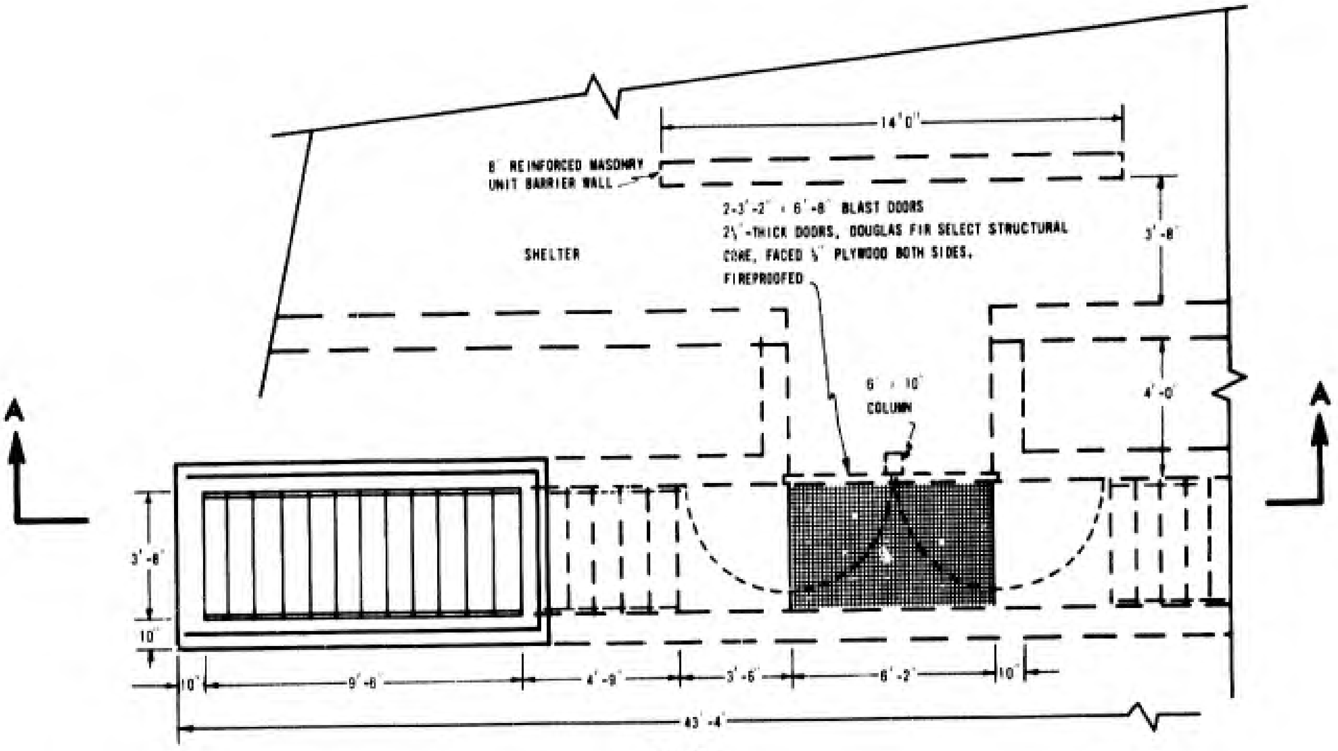
PLAN



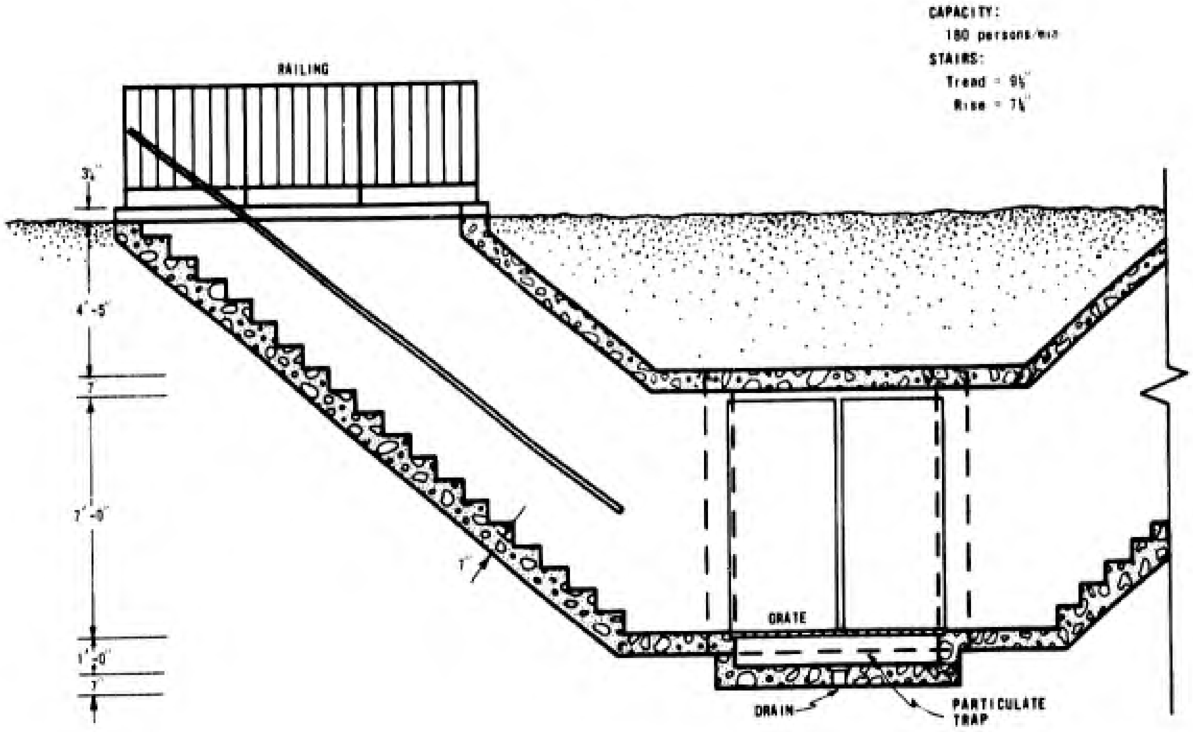
SECTION A-A

Figure 3-21

UNDERGROUND BLAST SHELTER ENTRANCEWAY, NO. J-4
Reinforced Concrete, Single Stair



PLAN

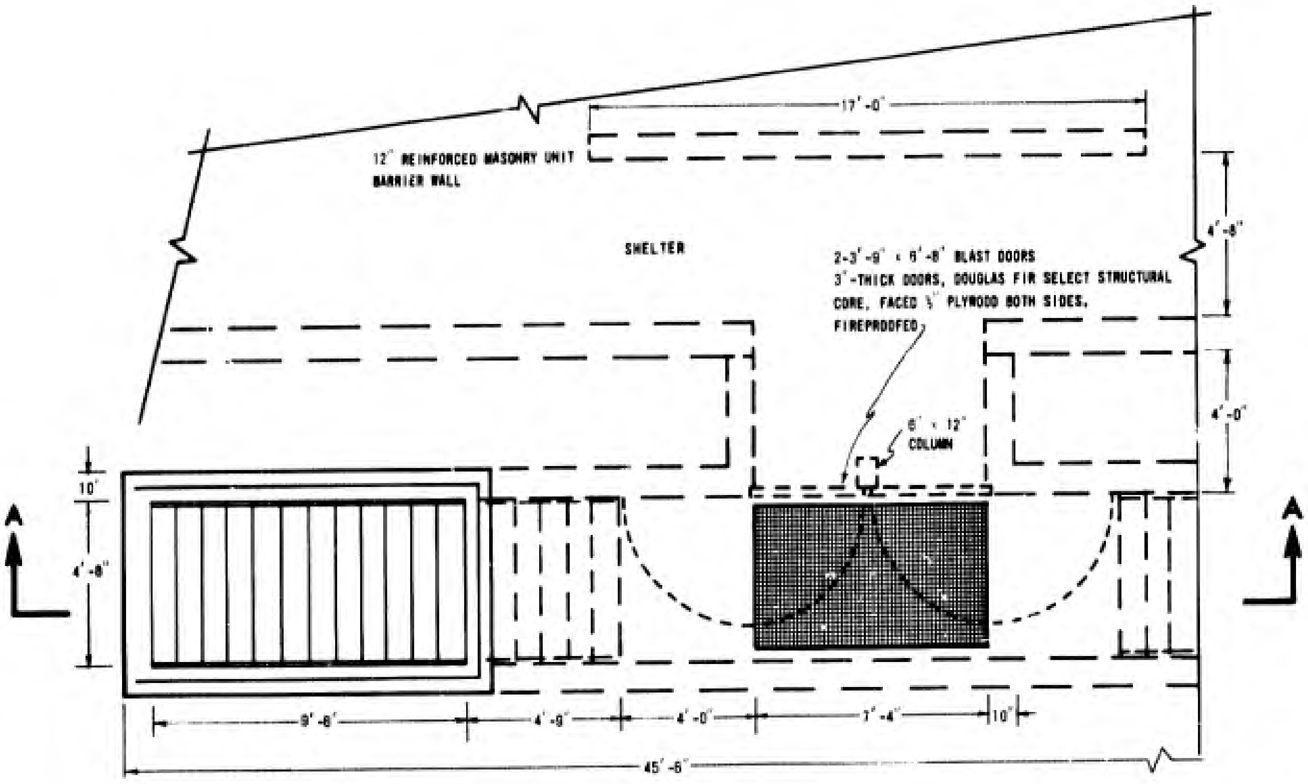


CAPACITY:
180 persons/min
STAIRS:
Tread = 9½"
Rise = 7½"

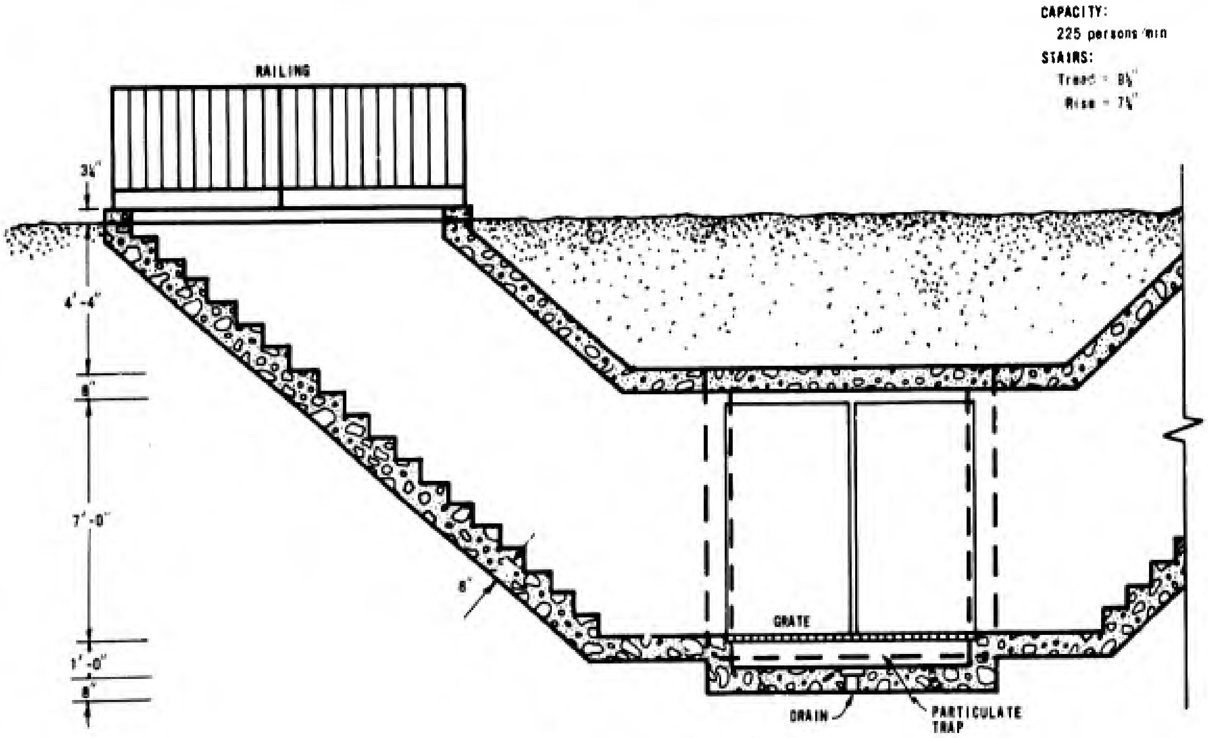
SECTION A-A

Figure 3-22

UNDERGROUND BLAST SHELTER ENTRANCEWAY, NO. K-1
Reinforced Concrete, Dual Stair



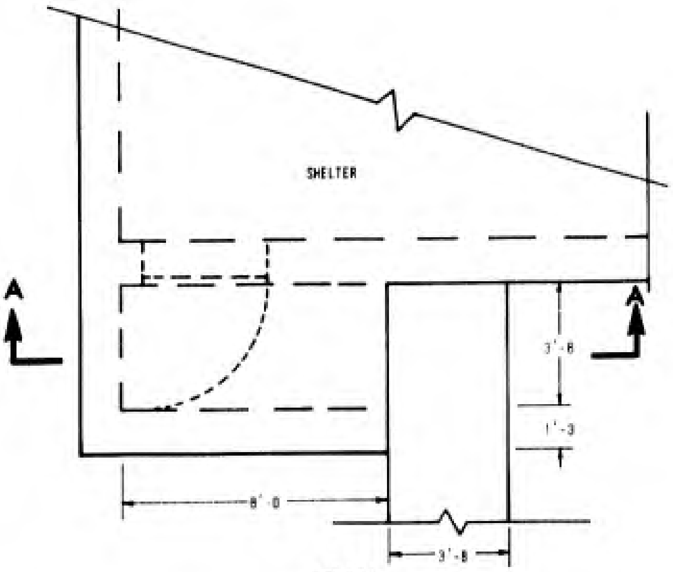
PLAN



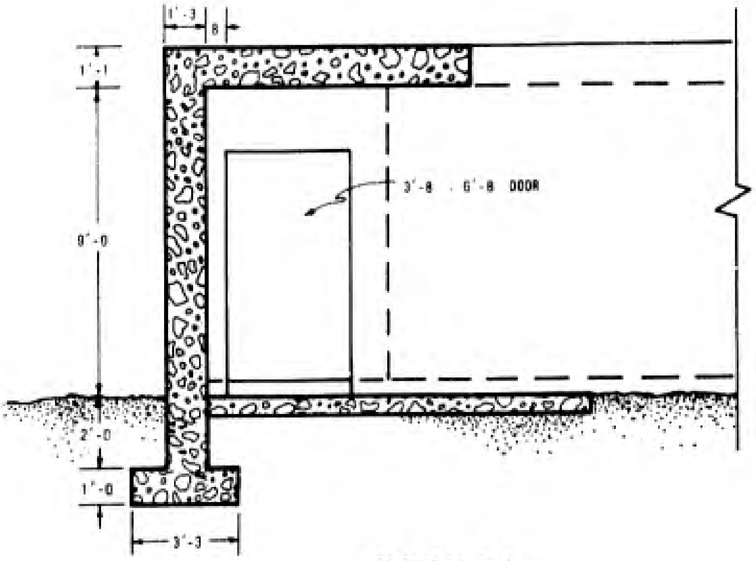
SECTION A-A

Figure 3-23

UNDERGROUND BLAST SHELTER ENTRANCEWAY, NO. K-2
Reinforced Concrete, Dual Stair



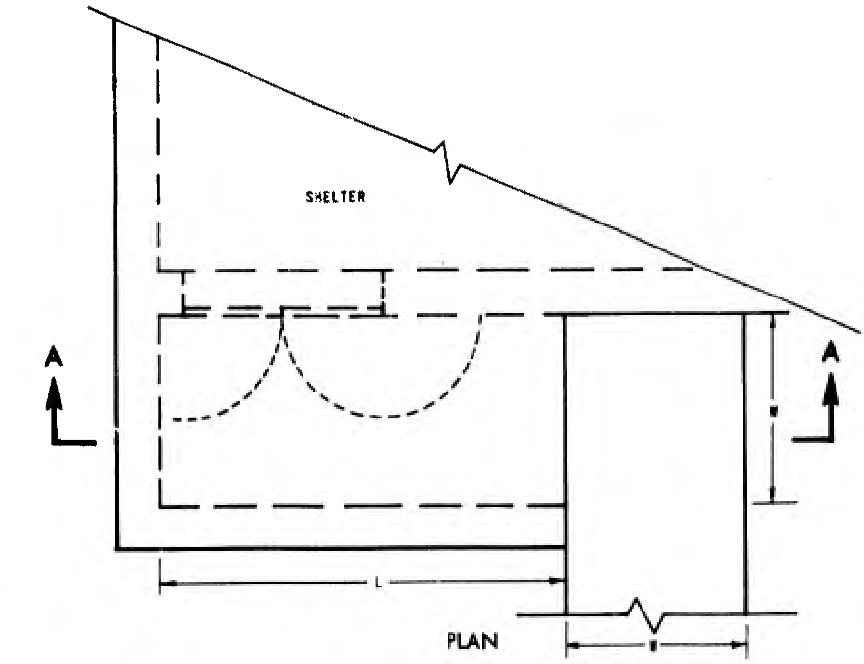
PLAN



SECTION A-A

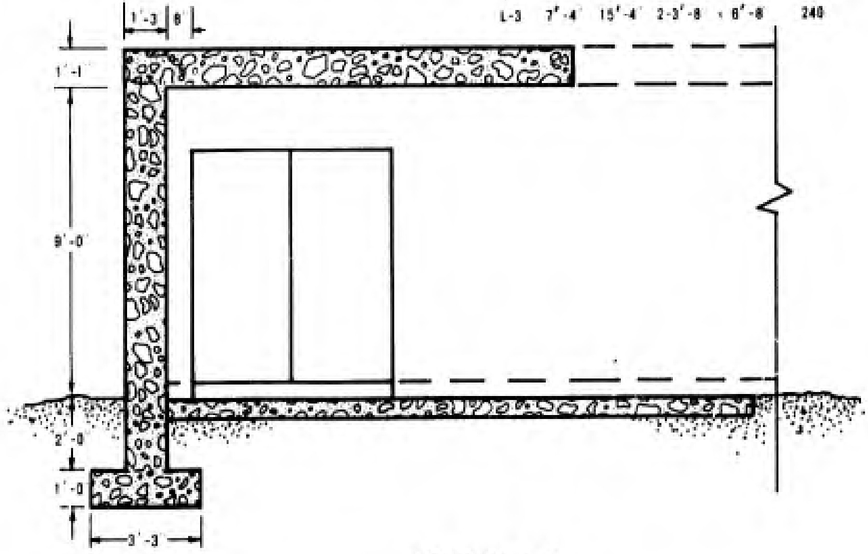
Figure 3-24

ABOVEGROUND FALLOUT SHELTER ENTRANCEWAY, NO. L-1
Reinforced Concrete, Without Basement



PLAN

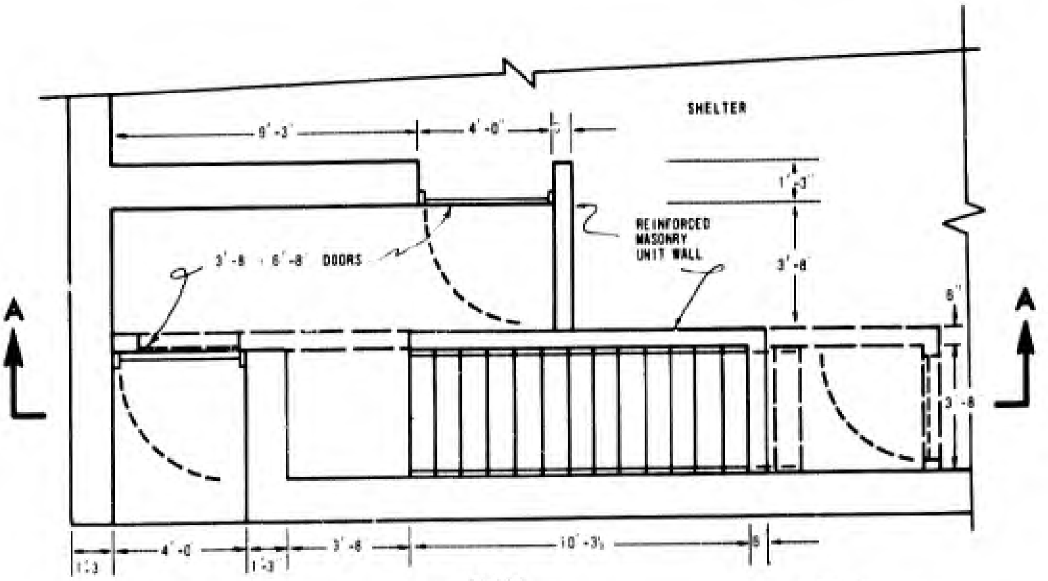
ENTR. NO.	ENTRANCEWAY WIDTH W	ENTRANCEWAY LENGTH L	DOOR SIZE	CAPACITY PERS./MIN
L-2	5'-8"	12'-2"	2-3'-0" x 6'-8"	180
L-3	7'-4"	15'-4"	2-3'-8" x 6'-8"	240



SECTION A-A

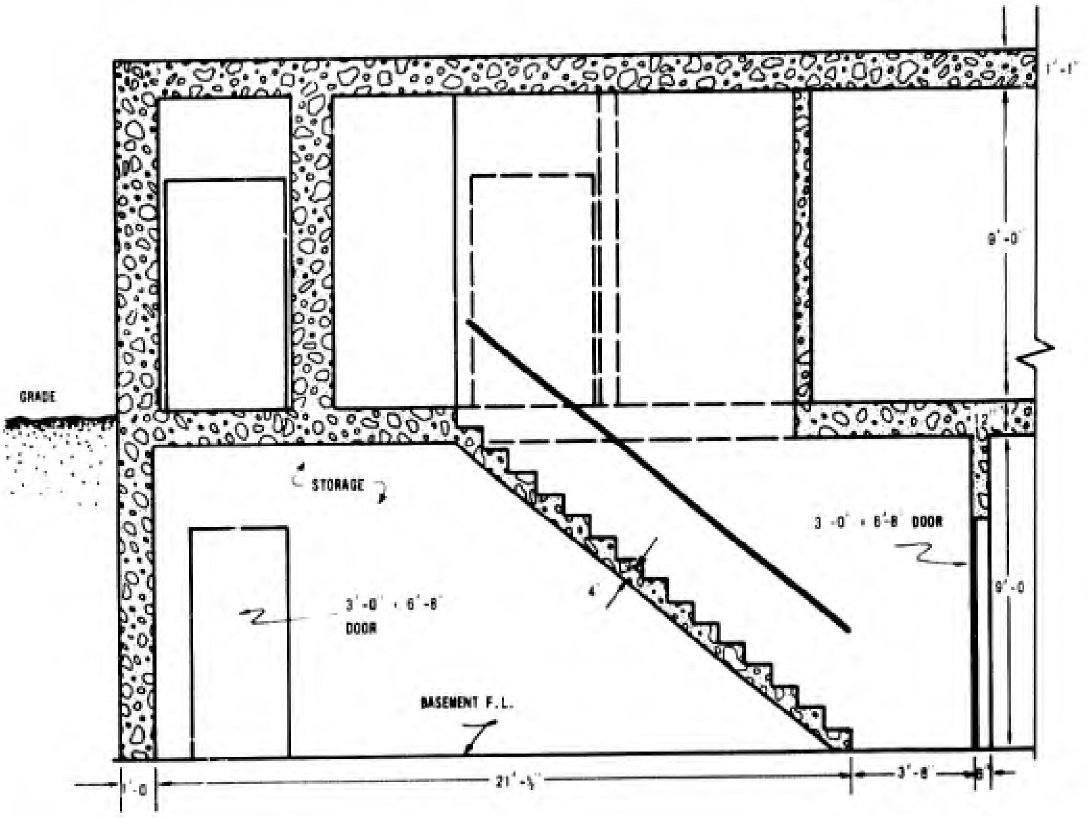
Figure 3-25

ABOVEGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. L-2 AND L-3
Reinforced Concrete, Without Basement



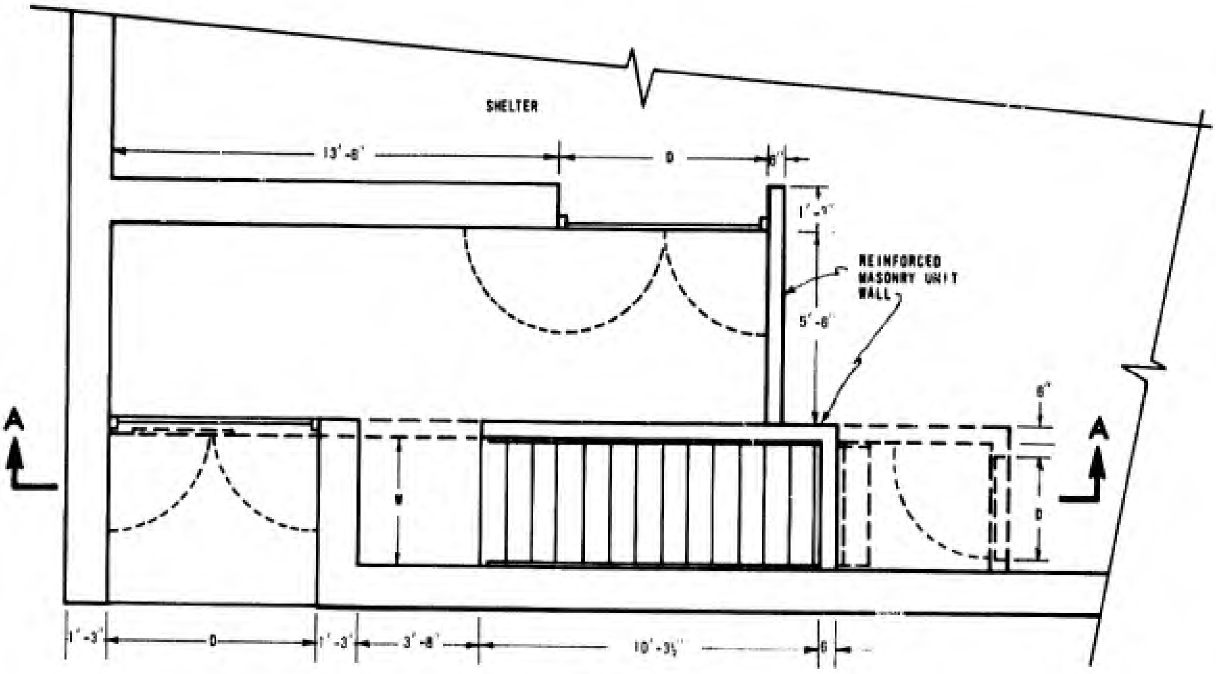
PLAN

CAPACITY:
120 persons/min
STAIRS:
Tread = 9½"
Rise = 7½"



SECTION A-A

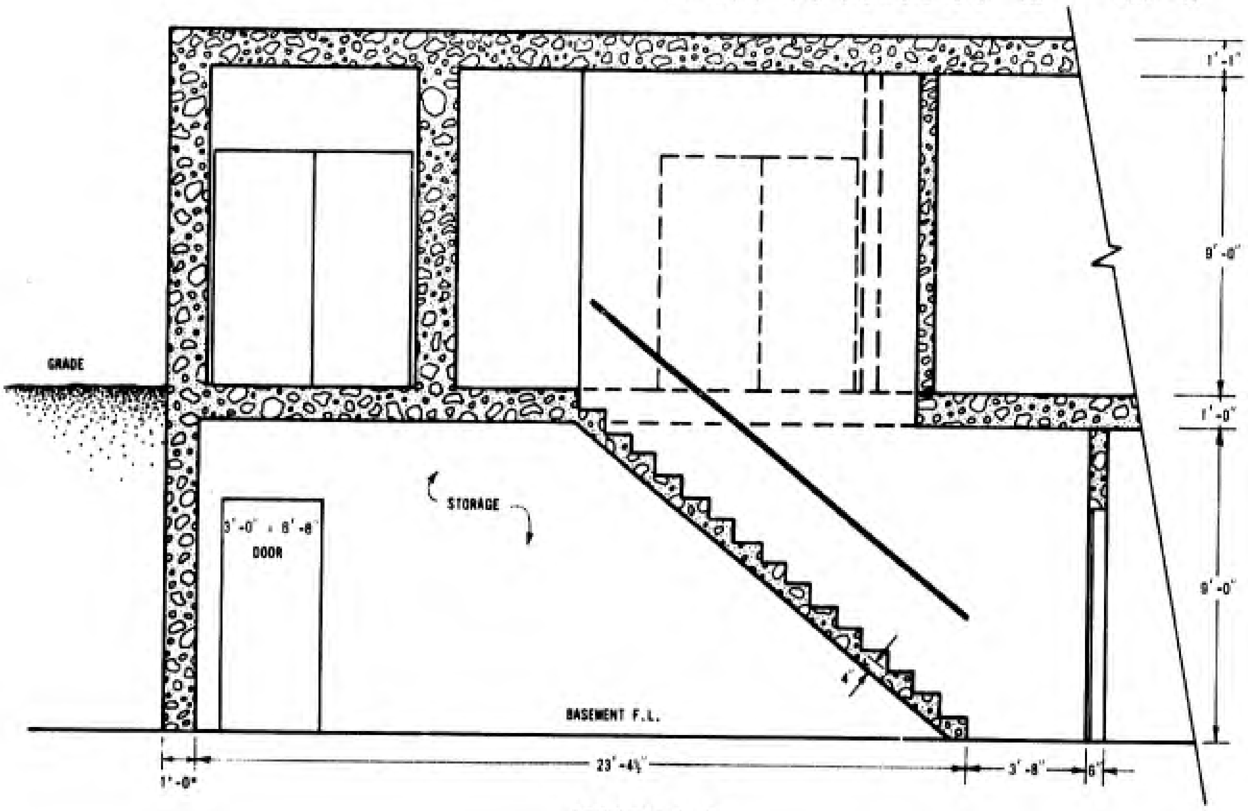
Figure 3-26
ABOVEGROUND FALLOUT SHELTER ENTRANCEWAY, NO. M-1
Reinforced Concrete, with Basement



PLAN

ENTR. NO.	DOOR SIZE FIRST FLOOR D	BASEMENT D	STAIR WIDTH W	CAPACITY PERS./MIN.
M-2	2-3'-0" x 6'-8"	[illegible]'-0 x 6'-8"	3'-8"	180
M-3	2-3'-0" 6'-8"	3'-8 x 6'-8"	5'-0"	240

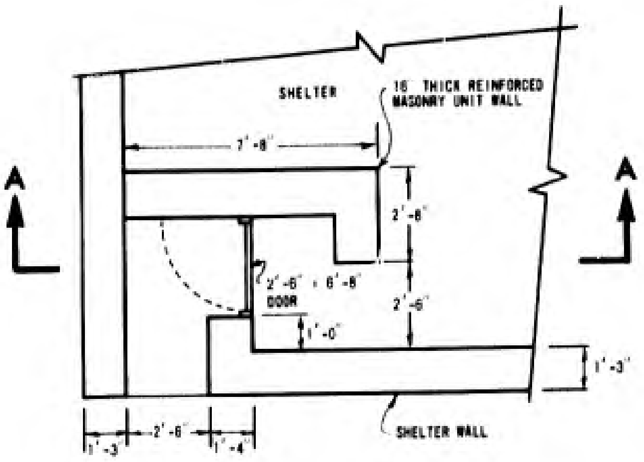
STAIRS:
Tread = 9½"
Rise = 7½"



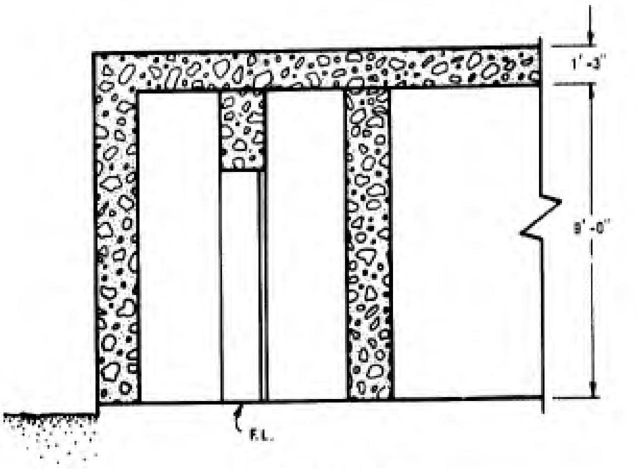
SECTION A-A

Figure 3-27

ABOVEGROUND FALLOUT SHELTER ENTRANCEWAY, NOS. M-2 AND M-3
Reinforced Concrete, with Basement



PLAN



SECTION A-A

Figure 3-28

ABOVEGROUND FALLOUT SHELTER ESCAPE EXIT, NO. N-1
Reinforced Concrete

<u>Appendix 4</u>

DEVELOPMENT OF COST DATA

Appendix 4

DEVELOPMENT OF COST DATA

Introduction

The cost data presented in this report were derived from detailed cost estimates performed on the 36 individual entranceways and 2 escape exits shown in Appendix 3. From this basic information, it was possible to develop entranceway cost-capacity (rate of persons entering per minute) curves for six separate entranceway categories. In addition, the information can be used for comparing the relative costs of all the various types of entranceways examined in this study. As noted in Section II, the possible combinations of variables that affect the entranceway costs are quite large, and it was therefore necessary for cost estimating purposes to reduce these to a manageable level.

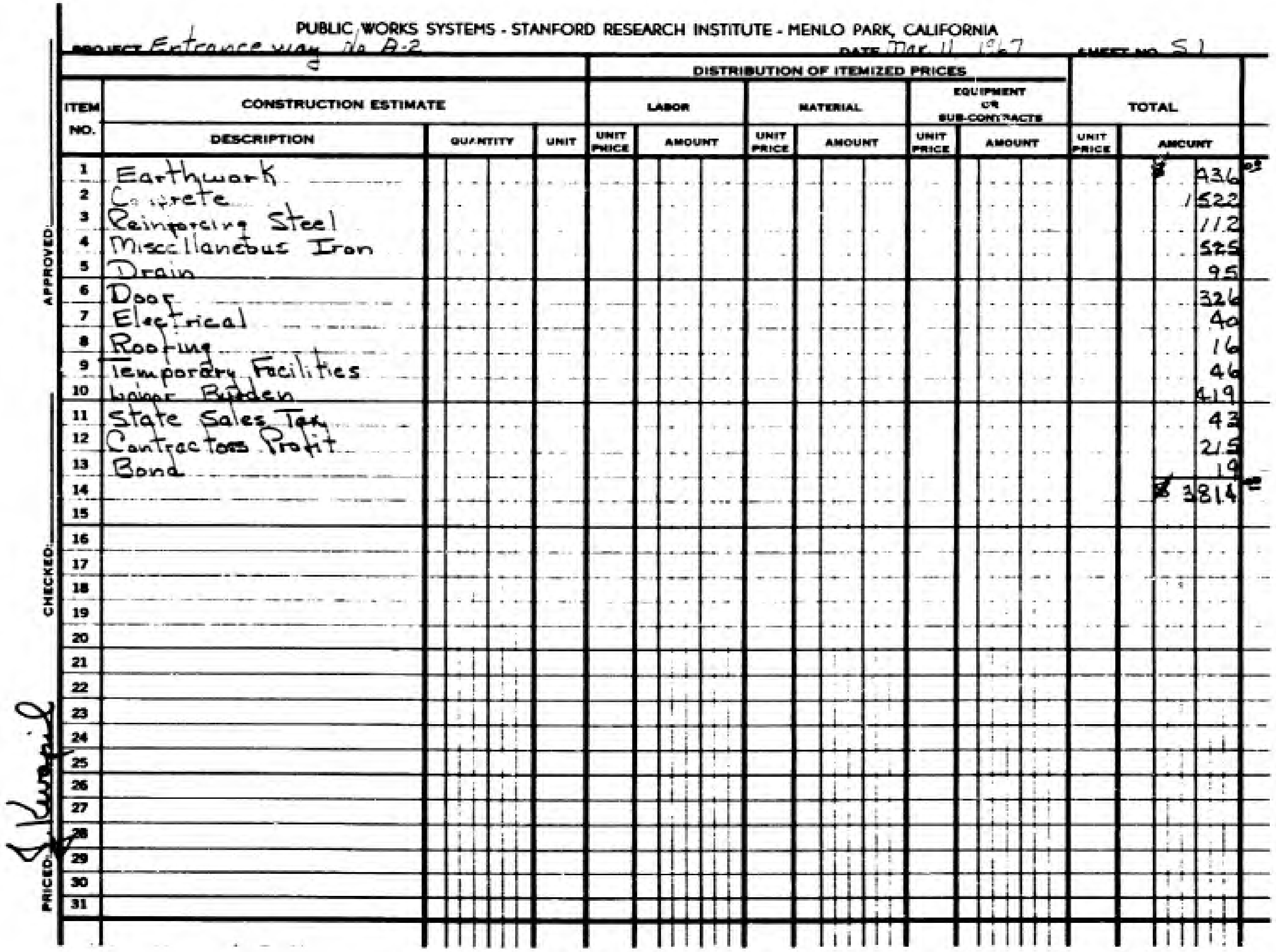
Because of the state of the art of cost estimating and the many variables that enter into a detailed estimate, cost estimating requires not only the establishment of unit cost data for materials and labor, but also considerable detailed knowledge of the economic and technical aspects of construction. Therefore, since a construction cost estimate is only as good as the experience and judgment of the estimator, a well-qualified construction cost consultant was retained to perform the estimates included in this report. Also, because of the different methods used by qualified cost estimators, all the cost estimates herein were performed by one individual to assure uniformity. The primary attempt in this study was to develop cost data that were internally consistent among the various entranceway configurations. Although such a goal is self-evident, it is sometimes difficult to achieve in actual practice because of the many alternative solutions to any construction project. Although the maintenance of consistent cost estimates permits valid comparisons to be made between the various entranceway types, it does not necessarily permit the indiscriminate use of the specific cost data for any other location or conditions without consideration for such factors as the variation in site conditions, construction practices, geographical location, and the changes in construction costs with time. On the other hand, the individual cost estimates are felt to be as accurate as possible within the current techniques for the type of soil conditions and prevailing labor and material rates in the San Francisco Bay Area for the spring of 1967. The data should also be generally applicable to other locations and times by using the appropriate factors from standard publications such as the Engineering News-Record cost index.

In addition to the inherent limitations of cost estimating, it becomes apparent on cursory examination that there are also a number of implicit assumptions in any cost data. For instance, in this study, it was assumed for the determination of the excavation and backfill quantities that local soil conditions permitted the use of a 1:1 slope during the construction period. Many such assumptions are required during the development of a cost estimate. Furthermore, without the benefit of a detailed study of the effect of each on the total cost, it is often difficult to judge the most economical alternative.

Another factor that can influence actual construction cost is a design alternative that influences the method of construction. For instance, for an underground fallout shelter with a reinforced concrete box section entranceway (Type A), an important cost factor was the compaction of the earth fill under the stair area, where it was necessary to excavate the soil for construction of the main shelter before construction of the entranceway. An alternative construction method would be to extend the walls of the stairway to the level of the shelter floor slab and to provide individual wall footings. Although additional concrete and reinforcing steel would be required, this cost would be partially or wholly offset by the reduced soil compaction cost. In any event, it should be kept in mind that because of the many alternative construction procedures and site problems, the cost estimate for a specific entranceway type presented herein may not necessarily be a minimum. For this study, what was considered a reasonable construction procedure generally was selected subjectively without the benefit of an investigation of all identifiable alternatives as would be justified under an actual shelter construction program.

Cost Estimates

Because of the wide geographic variation in unit costs for material and labor and because of the difference in methods used by competent cost estimators to arrive at a total construction cost, it was felt that a list of unit construction costs would be of little value to an understanding of the entranceway cost estimates prepared for this investigation. In addition, for small structures where complex formwork requires considerable labor in relation to the material quantities, the use of unit prices without detailed application to the specific situation can result in misleading cost estimates. Therefore, to demonstrate the operations required to obtain the cost of each entranceway, an actual detailed example of one cost estimate is presented in Figure 4-1.



PUBLIC WORKS SYSTEMS - STANFORD RESEARCH INSTITUTE - MENLO PARK, CALIFORNIA

PROJECT Entranceway No A-2 DATE Mar 11 1967 SHEET NO. S-1

APPROVED:

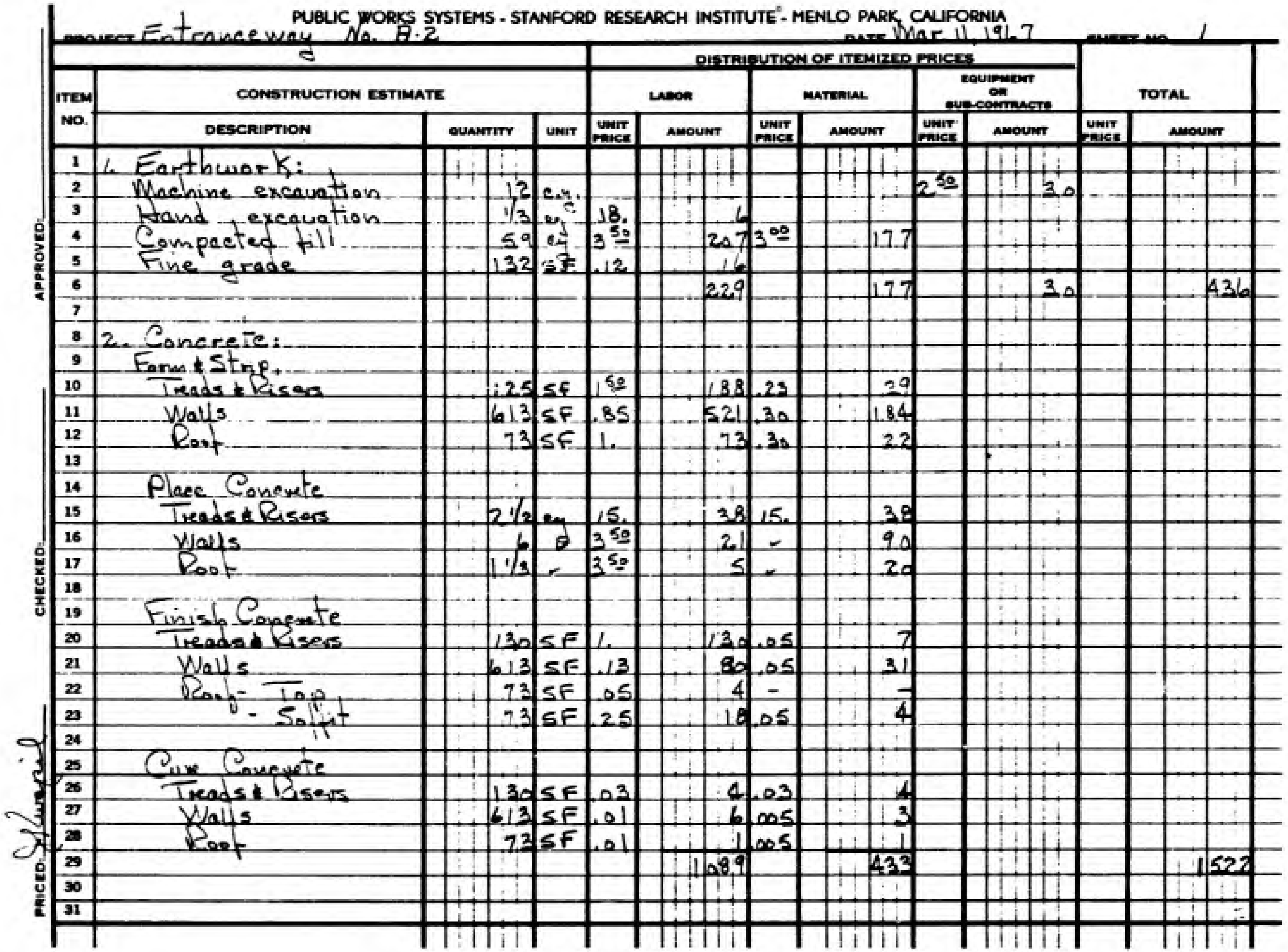
CHECKED:

PRICED:

ITEM NO.	CONSTRUCTION ESTIMATE			DISTRIBUTION OF ITEMIZED PRICES						TOTAL	
				LABOR		MATERIAL		EQUIPMENT OR SUB-CONTRACTS			
	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT
1	Earthwork										$ 436 00
2	Concrete										1522
3	Reinforcing Steel										112
4	Miscellaneous Iron										525
5	Drain										95
6	Door										326
7	Electrical										40
8	Roofing										16
9	Temporary Facilities										46
10	Labor Burden										419
11	State Sales Tax										43
12	Contractors Profit										215
13	Bond										19
14											$ 3814 00
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											
29											
30											
31											

Figure 4-1

EXAMPLE OF CONSTRUCTION COST ESTIMATE FOR UNDERGROUND FALLOUT SHELTER ENTRANCEWAY NO. A-2



PUBLIC WORKS SYSTEMS - STANFORD RESEARCH INSTITUTE - MENLO PARK, CALIFORNIA

PROJECT Entranceway No. B-2

DATE Mar 11, 1967

SHEET NO. 1

ITEM NO.	CONSTRUCTION ESTIMATE			DISTRIBUTION OF ITEMIZED PRICES						TOTAL	
				LABOR		MATERIAL		EQUIPMENT OR SUB-CONTRACTS			
	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT
1	1. Earthwork:										
2	Machine excavation	12	c.y.					2^{50}	30		
3	Hand excavation	1/3	c.y.	18.	6						
4	Compacted fill	59	c.y.	3^{50}	207	3^{00}	177				
5	Fine grade	132	SF	.12	16						
6					229		177		30		436
7											
8	2. Concrete:										
9	Form & Strip.										
10	Treads & Risers	125	SF	1^{50}	188	.23	29				
11	Walls	613	SF	.85	521	.30	184				
12	Roof	73	SF	1.	73	.30	22				
13											
14	Place Concrete										
15	Treads & Risers	2 1/2	cy	15.	38	15.	38				
16	Walls	6	〃	3^{50}	21	〃	90				
17	Roof	1 1/3	〃	3^{50}	5	〃	20				
18											
19	Finish Concrete										
20	Treads & Risers	130	SF	1.	130	.05	7				
21	Walls	613	SF	.13	80	.05	31				
22	Roof - Top	73	SF	.05	4	-	-				
23	〃 - Soffit	73	SF	.25	18	.05	4				
24											
25	Cure Concrete										
26	Treads & Risers	130	SF	.03	4	.03	4				
27	Walls	613	SF	.01	6	.005	3				
28	Roof	73	SF	.01	1	.005	1				
29					1089		433				1522
30											
31											

APPROVED:

CHECKED:

PRICED:

Figure 4-1 (continued)

PUBLIC WORKS SYSTEMS - STANFORD RESEARCH INSTITUTE - MENLO PARK, CALIFORNIA

PROJECT Entranceway No. A-2

DATE Mar 11 1967

SHEET NO. 2

APPROVED:

CHECKED:

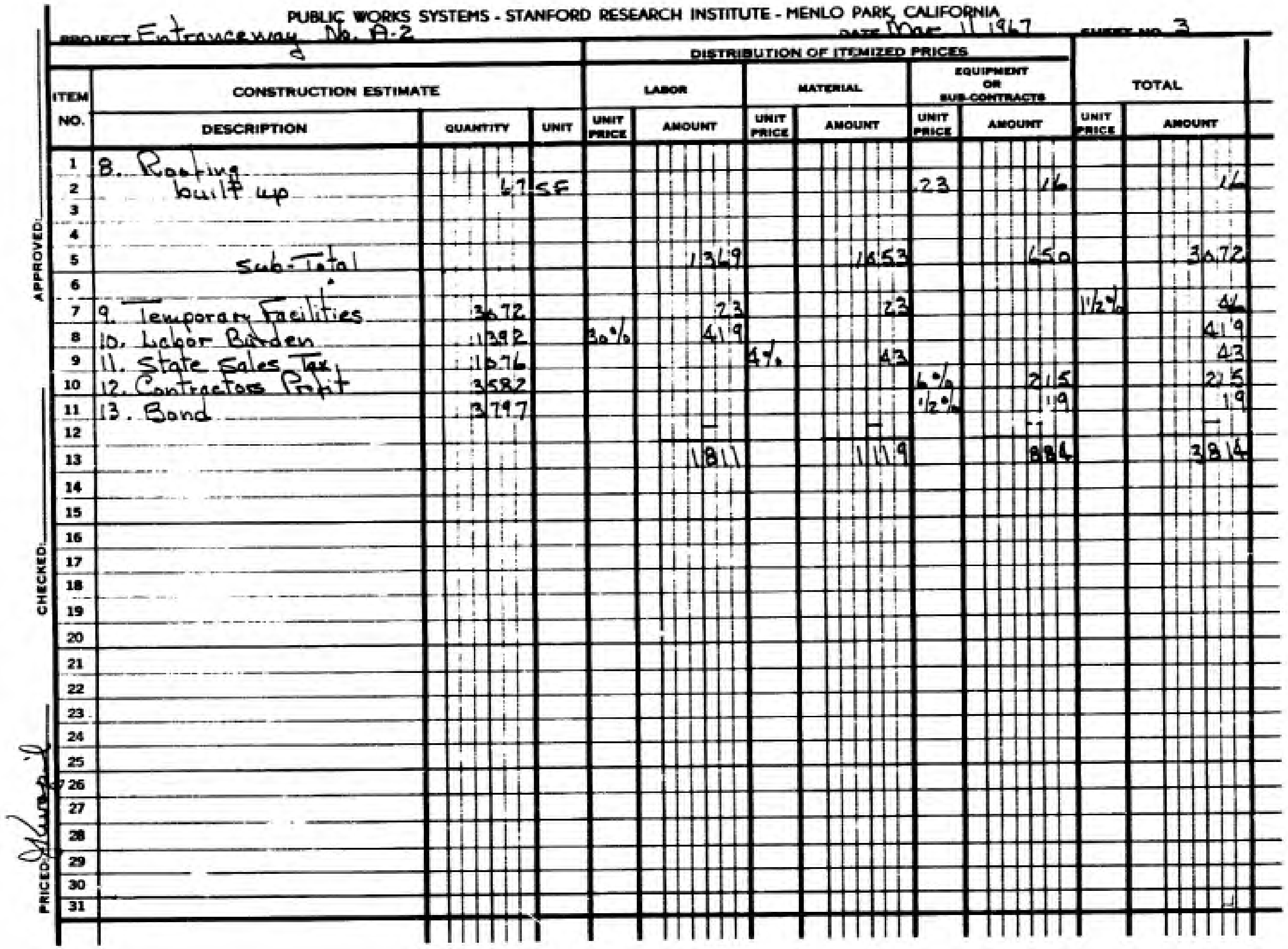
PRICED:

ITEM	CONSTRUCTION ESTIMATE			DISTRIBUTION OF ITEMIZED PRICES						TOTAL	
				LABOR		MATERIAL		EQUIPMENT OR SUB-CONTRACTS			
NO.	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT
1	3. Reinforcing Steel:										
2	bar	934	lbs.					.12	112		112
3											
4											
5	4. Miscellaneous Iron:										
6	Handrail caps	8	ea.	1.	8	1.50	12				
7	Handrail, floor mounted	24	LF					7.00	168		
8	" wall "	54	LF					3.50	189		
9	Angle iron frame	59	lbs.	.13	6	.45	27				
10	Grating	25	SF	.30	8	4.27	107				
11					22		146		357		525
12											
13	5. Drain:										
14	Floor drain	1	ea					75.	75		
15	Pipe - 2"	10	LF					2.	20		
16									95		95
17											
18	6. Door:										
19	Hollow Metal jamb-$3^{0} x 6^{8}$,	1	ea.	8.	8	35.	35				
20	" " door, A label	1	ea.	10.	10	115.	115				
21	Hardware	1	set	—	—	50.	50				
22	Panic device	1	set	10.	10	93.	93				
23	Threshold	1	ea.	1.	1	4.	4				
24					29		297				326
25											
26	7. Electrical										
27	Conduit & wire	10	LF					1.	10		
28	Outlet & fixture	1	ea					30.	30		
29									40		40
30											
31											

Figure 4-1 (continued)

PUBLIC WORKS SYSTEMS - STANFORD RESEARCH INSTITUTE - MENLO PARK, CALIFORNIA

PROJECT Entranceway No. A-2 DATE Mar. 11 1967 SHEET NO. 3



ITEM NO.	CONSTRUCTION ESTIMATE			DISTRIBUTION OF ITEMIZED PRICES: LABOR		MATERIAL		EQUIPMENT OR SUB-CONTRACTS		TOTAL	
	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT
1	8. Roofing										
2	built up	67	SF					.23	16		16
3											
4											
5	Sub-Total				1369		1653		650		3672
6											
7	9. Temporary Facilities	3672			23		23			1½%	46
8	10. Labor Burden	1392		30%	419						419
9	11. State Sales Tax	1676				4%	43				43
10	12. Contractors Profit	3582						6%	215		215
11	13. Bond	3797						½%	19		19
12					—		—		—		—
13					1811		1119		886		3816
14											
15											
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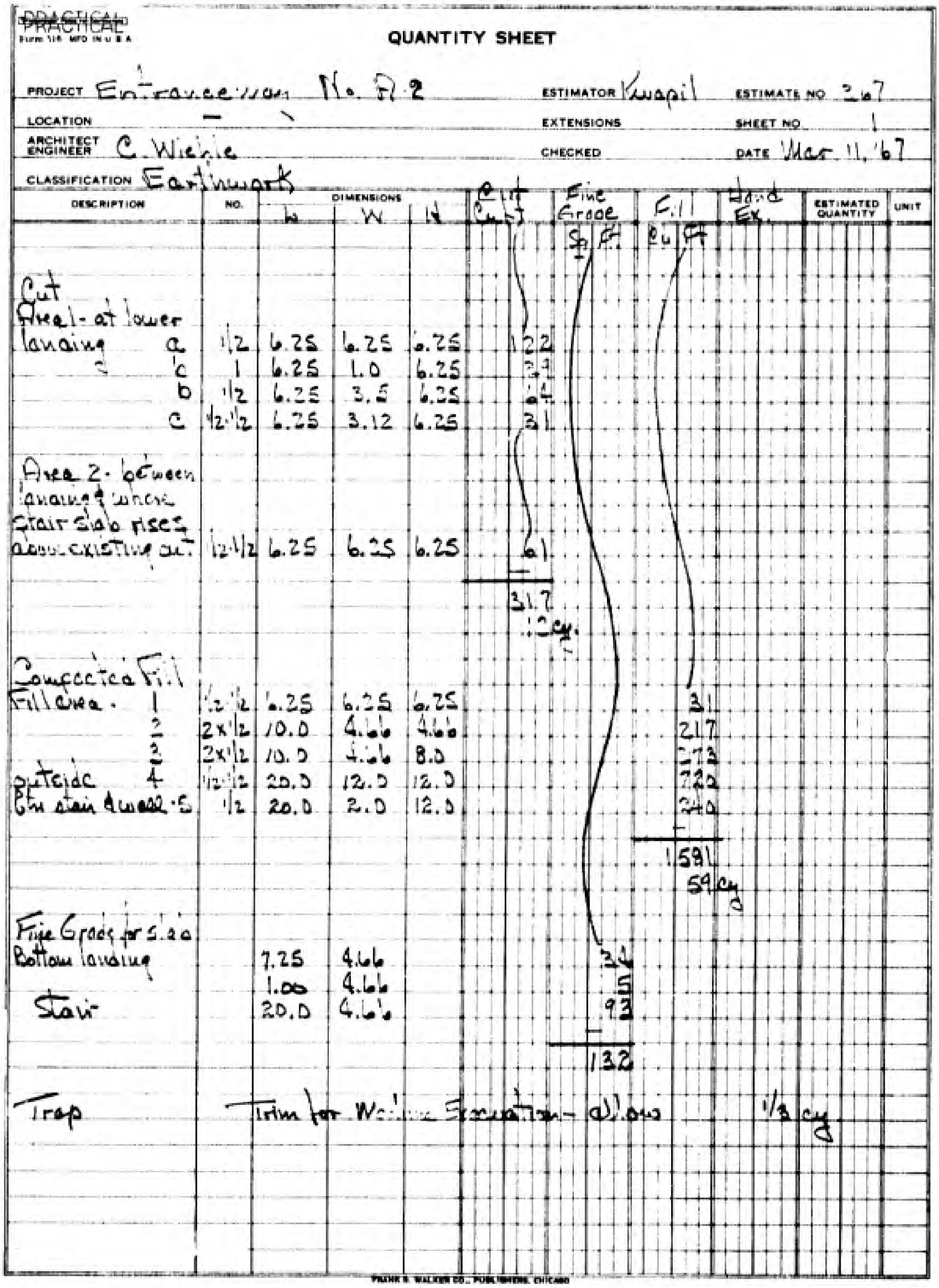
31											

APPROVED:

CHECKED:

PRICED:

Figure 4-1 (continued)



PRACTICAL
Form 118 MFD IN U.S.A.

QUANTITY SHEET

PROJECT Entranceway No. A-2 ESTIMATOR Kwapil ESTIMATE NO. 267
LOCATION — EXTENSIONS SHEET NO. 1
ARCHITECT ENGINEER C. Wiehe CHECKED DATE Mar 11, '67
CLASSIFICATION Earthwork

DESCRIPTION	NO.	DIMENSIONS L	DIMENSIONS W	DIMENSIONS H	Cut	Fine Grade Sq Ft	Fill Cu Ft	Hand Ex.	ESTIMATED QUANTITY	UNIT
Cut										
Area 1 - at lower landing a	1/2	6.25	6.25	6.25	122					
c	1	6.25	1.0	6.25	39					
b	1/2	6.25	3.5	6.25	64					
c	1/2·1/2	6.25	3.12	6.25	31					
Area 2 - between landing & where stair slab rises above existing cut	1/2·1/2	6.25	6.25	6.25	61					
					317 12 cy					
Compacted Fill										
Fill area 1	1/2·1/2	6.25	6.25	6.25			31			
2	2×1/2	10.0	4.66	4.66			217			
3	2×1/2	10.0	4.66	8.0			373			
outside 4	1/2·1/2	20.0	12.0	12.0			722			
btw stair & wall 5	1/2	20.0	2.0	12.0			240			
							1581 59 cy			
Fine Grade for slab Bottom landing		7.25	4.66			34				
		1.00	4.66			5				
Stair		20.0	4.66			93				
						132				
Trap	Trim for Wall Excavation – allow							1/3 cy		

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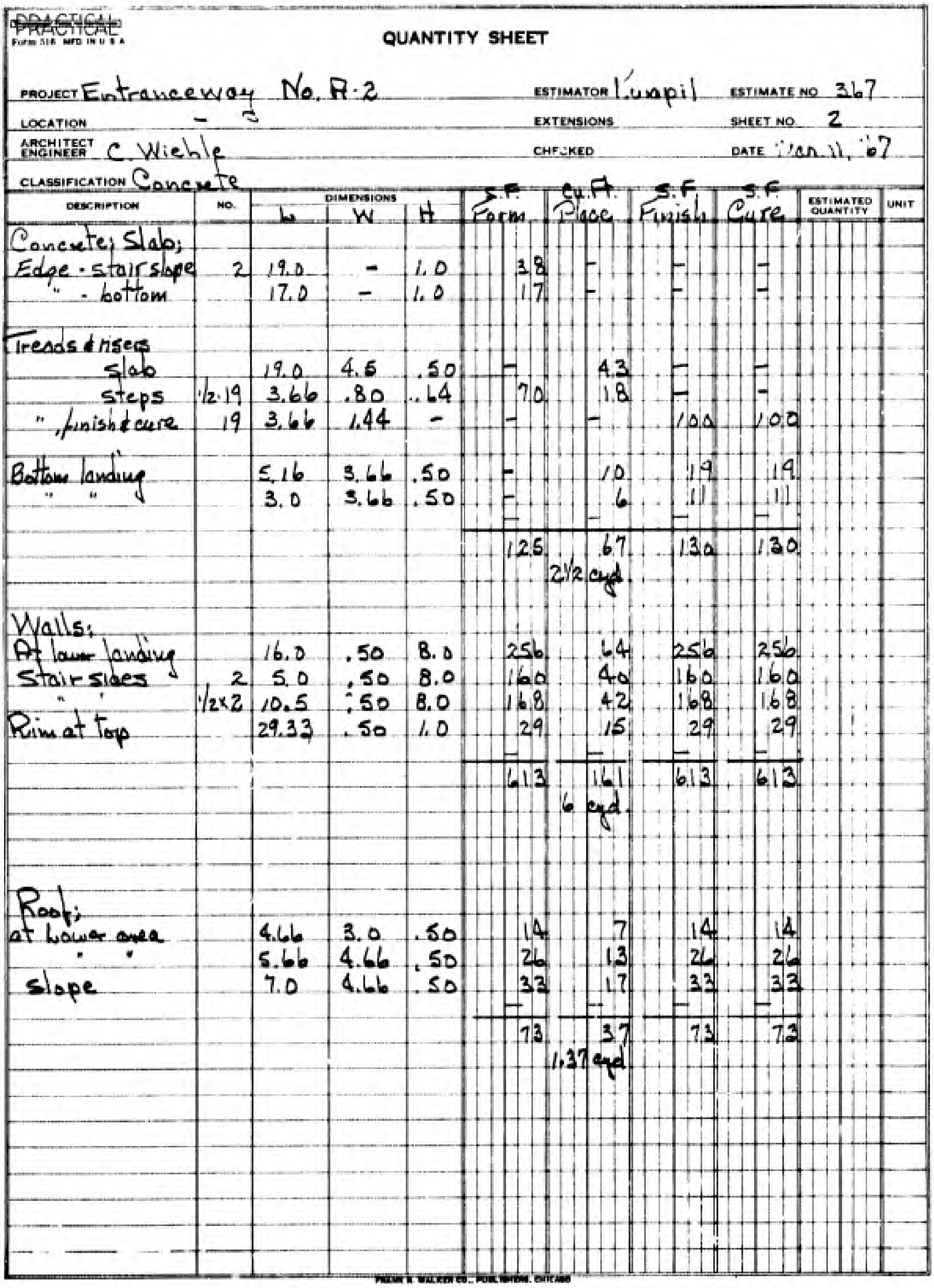
Figure 4-1 (continued)



PRACTICAL
Form 518 MFD IN U.S.A.

QUANTITY SHEET

PROJECT Entranceway No. R-2 ESTIMATOR Kuapil ESTIMATE NO. 367
LOCATION – EXTENSIONS SHEET NO. 2
ARCHITECT ENGINEER C. Wiehle CHECKED DATE Jan. 11, '67
CLASSIFICATION Concrete

DESCRIPTION	NO.	DIMENSIONS L	W	H	S.F. Form	Cu.Ft. Place	S.F. Finish	S.F. Cure	ESTIMATED QUANTITY	UNIT
Concrete; Slab;										
Edge - stairslope	2	19.0	–	1.0	38	–	–	–		
" - bottom		17.0	–	1.0	17	–	–	–		
Treads & risers										
slab		19.0	4.6	.50	–	43	–	–		
steps	1/2·19	3.66	.80	.64	70	18	–	–		
" , finish & cure	19	3.66	1.44	–	–	–	100	100		
Bottom landing		5.16	3.66	.50	–	10	19	19		
" "		3.0	3.66	.50	–	6	11	11		
					125	67 2½ cyd	130	130		
Walls;										
At lower landing		16.0	.50	8.0	256	64	256	256		
Stair sides	2	5.0	.50	8.0	160	40	160	160		
" "	1/2×2	10.5	.50	8.0	168	42	168	168		
Rim at Top		29.33	.50	1.0	29	15	29	29		
					613	161 6 cyd	613	613		
Roof;										
at lower area		4.66	3.0	.50	14	7	14	14		
" "		5.66	4.66	.50	26	13	26	26		
slope		7.0	4.66	.50	33	17	33	33		
					73	37 1.37 cyd	73	73		

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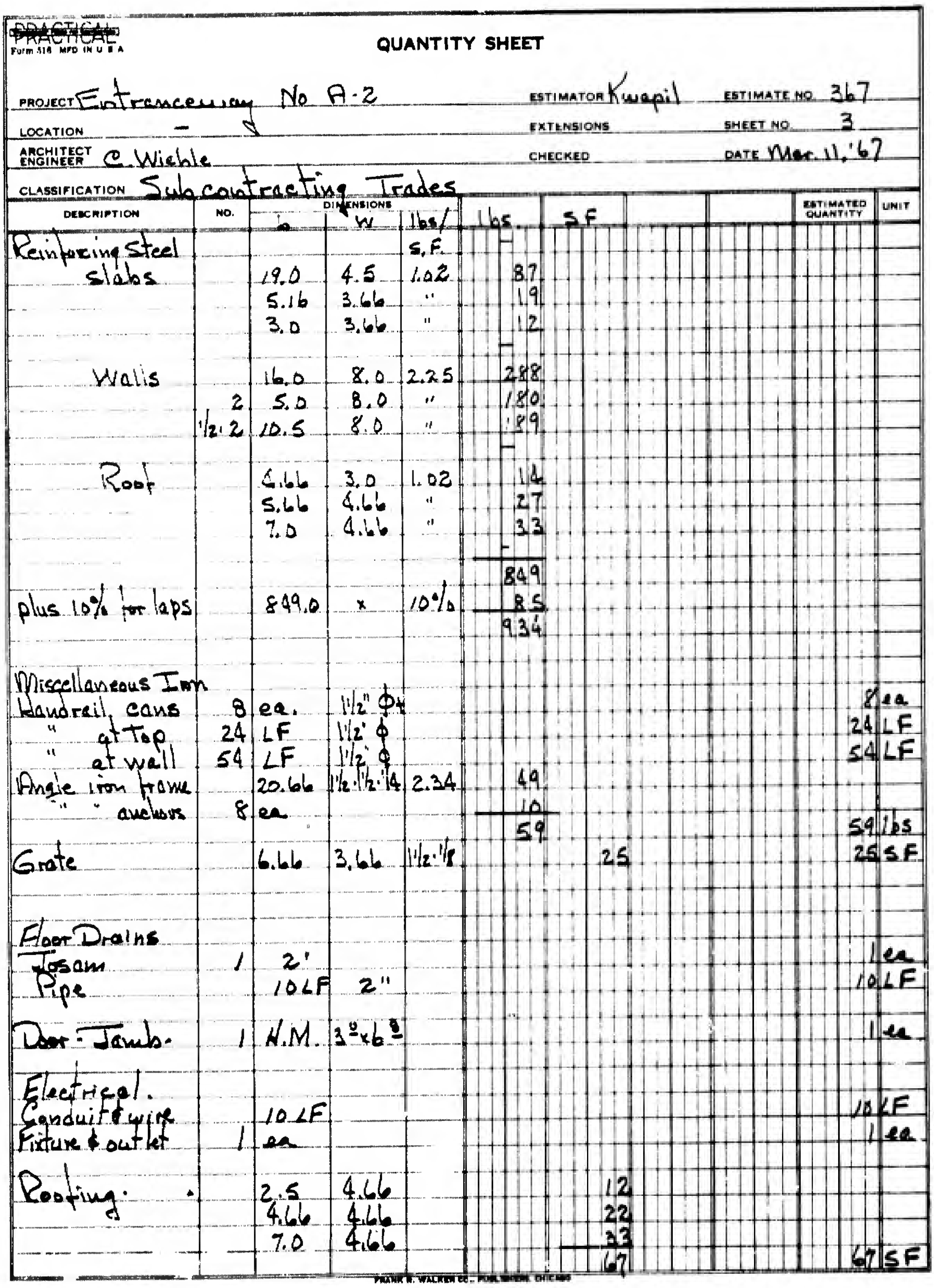
Figure 4-1 (continued)



PRACTICAL
Form 516 MFD IN U.S.A.

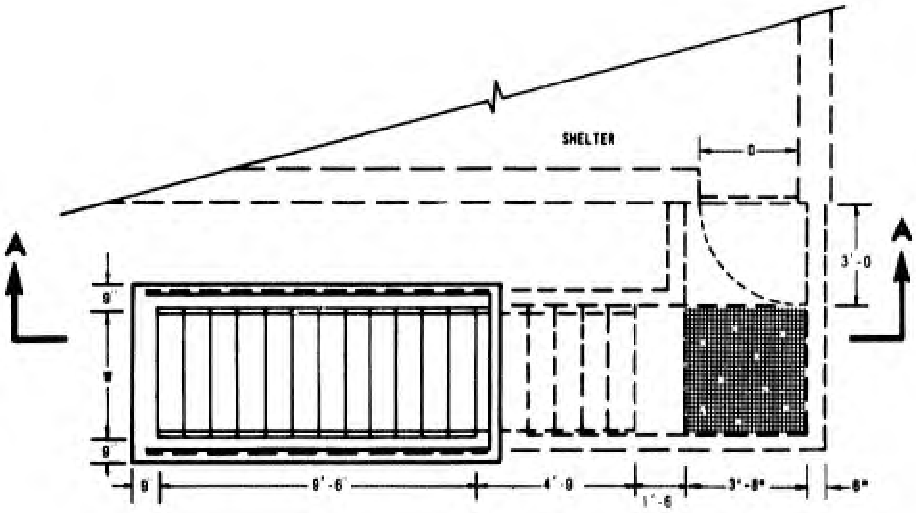
QUANTITY SHEET

PROJECT Entranceway No A-2
ESTIMATOR Kwapil
ESTIMATE NO. 367
LOCATION –
EXTENSIONS
SHEET NO. 3
ARCHITECT ENGINEER C. Wiehle
CHECKED
DATE Mar. 11, '67
CLASSIFICATION Subcontracting Trades

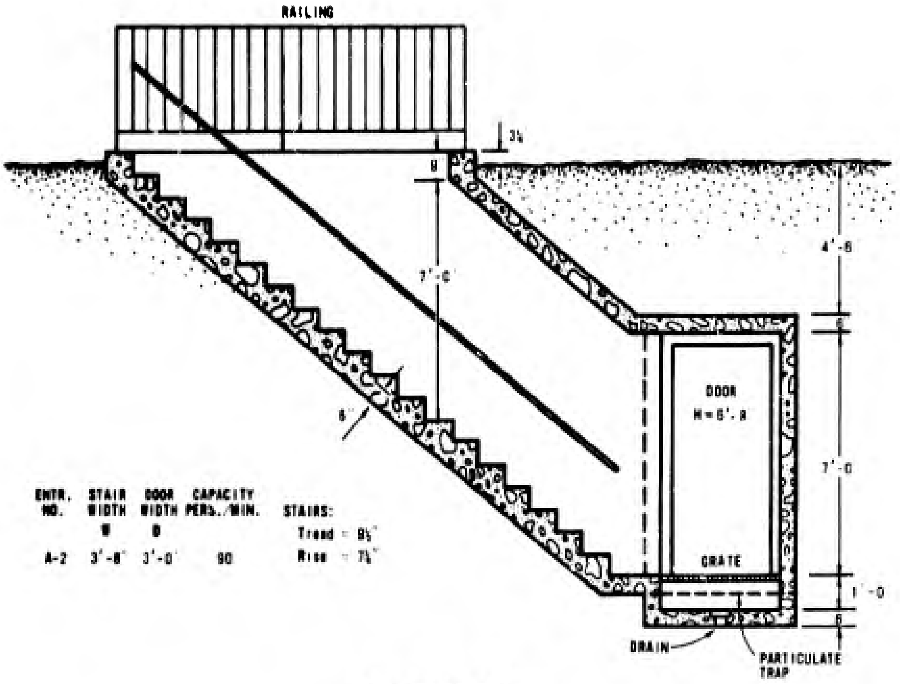
DESCRIPTION	NO.	DIMENSIONS L	W	lbs/ S.F.	lbs.	SF	ESTIMATED QUANTITY	UNIT
Reinforcing Steel								
slabs		19.0	4.5	1.02	87			
		5.16	3.66	"	19			
		3.0	3.66	"	12			
Walls		16.0	8.0	2.25	288			
	2	5.0	8.0	"	180			
	½·2	10.5	8.0	"	189			
Roof		4.66	3.0	1.02	14			
		5.66	4.66	"	27			
		7.0	4.66	"	33			
					849			
plus 10% for laps		849.0	x	10%	85			
					934			
Miscellaneous Iron								
Handrail, cans	8	ea.	1½" Φ				8	ea
" at Top	24	LF	1½" Φ				24	LF
" at wall	54	LF	1½" Φ				54	LF
Angle iron frame		20.66	1½·1½·¼	2.34	49			
" " anchors	8	ea			10			
					59		59	lbs
Grate		6.66	3.66	1½·⅛		25	25	SF
Floor Drains								
Josam	1	2'					1	ea
Pipe		10 LF	2"				10	LF
Door Jamb.	1	H.M.	$3^{0} \times 6^{8}$				1	ea
Electrical.								
Conduit & wire		10 LF					10	LF
Fixture & outlet	1	ea					1	ea
Roofing.		2.5	4.66			12		
		4.66	4.66			22		
		7.0	4.66			33		
						67	67	SF

FRANK R. WALKER CO., PUBLISHERS, CHICAGO

Figure 4-1 (continued)



PLAN



ENTR. NO.	STAIR WIDTH W	DOOR WIDTH D	CAPACITY PERS./MIN.
A-2	3'-8"	3'-0"	90

STAIRS:
Tread = 9½"
Rise = 7½"

SECTION A-A

Figure 4-1 (concluded)

To develop the cost data in this report, unit prices appropriate to the San Francisco Bay Area were obtained from the records maintained by the SRI cost consultant, supplemented by direct quotation from local vendors where applicable. These unit prices were used as indicated in the example to obtain the construction cost estimate for the 36 entranceways and 2 escape exits examined. A summary of the major cost items for all entranceways is shown in Tables 4-1 through 4-6. An explanation of the more important factors included in each major item shown in the tables is as follows.

Earthwork

The earthwork costs include the costs of all soil excavation and removal, purchase of a local borrow f.o.b. job site, and backfilling and compaction. The cost is comparable to that related to reuse of the shelter excavated soil where both stockpiling and handling of the excavated material are required. The quantities of excavated and backfilled soil chargeable to the entranceway cost were determined by assuming that the excavation for the basic underground shelter extended 2 ft beyond the shelter footing at the subgrade level and was cut on a 1:1 slope to grade--it was also assumed that the floor grade for the underground shelter was 12 ft below surface grade. A 1:1 slope was also assumed for the compacted backfill where required under the entranceway in the areas excavated for the shelter construction. The term fine grading refers to the precision filling or removal of soil to meet plan specifications, such as the fine grading required to obtain the proper thickness of the concrete stair slab.

Concrete

The concrete costs include those of all labor and material required to form, place, finish, and cure ready-mix concrete. It was assumed that used form lumber was available, which is equivalent in cost to using the same forms approximately three times. Also included are such supplementary items as snap ties, bolt ties, and form oil.

Reinforcing Steel

The reinforcing steel costs include the cost of all labor and materials incidental to tying and installing all concrete steel reinforcement.

Table 4-1

CONSTRUCTION COST ESTIMATE FOR UNDERGROUND FALLOUT SHELTER ENTRANCEWAY TYPE A

(Dollars)

	Entranceway Number						
	A-1	A-2	A-3	A-4	A-5	A-6	A-7
Capacity (persons/min)	67	90	112	120	180	45	90
Earthwork	$ 355	$ 436	$ 471	$ 438	$ 380	$ 56	$ 225
Concrete	1,390	1,522	1,721	1,849	2,279	1,093	1,277
Reinforcing steel	125	112	116	140	302	97	95
Miscellaneous iron	416	525	517	555	763	387	420
Drain	95	95	95	95	95	95	95
Door	326	326	374	374	629	326	326
Electrical	40	40	40	40	40	40	40
Roofing	12	16	19	20	30	8	11
Temporary facilities	42	46	50	52	68	30	38
Labor burden	380	419	470	496	567	260	295
State sales tax	38	43	46	48	65	25	38
Contractor's profit	193	215	235	246	313	145	171
Bond	17	19	21	22	28	13	15
Total cost	$3,429	$3,814	$4,175	$4,375	$5,559	$2,575	$3,046
Cost/person/min*	51.18	42.38	37.28	36.46	30.88	57.22	33.84

---

* The cost/person/min is obtained by dividing the total entranceway cost by the entranceway design capacity.

Table 4-2

CONSTRUCTION COST ESTIMATE FOR UNDERGROUND FALLOUT SHELTER ENTRANCEWAY TYPES B AND C
(Dollars)

	Entranceway Number							
	B-1	B-2	B-3	B-4	B-5	C-1	C-2	C-3
Capacity (persons/min)	120	135	180	225	270	90	120	180
Earthwork	$ 641	$ 660	$ 665	$ 733	$ 823	$ --	$ --	$ --
Concrete	2,499	2,599	2,757	2,852	3,063	1,767	2,250	3,054
Reinforcing steel	192	212	220	268	326	83	165	257
Miscellaneous iron	729	802	840	843	949	386	482	901
Drain	95	95	95	95	95	83	83	83
Door	374	629	629	674	955	487	487	652
Electrical	110	110	110	110	110	80	80	80
Roofing	21	25	26	39	47	--	--	--
Temporary facilities	72	78	82	84	96	44	54	76
Labor burden	666	695	730	767	854	398	517	692
State sales tax	57	68	72	77	89	42	49	72
Contractor's profit	327	358	374	393	444	202	249	352
Bond	29	32	33	35	37	18	22	31
Total cost	$5,812	$6,363	$6,633	$6,970	$7,888	$3,590	$4,438	$6,250
Cost/person/min*	48.43	47.13	36.85	30.98	29.21	39.89	36.98	34.72

---

* The cost/person/min is obtained by dividing the total entranceway cost by the entranceway design capacity.

Table 4-3

CONSTRUCTION COST ESTIMATE FOR UNDERGROUND FALLOUT SHELTER ENTRANCEWAY TYPES D AND E

(Dollars)

	Entranceway Number						
	D-1	D-2	D-3	D-4	D-1A	D-1B	E-1
Capacity (persons/min)	67	90	120	180	67	67	--
Earthwork	$ 69	$ 107	$ 244	$ 319	$ 69	$ 69	$ 15
Concrete	983	1,121	1,559	1,984	983	983	351
Reinforcing steel	155	212	438	885	155	155	6
Miscellaneous iron	528	563	746	1,096	528	528	15
Drain	85	85	95	99	85	85	--
Door	326	326	374	629	326	326	232*
Electrical	35	35	35	35	35	35	--
Stairs	446†	478†	808†	1,177†	1,283‡	198§	--
Temporary facilities	40	44	64	94	52	36	9
Labor burden	210	236	326	415	212	233	84
State sales tax	32	33	45	68	30	35	14
Contractor's profit	175	194	284	408	225	161	44
Bond	15	17	25	36	20	14	4
Total cost	$3,099	$3,451	$5,043	$7,245	$4,003	$2,858	$774
Cost/person/min**	46.25	38.34	42.03	40.25	59.75	42.66	--

---

* Includes $14 for surface hatch cover.

† Precast concrete stairs.

‡ Steel stairs.

§ Treated wood stairs.

** The cost/person/min is obtained by dividing the total entranceway cost by the entranceway design capacity.

Table 4-4

CONSTRUCTION COST ESTIMATE FOR UNDERGROUND FALLOUT SHELTER ENTRANCEWAY TYPES F, G, H, AND I

(Dollars)

	Entranceway Number				
	F-1	G-1	G-2	H-1	I-1
Capacity (persons/min)	90	22	45	67	67
Earthwork	$ 130	$ 117	$ 163	$ 474	$ 799
Concrete	1,861	285	320	196	2,319
Reinforcing steel	189	26	51	23	239
Steel pipe	--	768	809	2,641	--
Stairs	--	1,600*	2,000*	186†	--
Miscellaneous iron	520	44	89	424	1,403
Drain	91	75	75	83	95
Door	326	326	326	326	326
Electrical	80	35	35	42	85
Roofing	--	--	--	226‡	28
Temporary facilities	48	50	60	70	80
Labor burden	421	180	193	196	545
State sales tax	43	36	40	41	73
Contractor's profit	223	213	249	295	359
Bond	20	19	22	26	32
Total cost	$3,952	$3,774	$4,432	$5,249	$6,383
Cost/person/min§	43.91	171.55	98.49	78.34	95.27

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* Steel stairs.

† Wood stairs.

‡ Waterproofing.

§ The cost/person/min is obtained by dividing the total entranceway cost by the entranceway design capacity.

Table 4-5

CONSTRUCTION COST ESTIMATE FOR UNDERGROUND BLAST SHELTER ENTRANCEWAY TYPES J AND K
(Dollars)

	Entranceway Number					
	J-1	J-2	J-3	J-4	K-1	K-2
Capacity (persons/ min)	90	120	90	90	180	225
Earthwork	$ 392	$ 462	$ 129	$ 551	$ 690	$ 711
Concrete	1,967	2,788	2,174	2,723	3,000	3,459
Reinforcing steel	194	289	211	415	338	430
Miscellaneous iron	545	662	525	189	818	876
Drain	95	95	107	--	95	95
Door, entry	326	374	326	326	--	--
Door, blast	282	303	282	282	708	751
Electrical	80	80	76	90	85	85
Roofing	21	35	18	40	37	50
Barrier wall	110	147	110	110	258	313
Temporary facilities	60	78	60	72	90	102
Labor burden	515	699	503	661	766	868
State sales tax	53	69	50	64	71	80
Contractor's profit	278	365	274	331	417	469
Bond	25	32	24	29	37	39
Total cost	$4,943	$6,478	$4,869	$5,883	$7,410	$8,328
Cost/person/min*	54.92	53.98	54.10	65.37	41.17	37.01

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* The cost/person/min is obtained by dividing the total entranceway cost by the entranceway design capacity.

Table 4-6

CONSTRUCTION COST ESTIMATE FOR ABOVEGROUND FALLOUT SHELTER ENTRANCEWAY TYPES L, M, AND N

(Dollars)

	Entranceway Number						
	L-1	L-2	L-3	M-1	M-2	M-3	N-1
Capacity (persons/ min)	120	180	240	120	180	240	--
Earthwork	$ 56	$ 82	$ 85	$ --	$ --	$ --	$ --
Concrete	867	1,076	1,470	789	921	1,269	262
Reinforcing steel	94	135	193	115	135	208	17
Masonry	--	--	--	1,022	1,107	1,402	--
Miscellaneous iron	--	--	--	112	112	112	--
Door	379	629	654	1,018	1,364	1,647	324
Electrical	36	36	36	--	--	--	--
Roofing	15	21	33	--	--	--	--
Temporary facilities	22	30	36	46	54	70	10
Labor burden	177	221	289	213	240	324	58
State sales tax	29	42	50	46	62	76	16
Contractor's profit	100	136	170	200	238	304	41
Bond	9	12	15	18	21	27	4
Total cost	$1,784	$2,420	$3,031	$3,579	$4,254	$5,439	$732
Cost/person/min*	14.87	13.44	12.63	29.83	23.63	22.66	--

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* The cost/person/min is obtained by dividing the total entranceway cost by the entranceway design capacity.

Miscellaneous Iron

The costs in the miscellaneous iron category include those of labor and material to fabricate and install such items as wall- and floor-mounted handrails, handrail cans, and all galvanized grating, including angle iron, as shown on the entranceway sketches.

Steel Pipe

The cost estimate for the steel pipe entranceways includes all labor, materials, shop fabrication, if required, and erection in the field of Armco Multi Plate pipe.

Drain

The drain costs include the cost of the material and labor necessary to install a standard floor drain, such as Josam or equivalent, and sufficient 2-in. diameter cast iron pipe to connect the floor drain to the existing shelter drain tile at the foundation level.

Door

The entry door costs include those of all material and labor incidental to door installation, such as the door, hinges, lock set, jamb, threshold, and panic type hardware device. Entry doors and jambs are of the hollow metal type, designated as Underwriters' Laboratories "A" label, which meet the fire code standards (Ref. 35) for a three-hour fire rating.

Blast Doors

To obtain the cost estimates for the blast doors, it was assumed that the doors were constructed with a Douglas fir select structural grade, tongue-and-groove wood core, faced on both sides with 1/2 in. thick plywood. The inner edge of the door was faced with a welded angle iron frame to transfer the door loads to a 6-in. channel jamb frame. A simple gasket seal was assumed to be adequate for blast sealing, together with dog-type latches to prevent door rebound during shelter button-up periods. Included in the costs were those of door hardware and the pressure impregnation of the wood with a fire-retardant chemical. Panic devices were not included in the blast door cost estimates for those entranceways that also had an entry door (Type J), but were included in the blast door costs where there was no other entry door in the entranceway (Type K).

Electrical

The electrical costs include those of the labor and materials required for the installation of the conduit, wire, outlet, and fixtures required to connect one, two, or three entranceway lights, as required, to the shelter electrical system.

Roofing

Roofing costs include the labor and material costs of providing a built-up multiple ply felt and asphalt type roofing on the entranceway, which would be similar to the roof covering for the basic reinforced concrete shelter.

Temporary Facilities

Temporary facilities costs include various miscellaneous costs not directly chargeable against any other construction cost. The estimate of 1-1/2 percent of the construction cost (excluding labor burden, sales tax, profit, and bond) represents an average for this type of construction for medium size construction projects in the San Francisco Bay Area. Included in the costs are job overhead; job supervision at superintendent level or above; field engineering; and temporary utilities such as water, electrical power, toilet, telephone, and office space. Other items included are miscellaneous tools and equipment, office supplies, building permits, and material tests.

Labor Burden

A labor burden of 30 percent represents an estimate of the charges against the direct payroll costs for construction contractors in the San Francisco Bay Area. Included in the labor burden are such items as payment for Federal Insurance Contributions Act and State Unemployment Compensation, and charges for employee fringe benefits such as pension and retirement funds, vacation, holiday, and sick pay, and group health and accident insurance programs.

Contractor's Profit

The contractor's profit of 6 percent of the total construction cost (excluding bond) represents an average charge for construction projects of shelter size. Included in this item are general office overhead, income taxes, and profit.

Bond

A fee of 0.5 percent of the total construction is an estimated charge for a performance bond provided by the contractor as a guarantee to the owner of job completion.

Entranceway Cost versus Capacity Data

After development of the cost data for the individual entranceways and escape exits, the information was used to establish a total entranceway cost versus the capacity in persons/min through the entranceway. Since the appropriate use of the cost data is dependent on an understanding of both the method used to develop the curves and the inherent limitations of the basic data, a detailed explanation of the procedure is warranted.

From the basic cost data in Table 4-7,* it was possible to develop total cost versus capacity curves for the following six types of entranceways:

1. Underground shelter, reinforced concrete entranceways.
    a. Single and dual stair--fallout (Types A and B)
    b. Covered stairwell--interior location--fallout (Type C)
    c. Open stairwell--exterior location--fallout (Type D)
    d. Single and dual stair--fallout plus direct effects (20 psi) (Type J and K)
2. Aboveground shelter, reinforced concrete entranceways.
    a. Surface entranceway--no basement--fallout (Type L)
    b. Surface entranceway--with basement--fallout (Type M)

To develop the cost information for a meaningful range of entranceway capacities, it was necessary first to obtain cost estimates for entranceways

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* This table is a summary of the pertinent cost data from Tables 8, 9, and 10 in Section IV.

Table 4-7

SUMMARY OF CONSTRUCTION COST ESTIMATES

Entranceway Type	Capacity (persons/ min)	Total Cost (dollars)	Cost/ Person/Min (dollars)
Underground fallout shelter entranceway			
A-1 Reinforced concrete, single stair	67	$3,429	$51.18
A-2 Reinforced concrete, single stair	90	3,814	42.38
A-3 Reinforced concrete, single stair	112	4,175	37.28
A-4 Reinforced concrete, single stair	120	4,375	36.46
A-5 Reinforced concrete, single stair	180	5,559	30.88
A-6 Reinforced concrete, single stair	45	2,575	57.22
B-1 Reinforced concrete, dual stair	120	5,812	48.43
B-2 Reinforced concrete, dual stair	135	6,363	47.13
B-3 Reinforced concrete, dual stair	180	6,633	36.85
B-4 Reinforced concrete, dual stair	225	6,970	30.98
B-5 Reinforced concrete, dual stair	270	7,888	29.21
C-1 Reinforced concrete, stairwell, interior location	90	3,590	39.89
C-2 Reinforced concrete, stairwell, interior location	120	4,438	36.98
C-3 Reinforced concrete, stairwell, interior location	180	6,250	34.72
D-1 Reinforced concrete, open stairwell, exterior location	67	3,099	46.25
D-2 Reinforced concrete, open stairwell, exterior location	90	3,451	38.34
D-3 Reinforced concrete, open stairwell, exterior location	120	5,043	42.03
D-4 Reinforced concrete, open stairwell, exterior location	180	7,245	40.25
E-1 Reinforced concrete escape exit	--	774	--

Table 4-7 (concluded)

Entranceway Type	Capacity (persons/ min)	Total Cost (dollars)	Cost/ Person/Min (dollars)
Underground blast shelter entranceway			
J-1 Reinforced concrete, single stair	90	$4,943	$54.92
J-2 Reinforced concrete, single stair	120	6,478	53.98
K-1 Reinforced concrete, dual stair	180	7,410	41.17
K-2 Reinforced concrete, dual stair	225	8,328	37.01
Aboveground fallout shelter entranceway			
L-1 Reinforced concrete, without basement	120	1,784	14.87
L-2 Reinforced concrete, without basement	180	2,420	13.44
L-3 Reinforced concrete, without basement	240	3,031	12.63
M-1 Reinforced concrete, with basement	120	3,579	29.83
M-2 Reinforced concrete, with basement	180	4,254	23.63
M-3 Reinforced concrete, with basement	240	5,439	22.66
N-1 Reinforced concrete escape exit	--	732	--

of various capacities within each type as shown in Table 4-7 and then to obtain the cost of various combinations of these entranceways. During the initial phase, cost estimates were made for a relatively large number of Type A and B entranceways, as noted in the table. However, once the general trend of the cost data was established, it became apparent that adequate cost versus capacity information could be developed from relatively few cost estimates for individual entranceways.

As noted in Table 4-7, in general, the cost/person/min within each entranceway type decreases with increasing entranceway capacity.* To determine the approximate maximum size entranceway that was economically advantageous, the cost/person/min data were plotted versus the capacity in persons/min. This information is shown on Figure 4-2 for entranceway Types A and B where the cost approaches a minimum. For the cases studied, this indicates that capacities greater than approximately 250 persons/min are of no significant cost advantage and, also, that extrapolation of the cost estimates by using combinations of entranceways would yield valid total costs for capacities up to at least 1,000 persons/min. Although not investigated, there are indications that the cost curves will increase with capacities very much larger than those shown on Figure 4-2. This is due both to the relative increase in cost resulting from increased structural requirements and to the need for longer corridors or barrier walls to provide adequate protection from fallout radiation for the larger entranceways.

The determination of the best combination of entranceways for various capacities required an examination of numerous possible combinations to establish the minimum cost. However, in most instances, it was not necessary to calculate all combinations, since an examination of the cost/person/min data usually revealed the minimum cost for any particular entranceway capacity. For example, for the single and dual stair entranceway for underground fallout shelters (Types A and B), it is evident that two 180 persons/min A-5 entranceways would provide the minimum total cost of $11,118 for a capacity of 360 persons/min. For capacities where only

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* An exception to this trend was found with the open stairwell entranceway, Type D, where the larger entranceways D-3 and D-4 were more costly per person/min than the smaller D-2 entranceway. The reason for this apparent inconsistency is that standard width, precast concrete stairs could be used with D-2, whereas the larger entranceways required non-standard width stairs, which resulted in an unusual price differential between these entranceways. Although, for the smaller entranceway, precast concrete stairs were less expensive than cast-in-place concrete stairs, this factor was not investigated for the larger stair widths.

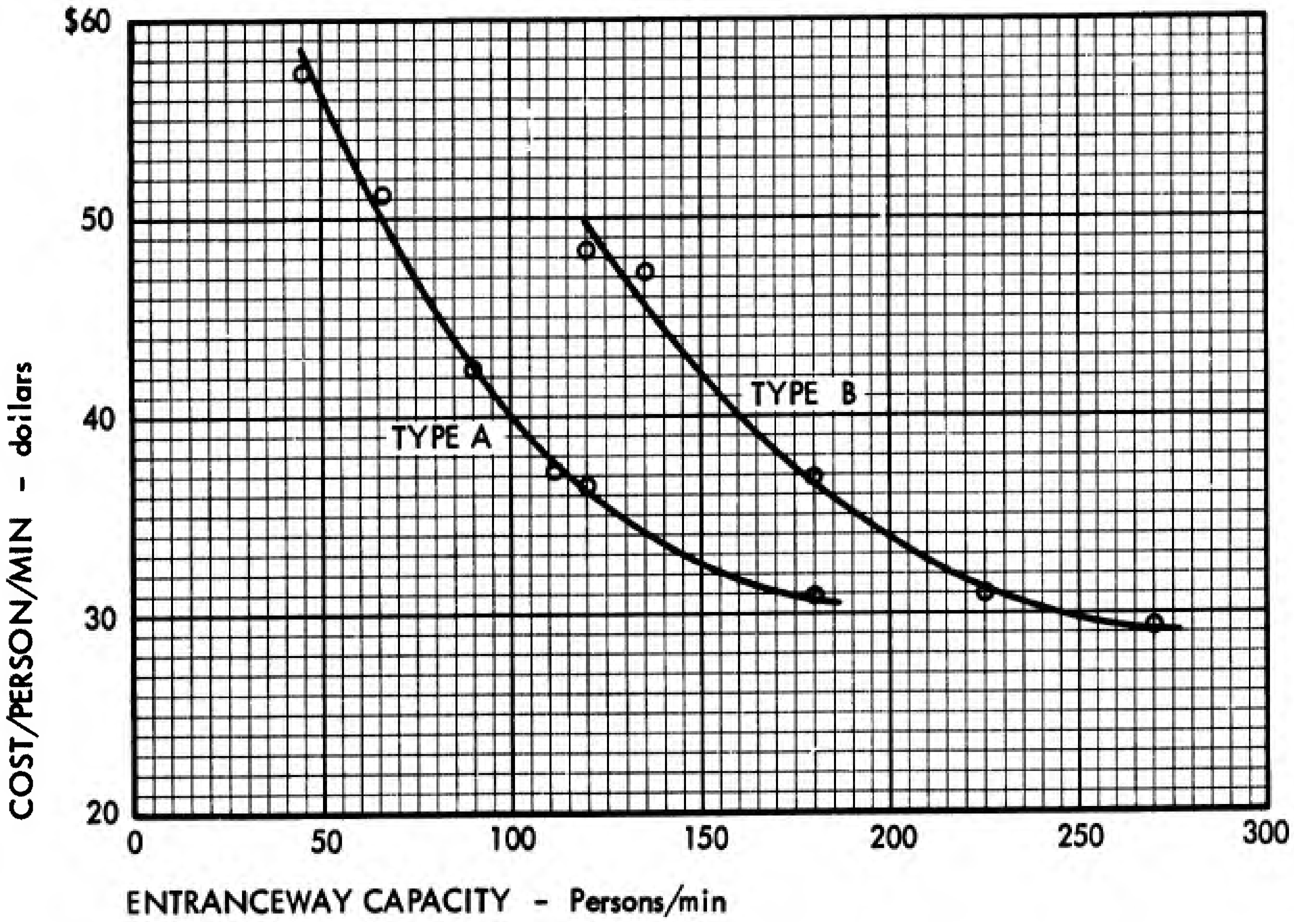

Figure 4-2

ENTRANCEWAY COST/PERSON/MIN VERSUS CAPACITY
Entranceway Types A and B

one entranceway was required, an escape exit (Type E-1 or N-1)* was included in the total cost since at least two means of exit are required by OCD for both fallout and blast shelters (Refs. 36 and 37) and by the National Fire Protection Association for emergency shelters designed for more than 10 persons (Ref. 26). Also, since entranceways with capacities less than 90 persons/min were below the fire code requirements (Ref. 26), they were not used in combination with other entranceways, but only to establish the cost at the lower capacities.

If the minimum total entranceway cost is plotted versus the capacity for the various entranceway combinations, the data approximate a smooth curve, as shown by the points on Figure 4-3 for an aboveground fallout shelter entranceway (Type M). However, this can be misleading, since the cost of an entranceway system increases in finite steps due to the requirement for increasing entranceway width by a minimum of one-half unit of exit width as discussed in Section III. For instance, it can be seen from the figure that the cost of an entranceway to provide an entering rate of 120 persons/min would cost about $5,100. If, however, an increase in capacity of only a few persons/min was required, it would be necessary to select the next larger entranceway at a cost of about $5,800. Even though the cost for an actual situation is a step function, it was felt that the data developed in this project would be more useful and more meaningful if an averaging technique was used to obtain a continuous function. Such an approach is justified on the basis of the inherent errors and differences in determining estimates of construction costs, which would result in a cost spread for each entranceway rather than a single value. Also, in most instances in this study, cost estimates were not made for each possible incremental increase in capacity and the actual cost steps would, therefore, be less than those calculated. For instance, in Figure 4-3, cost estimates could have been prepared for entranceways with changes in capacity of 30 persons/min (one-half unit of exit width) instead of 60.

To develop the curves shown on Figure 4 in Section IV, the calculated entranceway cost for each capacity was averaged with the cost for the next larger capacity. A standard SRI computer regression program was employed to determine the best least squares fit to the straight line through all the data. Figure 4-4 shows the results of the computer data for the same combination of Type M entranceways shown in Figure 4-3. As a matter of interest, the best fit to the quadratic equation through all the data was also obtained, but as can be seen, the slight improvement in fit does not

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* A single Type M entranceway requires both surface and basement escape exits.

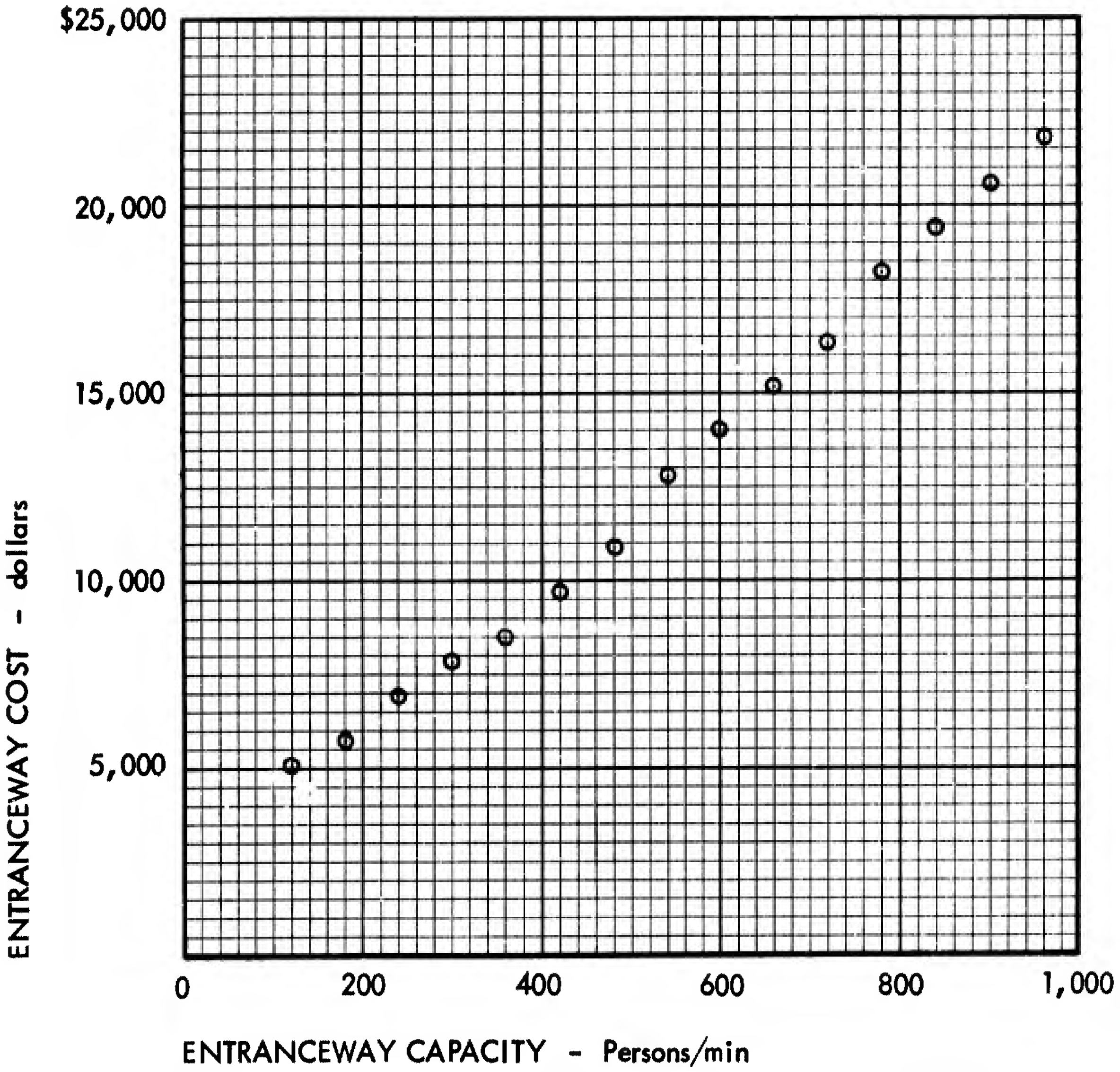

Figure 4-3

ACTUAL DATA FOR THE ENTRANCEWAY COST VERSUS CAPACITY
Aboveground Fallout Shelter Entranceway Type M

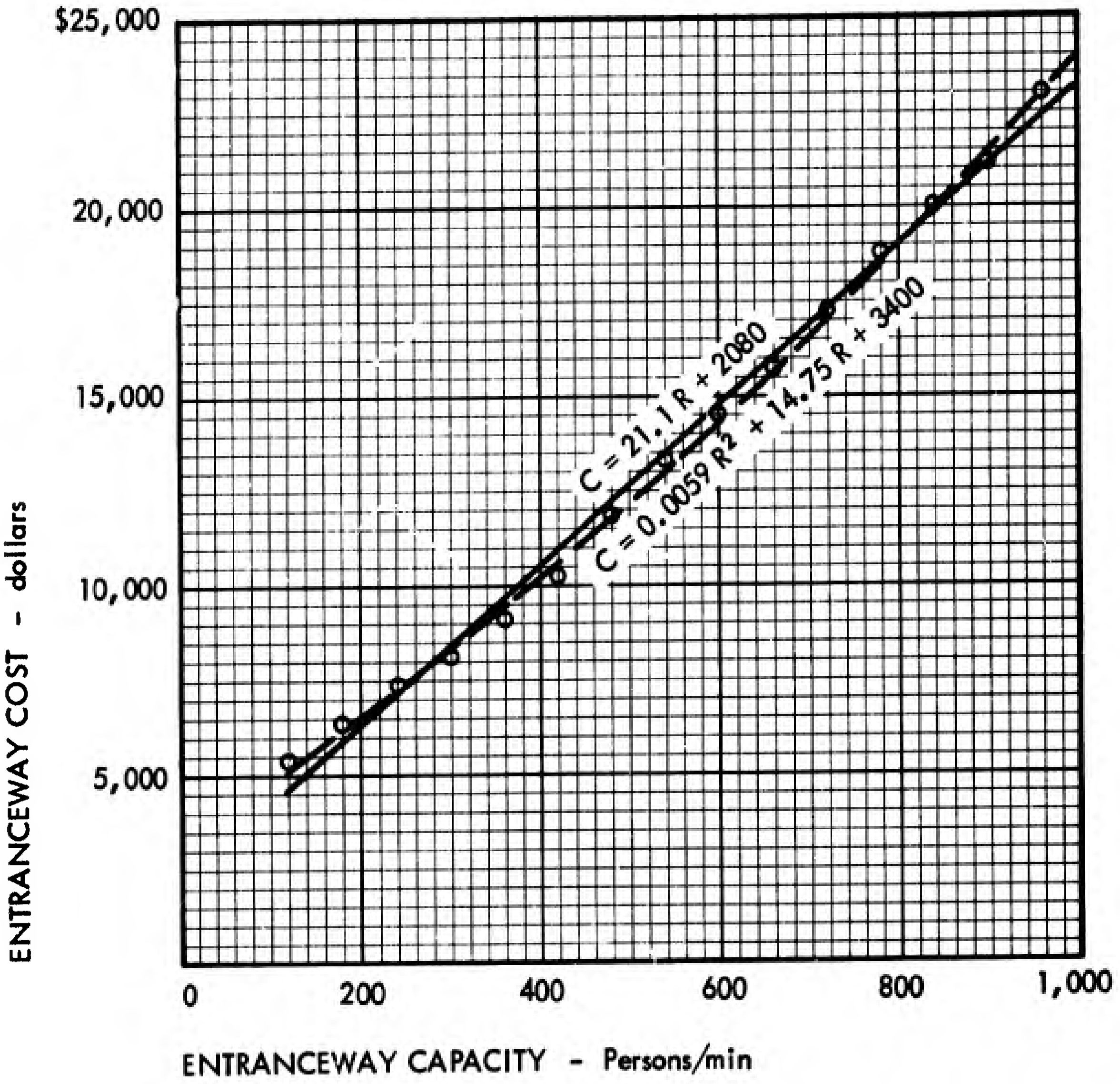

Figure 4-4

AVERAGED DATA FOR THE ENTRANCEWAY COST VERSUS CAPACITY
Aboveground Fallout Shelter Entranceway Type M

warrant the use of the more complex function.* The equations for all six types of entranceways are also presented in Section IV, Table 11.

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* The data for the example shown in Figure 4-4 for the Type M entranceway were the poorest fit to a straight line for any of the data for the six main types of entranceways. This is due to the fact that the lower three points on the figure represent only one entranceway, and the cost, therefore, includes both a basement and a surface escape exit (E-1 plus N-1).

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13. ABSTRACT

The objective of this investigation was to develop, test, and evaluate low cost shelter entranceways and openings for providing protection against the effects of nuclear weapons in the overpressure regions up to 20 psi. The approach adopted was (1) to identify as many factors as possible that influence, limit, or constrain the entranceway design; (2) to attempt to identify the multitude of interacting situations; and (3) to establish the situations most important to the design of entranceways for civil defense shelters. From an examination of the numerous influencing factors, parameters were selected as the basis for performing cost analyses for various entranceway configurations. Cost estimates were then prepared for 36 individual entranceways and 2 escape exits. From these data, it was possible to develop the total construction cost of shelter entranceways for loading capacities up to 1,000 persons/min for six general types of entranceways applicable for civil defense fallout and blast shelters. Since the loading capacity required for a specific entranceway system cannot be determined in a general manner beforehand (as explained in the body of the report), the cost data are presented on the basis of the entranceway cost/person for shelter capacities up to 10,000 persons for the six entranceway types and for entranceway loading capacities between 67 and 1,000 persons/min.

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