Professional Guide Series:

INCORPORATION OF SHELTER
INTO PARKING GARAGES

Department of Defense
Office of Civil Defense
Washington 25, D. C.
This Professional Guide is one of a series of technical publications prepared under the direction of the Office of Civil Defense. The purpose of the Office of Civil Defense Technical Publications Program is to assist architects and engineers in the planning and design of structures that contain protective features.

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INCORPORATION OF SHELTER INTO PARKING GARAGES

The Technical Publications Program consists of five categories:

- Professional Manuals present the technology of design and construction for protection against nuclear weapons effects.
- Professional Guides orient this technology to the incorporation of protective features into normal-use structures such as schools, apartment buildings, and industrial plants.
- Technical Memoranda present subjects not of sufficient scope to warrant presentation as a manual or guide. These
- Design Supplements provide additional design and construction funds for incorporation of protective features into normal-use structures.
- Engineering Case Studies are engineering case studies that enhance the design and construction of specific projects.

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PREFACE

This Professional Guide is one of a series of technical publications prepared under the direction of the Office of Civil Defense. The purpose of the Office of Civil Defense Technical Publications Program is to assist architects and engineers in the planning and design of structures that contain protective features.

This publication was prepared for the Department of Defense, Office of Civil Defense, by the Small Homes Council-Building Research Council of the University of Illinois, Rudard A. Jones, Director; Brian J. Crumlish, and Donald E. Brotherson, Principal Investigator and Author. Members of the staff of the Small Homes Council-Building Research council assisted in the investigation. The firm of Carroll-Henneman & Associates, Urbana, Illinois, was consulted on certain engineering phases of the investigation.

This publication is presented as an interim edition to meet the immediate need of architects and engineers, and to allow the professions to contribute their experience for consideration in preparation of the final version. Comments should be sent directly to the Engineering Services Division, Office of Civil Defense.

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Technical Memoranda present subjects not of sufficient scope to warrant presentation as a manual or guide. These generally consist of performance requirements for shelters and shelter components.

Design Studies present, in general outline form, suggested designs for incorporating protective features into normal-use structures.

Engineering Case Studies are engineering reports on the design and construction of specific projects.
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INTRODUCTION

Parking garages deserve special consideration as protective structures because, as currently constructed, they have many characteristics that resist the effects of a nuclear detonation.

A building type introduced to American cities only a few decades ago, the parking garage now represents a significant percentage of new downtown construction. As the popularity of automobile travel continues to rise, the need for more parking facilities naturally follows.

By demand, the parking facilities are easily accessible to the main traffic arteries of the urban area and are as close as economically possible to the center of the working population and the shopping areas of cities--areas where people are at some distance from their home or neighborhood shelters.

It is obvious that garages have some characteristics that are highly desirable for a protective structure. The wide ramps used to distribute automobiles provide easy, generous access to a mass movement of people. The relative openness of the plan allows a high degree of flexibility in arranging space in emergency conditions. The structure is frequently both fire resistive and of a massive construction desirable for radiation attenuation.

Complete protection against all nuclear effects is generally impractical. However, certain degrees of resistance to each effect can be developed.

The prime objective in a good shelter program is to protect the population. A garage utilizing the principles of mass and geometry shielding could reduce the hazards of radioactive fallout to citizens sheltered within. Increased structural resistance and special attention to the detailing of openings could reduce the dangerous effects of the blast and thermal waves.

Another objective is to reduce the reconstruction required in a post-attack period. Structures with a capacity to withstand thermal and blast effects could provide both a shelter during periods of high radioactive fallout and temporary quarters in the event of destruction of offices or residences. Eventually, it would revert to its peacetime use when the emergency situation ended. In any case, attention should not be limited to structural parts; the mechanical systems should also be designed for as nearly an efficient continuous function as possible.
The additional objective of preserving material goods will also assist in relieving the burden on the economy. Protection of goods stored would not be a primary consideration in the design of a parking garage, but the availability of some vehicles in an emergency period would be helpful. If the structure is to serve as a fallout shelter or emergency housing area, certain emergency goods must be stored and attention given to their protection. For example, the sleeping and food supplies must be protected from the possibility of ignition from thermal radiation, from devastation by blast pressures, and from contamination by radioactive fallout.

Many of the problems to be solved are similar to those of other structures, and they will not be dealt with in detail. The general emphasis in this Guide will be those problems peculiar to the design of a parking garage with protective features. In addition to those protective features incorporated in the original construction, the designer should be aware of the temporary protective measures that may be taken during emergency conditions. His design could make them faster, more economical, and more efficient. Wherever possible, hasty measures (those accomplished in a few hours), expedient measures (those requiring a day or so of preparation), and improvised measures (those involving a week or so of construction) will be pointed out.

This Guide does not establish mandatory design criteria. The intensity of all nuclear effects on a structure varies independently, depending on distance from the detonation, the height and magnitude of the explosion, atmospheric and geographic conditions, and so forth. A brief description of the phenomena accompanying a nuclear detonation has been prepared by the Office of Civil Defense and is included in this publication as Appendix A.

Specific loadings or intensities as established by OCD (such as 5 psi and 25 psi overpressure resistance qualifying as "limited" and "blast" protection, and a minimum protection factor of 100 for fallout) are not necessarily implied in the examples. In some cases, the expense or complications involved will not allow the structure to fully meet these criteria; yet, some protection can be provided. In other cases, higher degrees of protection may be gained at a moderate additional cost.

Garage structures are frequently limited to minimum budgets. Throughout this Guide, protective features are carefully considered for their effect on both the economical and efficient operation of the garage in peacetime as well as the advantages gained in its alternate use as a protective structure.
Certain garage types are inherently better suited for protective structures; other types will require the incorporation of special protective measures. In all cases, inclusion of some protective features should be investigated.

The discussion of cost is kept in a relative nature on each feature, and a detailed cost analysis is not included. For an example of cost analysis, the designer should refer to the design studies and engineering case studies (OCD DSG 35 series).

The general emphasis of this Guide is to discuss ideas which the architect or engineer may consider in his design of a parking garage. It is hoped these ideas will furnish sufficient background to the designer so that he is better able to determine the amount and type of protection that he may wish to incorporate into a structure.

As shown in the preface to this Guide, the Office of Civil Defense offers publications that will be of value to the architect-engineer in solving the design problems and answering questions raised in this guide.
CHAPTER I

THE DEMAND FOR AND CHARACTERISTICS OF THE PARKING GARAGE

1-1 General

This chapter discusses the demand for parking space as related to city planning, population densities and location, and the basic types of parking structures emerging from the demand.

1-2 The Parking Garage and the City

1-2.1 Parking Demand and City Size

The parking garage is a planning device used to concentrate the storage of automobiles in areas of heavy traffic potential. This type of a structure occurs most frequently in areas where land costs are high. The major purpose of this structure, aside from the storage of automobiles, is to gain maximum use from the land. The storage capacity of an expensive parcel of land can be increased as much as ten times by the use of multi-level garages; a dual use of the land may be accomplished by combining a parking garage with another type of structure; or the land may be left as open space when an underground garage is built.

In small cities where the cost of land is low, the areas of dense traffic are frequently limited to the vicinity of traffic generators such as shopping centers and small businesses. Adequate parking space is usually available at the curb in towns with less than 10,000 inhabitants. With the growth of a city, however, the street pattern seldom changes and the amount of curb parking consequently does not increase. Off-street parking spaces begin to appear as the city grows but rarely do economic factors demand parking garages before the city reaches a population of about 100,000.

In a new project, the area devoted to parking depends upon the nature of the project. This area often equals or exceeds the area assigned to the major function of the project. In residential projects, such as private homes, apartments, hotels, and motels, space for one or two cars per unit is customarily provided. Stores and offices require one parking space for every 200 to 400 square feet of leasable floor space. In places of assembly such as theaters, auditoriums, and churches, the parking area frequently exceeds the net area of the structure.
1-2.2 Parking as Part of a Coordinated Plan

Many new structures are, however, erected without regard to parking demands or traffic pattern. Small retail merchants are not financially able to construct parking structures. Space must be provided in privately erected and operated garages or the responsibility must be assumed by the city government. When private garages are constructed, they are seldom planned with respect to the traffic pattern. More often than not, these garages are erected on lower cost land, inconvenient to both the major traffic arteries and the destination of the patrons. Cities are becoming increasingly aware of this deficiency and are placing less reliance on private parking interests to assist in solving the problem.

Another major factor affecting the parking pattern is the expansion of the rapid transit facilities of a city. The direct effect of an efficient rapid transit system is the diversion of automobile traffic from the city center. Consequently, parking spaces must be provided in the fringe areas convenient to the transit terminals.

In order to achieve maximum efficiency, the planning and control of parking should be coordinated with the traffic layout, the land use, and the rapid transit design. This can be best accomplished by the city. The planners of a city also should be concerned with problems of sheltering citizens in the event of an enemy attack. If parking structures are used for shelter, Civil Defense activities can be coordinated with the traffic design by the planning departments.

The principal problem in establishing a coordinated parking plan is usually the acquisition of land. Private interests occasionally find that the tax on structures makes it profitable to demolish older buildings and convert land into vacant sites available for parking. In city government parking programs, the city often condemns the land, builds the parking structure and then leases the facilities to private operators.

As the need for parking increases, available land becomes scarce. Within the central business district, densities are high and the land is expensive. This is the hub of commercial activities of the urban area—a consolidation of offices and retail shops, frequently surrounded by a ring of light manufacturing areas.

The area generally referred to as the core of the central business district, where densities and land costs are highest, occupies about one-fourth of the central business district. It is the destination of the majority of shoppers and workers, but unfortunately contributes
only a small fraction of the parking facilities at the present time. Encouraged by high land values, the pattern of growth in the core has been towards taller buildings, which in turn generate more traffic. This traffic eventually forces the elimination of curb parking and the high land values increase the difficulty of providing off-street parking.

1-2.3 Parking Structures as Part of New Projects

This intense problem has produced many creative solutions. As a result of planning studies, most large cities are programming enormous parking facilities in the very heart of the city, conveniently located for shoppers and workers. Private interests have also provided excellent examples of structures which include built-in parking among their client-attracting facilities. The schemes are worth examination not only as good architecture and as solutions to the parking problem but also for the potential they hold a shelter program.

Among the schemes to provide parking within the city core, the Seattle plan which proposes a dramatic pedestrian platform covering twenty blocks, furnishes an excellent example of a well-protected area available to thousands of people. The unobtrusive parking, concealed in several layers below the surface of the plaza, returns a dignified aspect to a city threatened by the blight of automobile parking. Similarly, in Penn Center in Philadelphia, the automobile is skillfully restricted from the scene. Here, within the broad, open esplanades of the center, all modes of transportation come together in a single structure, which also houses six decks of parking to serve the area. In Rochester, the project of revitalizing the city core provides for a 3-story parking garage built below grade, with ramps connecting to a surrounding link road, and supporting an 18-story tower with banks, stores, offices, restaurants, and hotel space.

Though somewhat smaller in size, the parking innovations provided by private enterprise are nonetheless imaginative. Private parking garages are not uncommon in the central business districts as part of office buildings, apartments, and hotels.

In Chicago, twin towers containing almost 900 dwelling units have a parking space for each unit on a continuous spiral ramp system on the lower 16 floors. In many large cities, co-op and high-rise apartment buildings have ramped underground parking garages.

Office-building designers have used a variety of schemes to provide parking in order to attract clients. A new skyscraper in Montreal
is superimposed on a marble-paved, multi-level base which houses over 2,000 cars. An office building in Kansas City has provided parking for its tenants in a five-level, aboveground structure joined to the office building by a pedestrian bridge. In New Orleans, where the water table is near the ground surface, an elevated plaza screens an "underground" parking garage.

Urban renewal also furnishes many examples of interesting parking structures. Many cities are using renewal schemes as a means of providing some relief to the parking problem. Expansive parking facilities within a project close to the business district serve both the inhabitants of the area and shoppers and business visitors.

In LaFayette Park in Detroit, a multi-level parking structure has been constructed between two 22-story apartment buildings. Appearing as a brick-walled horizontal slab, topped by a terrace and swimming pool for the 300 families, the structure conceals 370 cars.

In the new Carl Sandburg Village in Chicago, no traffic penetrates into the housing and shopping center and all parking is underground. The considerable extra expense was justified by the creation of an atmosphere of quiet.

The areas surrounding cities provide fewer examples of parking structures. Parking garages in fringe areas are not usually successful. Many housing developments provide enclosed parking facilities, but, in general, parking lots are sufficient.

In suburban areas, large concentrations of cars occur at shopping centers; but, without the pressure of high land costs, parking is usually allowed to cover the landscape. Rarely are parking garages provided. The chief motive for housing automobiles in the suburbs is not land conservation but aesthetics.

A noteworthy example, which also testifies to the ubiquity of the parking garage structure, is an office building standing alone on a rolling 100-acre site in Connecticut. The elevated square "doughnut" of offices surrounds a covered ground-floor garage. The roof of the garage forms a landscaped entrance court. This approach solves the vexing problem of what to do with employee cars in a rural setting. With the building raised above the ground, cars can be parked beneath it, minimizing walking distance and providing shelter during bad weather. Unsightly parking fields are eliminated so that panoramic views from inside the building, already enhanced by elevation, are not interrupted by the usual sea of
automobiles.

1-3 Current Garage Construction

1-3.1 General

In such a rapidly changing field of design, generalization can be misleading. However, in order to make this guide most useful, some attempt has been made to determine which garage characteristics are most common in current construction or promise to become so. Dimensional layout of structures, for example, is greatly modified by structural innovation and by the constantly changing dimensions of the automobile. Area requirements reflecting these standards may be valid for only a few years.

1-3.2 Garage Types

Current garage construction may be classified by the location within the structure, method of management, or method of interfloor travel. Of these, the location of the parking facilities within the structure has the most influence on the effectiveness of the garage as a shelter, but the management and vertical circulation system also have some effect.

1-3.3 Location Within the Structure

The most representative commercially operated garage used solely for parking is the aboveground structure. This is usually a multilevel structure and may be either an open-air or closed type.

The open-air structure is less vulnerable to blast pressures as a result of its open construction but would offer the occupants little protection from thermal, blast, dynamic, and initial radiation effects. However, being an aboveground structure that is likely to remain standing within the destructive area of the blast pressures, the upper floors of an open-air garage could serve as a fallout shelter to relieve crowded conditions in nearby blast shelters after the initial effects have passed if shielding analysis shows that it meets fallout shelter requirements.

Almost no aboveground enclosed garages are being constructed except as integral types where the parking is enveloped by an office building or hotel. The enclosed type could be developed into an excellent shelter. It cannot be expected that the expense involved for massive exterior walls, forced ventilation, and lighting will be met without some
incentive. This type of structure might be built in those locations where the prime motivation is to build a shelter with an alternate use as a parking garage.

The underground garage structure has no operating advantage over the aboveground structure. In addition to requiring more light and ventilation, construction costs usually exceed that of an aboveground garage. As a consequence, this type of solution is used only where underground space can be easily and cheaply acquired. The main advantage is that the ground surface can remain open for its original use. The underground garage combines the least vulnerability to blast with the best thermal and radiation protection. It is uniquely qualified as a shelter.

Examples of the completely underground type occur in large cities--usually under public spaces. The most common type of privately owned underground garage is that located in basement space of an office or apartment building.

A combination of both aboveground and underground parking is occasionally used. Because this usually requires two sets of ramps on the main floor (depending on the method of ramping), combination schemes are not usually economical. Under emergency conditions, the belowground portion could serve as a blast shelter and the aboveground floors later could serve as a fallout shelter if shielding analysis shows that it meets the necessary requirements.

Whenever the structure is adjacent to a sloping street, direct access is used for all floors. Thus, aboveground and belowground space is utilized without the use of interior ramps since the structure may be entered at several levels. Costs can be kept low because, by the usual code definitions, the structure is open-air and no mechanical ventilation is required.

An integral structure includes provision for parking within a structure intended for other purposes. This is rapidly becoming popular in office, hotel, and apartment structures. There are positive advantages for this type of structure as a shelter. When the parking is enveloped within another structure, the shelter area gains protection from the surrounding walls. There is also access to the utilities of the surrounding structure.

1-3.4 Type of Management

The type of management is reflected both in the amount of space devoted to other uses and in the location of the structure. These factors
may, in turn, influence the usefulness of the structure in a Civil Defense program.

If the garage is exclusively a commercial enterprise, privately owned and operated, it is unlikely to be placed in a location determined by the community planning organization. This does not mean it cannot be utilized for shelter purposes, but its location may not be the most desirable. Since commercial garages usually charge fees on an hourly, daily, weekly, or monthly basis, the main floor will have enclosed areas devoted to offices and customer facilities. Frequently, prime space on the main level is leased to another facility.

A parking facility erected by the city may be either city-operated or leased. When operated by the city it may or may not charge a fee, but it is almost always a self-parking facility. When operated privately, it may or may not be a self-parking facility.

A private parking garage is that type usually used in connection with another building function and provided for the convenience of the tenants. Usually the client parks his own vehicle and parking fees are normally included as part of the rent for the office or dwelling unit.

1-3.5 Interfloor Travel

Vertical circulation within the structure may be either by ramps or elevators. If ramps are used, considerable space is taken by them on each level. Though this limits parking space, the ramps may be used for shelter since their slopes are low. The minimum size garage that can be designed with ramps is approximately 110 by 160 feet. In this design, however, over two-thirds of the area is taken by ramps—a very uneconomical ratio of circulation space to storage. As the structure increases in size, the ramping system becomes more economical, and the garage becomes a better shelter.

A garage using an elevator for vertical circulation requires only about 25 percent of the area to be devoted to elevating devices. The structure can be placed on lots as narrow as 24 feet if there is access on two sides. The relative openness and typical narrowness of a building using elevator parking usually eliminates it as a shelter.

The ramping systems that may be adopted in a garage are numerous, and the selection should be based primarily on the proportions and space available. Ease of construction, area required, number and sharpness of turns, length of path of travel, separation of traffic, and
numerous other advantages or disadvantages of the various methods has little influence on the protection afforded by the structure. The openings into the ramping system are the only critical considerations.

1-3.6 Size

The parking capacity of a structure varies with the facility associated with the garage. However, even small garages have a large shelter capacity if they incorporate protective construction.

Ramped structures usually do not exceed five stories above grade for commercial installations, since additional height requires critical travel time regarded as an inconvenience to the customer. The approximate limit is eight stories. With respect to radiation protection, the taller structures are preferable since they offer greater overhead mass shielding.

1-3.7 Auxiliary Facilities

Private garages have few, if any, facilities such as rest rooms and lounges within the parking areas. Commercial garages usually include facilities for the convenience of customers, but these are limited to the ground floor. About half of the garages now being built include some rentable space on the street level, with the remainder of this level accommodating circulation, administration, and temporary storage space. The ground level of integral structures is usually used for lobbies or terraces. The other floor levels are typically open space, uninterrupted except by vertical circulation elements. Therefore, the space available for shelter will usually be open. Auxiliary features located on the main floor will not be useful because they will not have a high degree of protection.

1-3.8 Structure

Although, for flexibility, long spans are recommended for parking garages, the majority of the commercial garages built use a structural grid varying from 20 to 30 feet square. This bay size is based on an economical structural span modified by the stall layout, angle of parking, and circulation system using current car dimensions. Reinforced concrete is most often used for the structural system, but precast shapes are gaining in popularity. Exposed structural steel is generally limited in application to open-air elevator structures where local codes permit its use. In parking garages located beneath other buildings, the structural bay is frequently a projection of the bay size selected for the superstructure.
The reinforced concrete structure is preferable for radiation shielding because of its mass. However, spans should be limited because of their structural behavior under blast loadings. Precast sections will require additional expense to achieve continuity over joints.

The successful design for a parking garage incorporating protective features requires several design criteria. For parking, the design must facilitate the approach, the maneuvering, the parking, and the storing of vehicles, as well as include the special facilities required for the employees and the customers. This must be done in a manner which does not endanger the health or the safety of the public, as outlined by the building codes. In addition, new criteria needed for resistance to nuclear effects must be included in the design.

This chapter briefly summarizes these design requirements, and comments on those requirements which have effect on the usefulness of the structure as a shelter.

2-3 Garage Criteria

2-3.1 Main Floor Requirements

The main floor of any parking garage, whether it is a commercial or private facility, is devoted at least partially to the requirements of receiving and dispatching the vehicles, since the entrances and exits of the structure penetrate at this level.

The entrances are laid out on principles similar to those applied to intersection design; that is, they are designed so that the cars may enter and leave the garage either at a right angle to the street traffic or be able to merge with the traffic. The entrances are designed for relatively low speed operation, admitting cars easily without any danger of collision and with clear sight lines for both traffic and pedestrians. Entrances should be located as far as possible from street intersections. Double or even triple lanes are preferred, with each lane at least 12 feet wide.

These wide lanes ideally suit the garage entrances to the ready movement of people. As discussed earlier, a merging type of exit may provide better blast protection. It should also be noted that the requirements for clear sight lines will automatically eliminate certain areas as fallout shelters.

Immediately after entering the garage, a large reservoir area
CHAPTER II

DESIGN STANDARDS OF THE GARAGE STRUCTURE

2-1 General

The successful design for a parking garage incorporating protective features involves several design criteria. For parking, the design must facilitate the approach, the maneuvering, the parking, and the storing of vehicles, as well as include the special facilities required for the employees and the customers. This must be done in a manner which does not endanger the health or the safety of the public, as outlined by the building codes. In addition new criteria needed for resistance to nuclear effects must be included in the design.

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These wide lanes ideally suit the garage entrances to the mass movement of people. As discussed later, a merging type of exit may provide better blast protection. It should also be noted that the requirement for clear sight lines will automatically eliminate certain areas as fallout shelters.

Immediately after entering the garage, a large reservoir area
should be located to absorb peak in-bound traffic, and to provide a place for temporary storage. The extent of this area depends upon the type of garage planned. If it is to be a self-parking facility, the cars will move through the area rapidly and only a small space is needed for distribution of tickets. In a commercial garage with attendant parking, the size of the reservoir, which in most cases will exceed space for ten cars, is dependent upon the calculated rate of car arrival during the peak parking period, the average time required for parking, and the number of parking attendants. The reservoir area should conveniently form a transition between the entrance and ramps. If the driver is to leave his car there, the area should be designed for pedestrians to circulate safely and it should be convenient to the customer facilities.

If the garage is a commercial type, facilities which require public contact are located on the main floor adjacent to the reservoir area. Because of the commercial value of these spaces, they are kept to a minimum. The cashiers booth, for example, should be only large enough to issue tickets and collect fees. Bookkeeping and personnel administration should be housed in less valuable space. Public telephones, restrooms and check rooms, and essential customer facilities, as well as some optional facilities such as manager's office, service and repair, and sales are also located on the main floor.

This reservoir space could be a useful area for processing the entering shelter occupants. Placing these facilities on the ground floor should be reconsidered if the structure is to serve as a fallout shelter. Ramping down one level before entering this area could bring it within the shelter area. This would reduce the number of car stalls but would increase the rentable ground-floor space.

From the reservoir area, the flow of traffic leads directly to the ramps. The ramp location is primarily determined by the layout of the storage floors. It should be designed so that the terminal points on the storage floors will permit an efficient parking and travel arrangement. On the main floor, development of maximum reservoir space would ideally place the ramps farthest from the entrance. For both efficiency and ease of travel, ramps should have grades between 10 and 15 percent. A 20 percent grade is permissible for short ramps such as those used between staggered floors. All ramps should be eased to six percent grade at both the head and foot. Width of ramps should be 10 feet per lane and dividing strips between lanes should be 18 inches.

Preference should be given to separate ramps for the two directions of travel rather than combining the two. During the critical time of
entering the shelter, a single lane would be sufficient to handle the mass movement. Then, if it is decided to evacuate automobiles, confusion and even panic may be avoided by having separate and distinct lanes for the outgoing cars and the incoming shelterees.

2-2.2 Storage Floors

The principles of layout of a storage floor are evolved from the basic units of design: the car stall and the access aisle. The ideal layout of a floor is a maximum number of spaces with a minimum interference and restriction to car movement.

With the constant change in automobile sizes, the stall size also changes. Currently an 18-foot length will accommodate 95 percent of all cars. A car width of 6 1/2 feet, plus 1 foot of clearance on both sides is the minimum stall width. An 8-foot stall is used for attendant parking and 8 1/2 feet for self-parking.

Parking angles vary from 30° to 90°. A 90° angle is generally the most economical for a number of reasons. It is easier to coordinate the layout with the structural grid, the access aisles can be used for two-way movement, and dead-end aisles can be employed. Aisle widths are dependent upon the direction and angle of parking and the turning radius of the vehicles.

The total area per auto depends upon the stall width used, the angle of parking, and whether head-in or back-in parking is used. For example, an 8 1/2 foot, 30° head-in stall requires 363 square feet of stall and aisle as compared to 240 square feet for an 8-foot 90° back-in stall. For preliminary design purposes, 300 square feet per car is generally used. These figures do not include main circulation aisles.

2-3 Building Codes

2-3.1 Scope

Building codes are prime instruments in the evolution of a building type. Codes are a control and safeguard for the public where hazardous conditions could exist. The rather strict set of rules evolved for parking garages has become the criteria for design rather than merely an acceptable minimum. Some items required by codes will limit the construction to such a degree that the structure cannot effectively be used as a shelter unless protective measures of a temporary nature are planned.

Almost all the large cities where parking garages are being built
have published building codes. Stipulations set forth by them have been summarized from a survey of the following three basic codes:

The National Building Code

The Basic Building Code of Building Officials Conference of America

The Uniform Building Code

2-3.2 Definitions

A parking garage is generally defined as a building or structure or a portion of a building in which motor vehicles containing a flammable fluid in its fuel storage tank are stored. It may be an enclosed or an open-air structure. An enclosed parking garage means a garage having exterior closure walls and an open-air parking garage is defined by almost all codes as one having not less than 50 percent of two sides of the garage open to the air at each story. If an enclosed parking garage is located in a story with one-half or more of its clear height below grade, it is defined as a basement parking garage.

A parking garage does not include any areas for motor vehicle service or repair, and the parking of buses, trucks, or similar vehicles is not permitted.

2-3.3 Adjoining Uses

Unless the exterior walls are of fire-resistant construction and are without openings, a parking garage must not be located adjacent to property lines. If the structure is an open-air type, any wall with openings must be at least 15 feet from any line where another structure might be built. Open-air garages cannot be located within or attached to a building used for any other purposes unless separated from the other use by fire-resistant construction.

2-3.4 Area and Height Limitations

Requirements restricting height and area vary considerably among the codes. The codes are consistent in permitting unlimited height and area when fireproof construction is used. In open-air non-combustible construction, height limitations vary from five to eight stories and area limitations from 12,000 to 30,000 square feet. Increases in both height and area are permitted by some codes if open-air construction
is used on the third and fourth sides of the structure, or if a sprinkler
system is added to the garage.

2-3.5 Other Occupancies in the Structure

All codes prohibit any other occupancy within or attached to an
enclosed parking garage unless separated by barriers of non-combustible
material and unpierced by openings except doors equipped with self­
closing devices. Small areas, such as offices and salesrooms, are
permitted if they are constructed of a material that resists the passage of
smoke, gas, and odor.

2-3.6 Structure and Materials

Live loads in most codes are established at 100 pounds per square
foot and no reduction of live loads is permitted.

The construction of enclosed garages must be of non-combustible
materials and open-air garages must be of fire-resistive construction.
Codes further require that the floor surfaces shall be of non-combustible
material without pits or depressions, and graded to drains. Non-absorbent,
non-combustible materials such as concrete are required for floor finishes.
Parking on roofs is limited to structures of fireproof construction. Roof
parking further requires parapets and wheel guards. Adequate curb and
guard rails must be provided at openings in exterior walls of open-air
parking garages.

When basements of public garages are used for purposes other
than parking, access shall be from the outside only, and the first-floor
construction must be fire resistant and both water and vapor proof.

2-3.7 Exits

Only one exit way is required for each story of a structure of
fireproof construction. If the structure is of fire-resistive construction
and parks more than sixty vehicles per story, or of less than fire-resis­
tive construction and parks more than forty-five vehicles per story, two
separate exit ways are required. If mechanical parking is used in an
open-air structure, only one exit way is usually required for each floor.
Ramps which are not considered as required exits need not be enclosed in
fire-resistive, non-combustible, or sprinklered garages.

2-3.8 Openings

Where the exterior enclosing walls are omitted in an open-air
structure, it is not permitted to close the opening, partially or completely, with glass or tarpaulins. Openings from garages into spaces for other occupancies must be equipped with self-closing fire doors.

2-3.9 Lifts

In an enclosed structure, all vertical shafts for elevators or vents must be enclosed. In open parking garages, lifts used only to transport employees need not be enclosed except with a protective wire mesh.

2-3.10 Heating and Ventilation

In enclosed buildings used for parking automobiles operated under their own power, exhaust ventilation must be provided to produce one complete change of air every 15 minutes. Such exhaust ventilation shall be taken from a point at or near the floor level.

When garages are located below grade, they must be ventilated by a mechanical system with positive means for both intake and exhaust. Requirements for air changes can be as high as eight per hour. Mechanical ventilation may be omitted in small parking areas (5000 square feet or approximately 12 cars) if the space has unobstructed openings to outer air sufficient to provide necessary ventilation.

In those areas of the structure not used for storing automobiles, such as the offices and waiting rooms, light and ventilation must be provided either naturally or artificially. At least two changes of air per hour must be provided. Four air changes per hour are required for toilet rooms.

If the structure is enclosed and heated, all heating plants, except direct-fired heaters, must be located in separate buildings or must be enclosed within the structure with solid, watertight and vapor tight masonry. Entrance to these spaces must be from the outside, since no openings are permitted through the fire division.

2-3.11 Fire Protection Equipment

Sprinkler systems are required for enclosed garages over 65 feet high which exceed 10,000 square feet per floor if of fire-resistive construction or 8,000 square feet per floor if of protected non-combustible construction. Open-air garages over 65 feet in height and exceeding 15,000 square feet per floor also require a sprinkler system.

If the building is less than 75 feet high, a one-source system may
be used in buildings of which the upper stories are designed for other uses when the garage has a capacity of more than twenty automobiles. If a building is more than 75 feet high, a two-source system is required.

In addition to automatic fire-extinguishing systems, a portable fire extinguisher must be installed at each stair and lift opening on each parking level.

2-3.12 **Toilets**

If both sexes are employed in the garage, there should be two toilet rooms located within the structure. The number of fixtures depends upon the number employed. Toilet facilities for the convenience of the customers are not required.
CHAPTER III
NUCLEAR EFFECTS RESISTANCE AND SHELTER REQUIREMENTS

3-1 General

The previous sections discussed the design criteria for a parking garage intended for use under normal conditions. To these must be added the specific design criteria for resistance to nuclear effects and the requirements of habitability if the structure is to serve as a shelter. Knowledge of the details that increase the ability of the structure to withstand nuclear effects and to protect occupants can be used to take advantage of all the protection available.

3-2 Design Considerations

In the design phase of the building, the designer should decide how the structure can best be used as a shelter during an emergency period and then orient his improvements towards that use. The building could serve in three different capacities during an emergency period:

1) Designed to act as a shelter during the blast and thermal waves and also during the subsequent period of fallout, in which case all phases of nuclear effects must be considered.

2) Designed to remain standing through the blast and thermal waves and only after this be utilized for shelter purposes.

3) Designed to serve as a fallout shelter on the assumption that the intensities of both the blast and thermal waves are negligible.

The attention given to various nuclear effects depends on which type of protection the building is intended to offer. Equal resistance to all nuclear effects cannot easily be established, since the intensities of all nuclear phenomena vary independently. Certain assumptions must be made for each hazard and they can best be examined individually.

3-3 Thermal Intensities and Fire Hazards

Approximately one-third of the energy released from a nuclear detonation is in the form of thermal energy, which travels outward in a straight line in all directions. Traveling at the speed of light, it is the first effect to reach the area surrounding the target. The amount of energy received, the time period over which it is applied, the ignition
point and other properties of the material receiving the energy will determine the probability that fires may result. The thermal intensities received as a direct result of the thermal pulse are usually not sufficient to cause ignition of fire-resistant structures. The chief danger results from the ignition of more flammable materials in the neighborhood or in the interior of the structure.

Indirectly, fire hazards also exist as a result of blast effects. A fire may be caused within a structure that is otherwise isolated from ignitable material as a result of electrical short circuits or gas lines damaged by the blast wave.

It should be pointed out that thermal intensities which might not cause severe damage to a structure could be extremely dangerous to occupants. Therefore, if the structure is intended as a shelter, special attention should be given to the shielding of the occupants from the thermal pulse. This shield need not be massive, as any material which casts a shadow will offer protection.

Automobiles should also be shielded as they could possibly ignite. One of the main hazards is the fabric upholstery. At the tests in Nevada, thermal radiation ignited the upholstery and caused fire to spread in exposed automobiles. In a simulated parking lot, much of the damage to glass, paint, and interiors was due to fires caused by thermal radiation. Gasoline tanks of the parked vehicles are not particularly vulnerable to direct ignition from the thermal pulse, since they are shielded from exposure by the automobile bodies.

To design a structure less vulnerable to thermal and fire hazards, these design principles should be used:

Planning and material selection should be based on good fire prevention standards.

The occupants and vehicles should be shielded from exposure to the thermal pulse.

Materials that will not sustain combustion should be used on exposed surfaces of the exterior,

Exposed flammable materials should be shielded.

Where possible, the structure should be isolated from other elements that have low ignition points.
3-4 Blast Effects

The rapid expansion of air, caused by the high temperatures of the detonation, causes a blast front to move outward at approximately the speed of sound. This front will pass through the area surrounding the target shortly after the thermal pulse. The difference between the high pressure behind the shock front and the ambient pressure is referred to as overpressure. It may cause much structural damage. When this over-pressure strikes a surface, it results in a reflected overpressure, amplifying the overpressure to a degree varying with the angle of incidence between the shock front and the surface.

When the blast wave encounters a building, there is at first a pressure on the front face, which is increased by the reflected overpressure. This is followed by a gradual unloading of the front face as the blast wave progresses past the face and sequentially loads the roof and sides, then the back face. The overpressure acts equally in all directions, tending to compress any structure engulfed by the blast wave. This over-pressure is accompanied by a dynamic pressure or wind, which acts in the direction of movement of the blast front and tends to drag any engulfed object.

Because the location of a structure relative to the detonation is unknown, the exact loading cannot be predicted. Accordingly, design loads for blast analysis are usually established from an assumed value of peak overpressure.

The effects of blast loadings on a garage depend upon numerous conditions, but most important is the position of the structure relative to the ground surface.

In an aboveground, enclosed structure, the reflected overpressure on the front wall tends to move the entire structure because momentarily there is no equalizing pressure on the rear wall. Large buildings are more subject to this translational loading because of the time required to engulf the building. Any aboveground structure will be subjected to the dynamic pressures or wind, which generally apply translational loads for a longer period than the overpressure does.

In an open type of aboveground structure, however, the loadings caused by the overpressures, reflected overpressures, and drag forces may be substantially reduced. The reduction depends primarily on the percentage of area of the walls that are open and permit the blast wave to pass through the structure.
In an underground structure, the blast-induced forces result from the pressure exerted by the surface overpressure wave being propagated through the soil. Since no overturning or dynamic pressure forces are exerted the potential blast resistance is much higher.

In addition, plan configuration and building orientation have an influence on the amount of blast energy imparted to the structure.

As in the case of thermal radiation, increasing the structural resistance does not necessarily provide blast protection to the occupants. Structural resistance can be developed to resist 5 psi overpressure at moderate expense. Overpressures below this are not generally fatal, but secondary effects of the blast are still quite hazardous at these pressure levels. At less than 1 psi, the shattering of glass and flying debris can present problems that must be considered if the structure is intended to protect occupants immediately after a detonation. Also, the dynamic winds following the blast wave can blow people about, causing injuries.

Automobiles and busses were exposed to several of the nuclear test explosions in Nevada. In most cases, it was not primarily overpressure, but drag forces which produced damage to the vehicles. At a peak overpressure of 5 psi, motor vehicles were badly battered, their tops and sides pushed in, windows broken, and hoods blown open. However, the engines were still operable and the vehicles could be driven away after the explosion.

In shelter design, these principles will help increase the protection from blast effects:

- Protect occupants from flying debris and shattering glass.
- Protect occupants from hazardous pressures.
- Select material that will insure ductile response.
- Design to achieve maximum continuity in the structural frame.
- Avoid unnecessary fragile materials, projections, and fixtures.

3-5 Nuclear Radiation

The energy given off in the form of nuclear radiation may be either initial or residual. Initial radiation has a limited range, but within an area of a few thousand feet from the burst point can have intensities which can be lethal. Residual radiation in the form of
fallout can cover larger areas with lethal effects than the blast or thermal phenomena will. Hazardous levels of fallout can be expected in the downwind direction at distances up to several hundred miles from large yield surface or belowground bursts - considerably beyond the range of hazardous thermal radiation or blast levels. Upwind, or in the case of an air burst, the hazards of residual radiation will be less critical than those of thermal radiation and blast. Since fallout patterns are variable, the exact intensities cannot be predicted. The general practice is to assume a degree of protection and to design the structure to that standard.

None of the nuclear radiation emitted has any notable effect on building materials or motor vehicles. Radiation does not alter the structural properties or the appearance of the material exposed and the materials that attenuate radiation do not in turn become radioactive. However, most types of nuclear radiation are harmful to human beings.

If the parking garage is to serve as a fallout shelter, protection against radiation should be incorporated into the design. Protection may be accomplished by placing a shield between the source and those to be sheltered, or by reducing the intensity of the contributing source. Protection utilizing shielding may be accomplished either by the use of geometry, a barrier, or a combination of both. A complete description of the method of analysis of the two types of shielding is given in the Professional Manual 100.1 "Design and Review of Structures for Protection From Fallout Gamma Radiation".

Geometry shielding is protection offered due to distance from the source. Generally, the radiation intensity decreases as the distance increases. To take advantage of geometry shielding, the designer should select a shelter location as far as possible from the source of contamination. The center of a structure is farthest from the ground contribution and the lowest level is farthest from overhead contributions. In multi-level structures, the intermediate floors offer better shelter areas than the lower and upper floors. While located several levels below the overhead contribution, they are also still several levels above the neighboring ground contribution.

Barrier shielding is achieved by the application of the principle that rays are absorbed or attenuated in the course of their passage through any material. A decrease in radiation intensity depends on the mass of the material between the source and the point of observation. To accomplish the same degree of attenuation, a substance of low density requires a greater thickness than one of a high density. Therefore, the designer should select massive materials in preference to lighter weight ones, where economically feasible, and the massive materials should
enclose the shelter area.

Without altering the construction, the amount of radiation received in a protected area can be substantially reduced by partial removal of the fallout material from the area surrounding the shelter. Natural removal of the fallout material by wind or rain can be encouraged by using details and planning devices which will make decontamination of the area easier. However, they should not be expected to be completely effective. To make decontamination easier, use smooth finished materials on both vertical and horizontal surfaces. Equally important is avoiding designs that can trap fallout in critical areas. Decontamination by hosing or sprinkling requires large quantities of water that may be in critical supply and eventually requires a system to remove the collected particles from the immediate area. Vacuuming is more effective, but still requires disposal of the debris.

3-6 Habitability

If the shelter is designed for protection against radioactivity, the period of occupancy may extend to many days or even weeks. A structure not originally constructed for habitation, and yet one expected to house many people in an emergency, must be planned so that modifications can be made hastily to permit community life to continue under emergency conditions.

The prime purpose of a shelter is to keep the occupants in good mental and physical health. Consideration must be given to the problems of food and water supply, sanitation, ventilation, heating and cooling, lighting, administration, communication, fire safety, and space arrangement.

The treatment of injuries resulting from a nuclear detonation, as well as the usual sicknesses, births, and deaths, will have to be handled. For these purposes, a clinic should be considered as part of a complete shelter. The clinic would also function as the control center to maintain the health of the occupants.

Both food and water must have controlled distribution, but only the minimum daily requirements should be planned for. Food will undoubtedly be stored at a central point, and the distribution from this point would be directly to the occupants. If any additional food is available, it probably will require special preparation and eating areas. The emergency supplies do not require special facilities. The water supply will also be in a central location, whether it is from a supply that has been
built into the building (such as the firefighting reservoir) or from containers stored for emergency use. It should be made available throughout the shelter, not only for drinking but also for personal cleanliness, food preparation, cleaning utensils, removal of wastes, firefighting, and other uses.

Sanitation involves both personal hygiene of the occupants and keeping the shelter clean. Toilet facilities should provide privacy and separation of the sexes, and should be convenient to all areas of the shelter. Areas must be established for commodes and washing facilities. The design and selection of materials should consider ease of cleaning and the control of pests.

Special attention must be given to the heating or cooling of a structure not ordinarily used for sheltering large numbers of people. Control of humidity, oxygen, carbon dioxide, and odors will have to be studied for the physiological and psychological effect they might have on a confined group.

Closely related to ventilation are space and volume requirements. Either requirement could limit the shelter capacity. Under some situations, the large volume of air in the structure will be adequate for the occupants during emergency conditions without mechanically supplied fresh air. The space available should be studied so that the most efficient arrangement can be made and the maximum number of occupants accommodated. The large flexible space of the garage should be capable of being subdivided into areas providing sleeping, eating, and recreation areas for the occupants and special areas for toilets, administration, clinic and storage.

The lighting should also be studied. Minimum levels used in the garage will probably be acceptable in most areas, but special or auxiliary lighting may be required in the clinic, administration, and food preparation areas.

Parking garages are required by codes to meet standards for fire safety, but care should be taken to avoid the hazards that may arise if the building is used as a shelter. The disposal of trash and paper should be studied. Open-flame devices should be avoided. Under emergency conditions, even a small fire becomes a hazard, since it would consume valuable oxygen and the smoke produced could cause panic.
CHAPTER IV

INCORPORATION OF PROTECTIVE FEATURES

4-1 General

In the following chapter, planning principles and construction details are analyzed with respect to protection from various nuclear effects.

4-2 Site Considerations

4-2.1 Scope

The selection of a site will continue to be based primarily on economic principles for the parking garage, relative to the traffic pattern, parking demand, and land cost. However, if the parking garage is to serve as a shelter also, the desirability of the site as a location for a shelter should be considered. If the site has already been selected, or if the structure has already been built, certain features of the site, such as terrain or neighboring structures, should be considered to determine the type of protection which can be incorporated and how this protection can best be used.

4-2.2 Soil Conditions

The condition of the soil is an important factor for both aboveground and belowground structures. The characteristics and bearing capacities should be considered under both normal and blast loading. In general, it can be said that the soil types that behave best under conventional loading will also behave best under blast or dynamic loading. Under dynamic loading, the structure and the soil act together, which assists in resisting soil failure at pressures greater than those which would cause failure under static loads. Bearing pressures under dynamic loading are discussed in Professional Manual 100-5, "Design and Review of Structures for Integrated Protection from Nuclear Weapons." In general it can be said if detailed soil information is not available, the dynamic bearing pressure may be taken as twice the conventional allowable static value.

4-2.3 Surface and Topography

The terrain of the site and the surrounding area has some influence on the blast energy received on the structure. Variations in incident overpressure are produced by the character of the surface and the topography. A significant downward slope in the direction of the path of the blast front causes a decrease in peak overpressure, while an upward
slope produces an increase. As the incident level of peak overpressure increases, the change in peak overpressure caused by a given change in slope becomes a smaller proportion of incident overpressure. The presence of many buildings as in a city complex will cause local changes in the blast wave, especially in the dynamic pressure. Some shielding could result from intervening buildings, however multiple reflections between buildings and the channeling caused by streets may tend to increase overpressures and dynamic pressures. The resulting effect on damage is difficult to predict.

Fallout quantities will be affected by the terrain surface features. Even light winds will tend to sweep smooth surfaces and pile up fallout particles against curbs, buildings or other obstructions. Earth used in grading or landscaping on the surface of an underground structure will act as a barrier shield against radiation from fallout.

4-2.4 Neighboring Structure

Nearby structures could provide some degree of shielding from all nuclear effects. Non-combustible structures may be regarded as a thermal shield. If they are located between the detonation and the shelter, the shelter will not be exposed to thermal radiation. However, if they are flammable, nearby buildings could present a fire hazard. Careful selection of building locations could be an effective means of reducing area fires. The distance between buildings should be at least 50 feet if the probability of fire spread is to be limited to 50 percent. In order to eliminate the spread of fire almost completely, the distance between buildings should be over 300 feet.

The modification of the pressure wave by an obstacle or structure between a shelter and the explosion is particularly noticeable in the reflected overpressures and the drag loadings. If the obstacle and the shelter are closely spaced, the shock wave is disturbed, and the drag coefficients are modified. If the shock front has been substantially disturbed, reflected pressure effects on the shelter may almost disappear. If the distance between elements in the direction the shock wave is traveling is equal to or greater than approximately 10 times the lateral dimension of the windward element, the effects of shielding become very small and can be neglected. In open-air structures, the effects of shielding can usually be neglected even though the distance may be much less than ten times the lateral dimension mentioned.

In areas where there is a high percentage of ground coverage by
buildings, the place of fallout contamination is elevated and varied. This produces a variation in the contribution to the upper levels of shelter areas.

4-2.5 Utilities

In order to eliminate danger from falling utility poles and to insure continued service, underground utilities are preferable. Damage to underground services beyond the ground shock area is not probable. Where the utilities pass through exterior walls, provision must be made for relative motion between the structure and the adjacent earth in order to avoid rupture of the pipe or conduit. The possibility of loss of pressure through breakage of pipes at this point or even within the structure is more serious than failure of underground pipes. Damage to the water supply is critical for firefighting and the problem can be partially remedied by the use of flexible connections at the building. The water supply and sewage lines should be designed so that contaminated material cannot enter the protected installation through the piping. The emergency supplies stored in the shelter do not require the continued operation of these utilities and they can be shut off.

4-2.6 Landscaping

Landscaping elements in the vicinity of the shelter structure or above or belowground structure should be studied for the hazards that they may present. Trees, grass, and shrubs are all subject to sustained burning and should not be located near entrances or air intakes. Decontamination of a lawn area is almost impossible unless the earth is turned over. It is preferable to use paved areas that can be easily decontaminated. Pool surfaces are self-decontaminating since the fallout material will settle and the water then provides a barrier shield. However, a pool used on the roof of an underground structure will lose the mass shielding of the water as the fallout material settles.

4-2.7 Orientation

If the probable direction of the blast can be assumed, it should be considered in the structural plan. The general orientation of the garage should be used to resist the blast forces, since the elevation facing the detonation is subjected to the highest pressures. The difference in forces is not very pronounced in conventional rectangular structures, but a long, narrow structure is more resistant to blast against the end rather than on the side.
4-3 Space Requirements

4-3.1 Scope

In a garage structure, the shelter space, unlike a school or apartment building structure, is very open and the assignment of certain spaces for various shelter functions is not readily apparent. In a school, for example, the shelter administration area can logically be assigned to the suite of school offices and the clinic can be located in the health suite.

Space requirements and space arrangements should be studied beforehand. This can best be done by the architect when he is making the preliminary layout of the building, and it is recommended that the architect prepare a schematic emergency-use floor plan which would be available in the garage office to assist the shelter manager. The shelter then could be quickly organized to run efficiently according to the plan best suited for that particular shelter.

4-3.2 Capacity

In order to determine the necessary space for each emergency function, the approximate shelter capacity must be determined. As a general rule, those floors of the structure that will be used as a fallout shelter would have an occupancy of approximately 30 times the total car capacity. This assumes that the area per vehicle is 300 square feet and that 10 square feet is adequate for each shelter occupant. Both these figures should be refined by studying the various arrangements of parking and shelter facilities within the structure. The final figure is modified by the disposition of the automobiles during an emergency.

4-3.3 Recreation and Eating

During the period of shelter occupancy, the shelterees will be awake most of the time. A great deal of active recreation would not ordinarily be encouraged since it demands more space, food, and oxygen. Passive recreation is more desirable, and variety can be accomplished by defining numerous small group areas. Listening to music and watching films is an excellent diversion for both children and adults. Assuming the proper equipment has been supplied and that power is available, an isolated space should be assigned to these activities if possible, since the noise may be disturbing to some. Adults should have space for reading, discussions, and table games.
In most cases, no special area will have to be assigned for eating space. The emergency food rations recommended to be provided for adults are high-calorie biscuits. These need no preparation and only a distribution point is required. If it is anticipated that other food sources will be available - for example, an integral-type of garage shelter in a hotel could have access to the food of the hotel kitchen - then, preparation and distribution space, special eating areas, and dishwashing facilities must be provided. In all cases an area should be provided for preparation of infants food or other special diets where some cooking is required. However, special areas are the exception, and efforts will be limited to locating the emergency food and water distribution points. They should be both convenient to the shelterees and easy for the shelter management to control.

Under emergency conditions, seven square feet per occupant is an acceptable minimum area for recreation and eating. Since this space would be used for two-thirds of the day, about 4.7 square feet (2/3 x 7) should be allotted for each shelter occupant.

4-3.4 Sleeping Areas

The amount of area assigned to sleeping is the most variable since it depends upon the type of beds supplied in the shelter. Probably the most economical type of sleeping accommodations to supply and store is hammocks. These require fastening devices to be installed in the ceiling during construction. If the standard army cot is used, a large amount of floor space is needed. Including aisle space, an area about 4 by 8 feet is required for each bed. Assuming three shifts of sleeping, 10.7 square feet (32 x 1/3) are required for each shelter occupant. Special bunk beds could be designed and stocked in the shelter. If a unit 2 by 6 1/2 feet is used, requiring a floor area of 3 by 8 feet, double bunks require four square feet per shelter occupant (1/2 x 24 x 1/3). Triple bunks need be of special design because of the lower ceiling heights used in garages. These require 2.7 square feet per shelter occupant.

The area assigned to sleeping should be isolated from any noisy activities.

4-3.5 Toilets and Washing Facilities

Permanent toilet installations are probably limited to the minimum number required for the structure in its normal function. Additional water closets to accommodate all shelter occupants can not be installed without exorbitant expense. Emergency commodes included in
the supplies stocked within the shelter area provide the most economical solution.

Privacy is still important, and advance layout and location should be studied since considerable space will be required. The number of commodes should be far less than those required by codes for dormitory use.

The designer can assume a time-use per day and a total space assignment as a method of approximating the space required for toilet and washing facilities. For example, if 30 minutes per day per person and 30 square feet per station (including both commode and washing) are assumed, then 0.625 square feet \( \frac{30}{1440} \times 30 \) is required for each shelter occupant. If the shelter housed 1000 occupants, an area of 625 square feet is required.

Shower facilities should not be considered because of the space and water required. Decontamination by a flushing stream of water can be accomplished with a hose; or more simply, contaminated clothes can be brushed or changed before entering the shelter area.

4-3.6 Administration

From experience with shelters established during natural disasters, it has been found that proper control and administration of a shelter is the key to a successful period of occupancy. Without good shelter management, situations of near riot can arise. A familiarity with these problems should assist the designer in making a layout that lends itself to more efficient management.

Persons taking shelter lack any preparation, and few will be able to bring essential clothing or required bedding, food, water, or other supplies, since the garage structure will shelter people in the city on business or shopping. The people may be in a state of exhaustion or shock. One of the first duties of the shelter management is registration of the shelterees. If the entrance is pre-disaster, registration would probably be upon entering; however, in a post-disaster situation, medical aid, food, or clothing may have to be issued prior to registration. Throughout the entire emergency situation, the shelter manager is involved with accommodating the structure to the shelterees. The space use of the building must be designated; the assignment of duties to personnel for security patrol, distribution of supplies, and cleaning must be made; procedures must be established concerning communications, sanitation, entertainment, religious services, and many other items.
For the execution of these duties, an office should be established that has control over the shelter and yet can be physically isolated from it. Under emergency conditions, it would not seem unreasonable to provide working space of 60 square feet per worker, and that one staff member may be required in the administration office for each 50 shelter occupants. This would require a space assignment of 0.4 square feet per shelter occupant \((60/50 \times 1/3)\). These figures are only approximate and the architect-engineer should consult with the shelter management team before actual space allocations are made.

4-3.7 Health Center

In a designated shelter, medical supplies are furnished by Civil Defense authorities prior to the emergency and a proper storage point should be established. Closely related to this in the plan layout should be the location of the proposed health center.

If the occupants enter the shelter after a disaster, medical treatment will be an important function of the shelter. If the occupants enter prior to an emergency, a medical center will be required for the period of occupancy to assist the infirm and aged, as well as to control the spread of communicable diseases. Ward space will not require additional space as it can be taken from the dormitory and recreation space allowance.

4-3.8 Storage

A complete description of the materials recommended to be stored in a fallout shelter is described in OCD Manual 8520.1, "Description, Care and Handling of Supplies for Public Fallout Shelters". Briefly, the following kits are available and selected ones probably will be used in the shelter:

<table>
<thead>
<tr>
<th>Kit</th>
<th>Volume</th>
<th>Persons to be supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanitation Kit III</td>
<td>3.36 cu. ft.</td>
<td>25</td>
</tr>
<tr>
<td>Sanitation Kit IV</td>
<td>3.36 cu. ft.</td>
<td>50</td>
</tr>
<tr>
<td>Radiation Kit</td>
<td>1.08 cu. ft.</td>
<td>One Per shelter</td>
</tr>
<tr>
<td>Food</td>
<td>2.26 cu. ft.</td>
<td>7</td>
</tr>
<tr>
<td>Food</td>
<td>1.52 cu. ft.</td>
<td>5</td>
</tr>
</tbody>
</table>
4-3.9 Summary

The total net area per shelter occupant, including space for recreation, eating, toilets, administration, medical, and storage, but excluding sleeping space, is about 6 1/2 square feet. The space requirements vary chiefly with the sleeping arrangement proposed. If cots are used for sleeping 17.2 square feet is required, if double bunks are used 10.5 square feet, and if triple bunks are used, 9.2 square feet are required. If possible these areas should be further increased to 23, 14, and 12.5 square feet to allow for circulation space. The net areas discussed in this section are not in complete agreement with the minimum requirements of the National Shelter Survey and the architect-engineer is cautioned to carefully evaluate the needs of the individual shelter.

These figures only apply to free area not occupied by automobiles. The policy of evacuating automobiles from the shelter will vary with the structure and the particular situation. The occupancy rate of parking garages vary from nearly empty to, in some cases, over 100 percent. The average occupancy can be assumed to be 60 percent of the automobile capacity.

4-4 Special Considerations of the Automobile

4-4.1 Scope

The planning of a combination parking garage-shelter structure should consider the possible presence of automobiles in an emergency. As pointed out previously, the automobile presents some indirect hazards to the shelterees from blast and thermal energies. There are other disadvantages and problems presented by the automobile. There are also
some features which may be regarded as assets and sometimes the design can take advantage of the presence of automobiles.

4-4.2 Space

The two major limiting factors to the number of occupants which can be housed in a shelter are floor space and volume. Though the floor space and volume taken up by automobiles remaining in the shelter is difficult to use, it is not necessarily lost. The interior space and the volume above and including the vehicle is counted as part of the volume of the shelter.

The amount of warning time would determine whether or not the automobiles could be evacuated before an attack. A pre-attack evacuation is desirable for the most efficient use of the shelter. If the situation permits, the garage should be closed well in advance of a possible emergency. No problem of car removal would arise, and a maximum amount of space would be available.

In the event that evacuation is not possible prior to an attack, the automobile may or may not be removed during the emergency period. It should be noted that even if the garage is filled to its maximum capacity of automobiles, as much as half of its floor area is open to use by shelterees, and space is available in the interiors of the vehicles. Without attempting to remove the cars from the shelter, the space can be rearranged into more usable areas. The vehicles can be moved into areas of lower protection factors where their mass would provide additional shielding, or they can be concentrated in a single area and assigned as sleeping facilities.

If it is decided to remove the stored vehicles from the shelter after the attack, it will be difficult except in the case of the aboveground shelter. If the shelter is belowground, pushing many cars manually up a steep ramp would be very difficult. On the other hand, driving them out creates carbon monoxide, which might overtax the mechanical ventilation system.

In either case, the vehicles would have to be removed in the short period before fallout occurs or after the radiation intensity falls low enough to permit short periods of stay in unprotected areas. In high-density areas, there would be little or no space for autos without blocking critical traffic routes.
4-4.3 Supplies

Whether the automobiles remain or are removed from the shelter, certain items within them may be useful in an emergency. The presence of automobiles should not be relied on in planning for the efficient operation of the shelter since it is preferable to have the automobiles evacuated prior to occupancy.

Water is the most useful commodity that must be supplied. The water stored in the emergency supply kits will be needed for drinking, and may not be generally available for washing or cleaning. The water in automobiles, even though containing antifreeze and not potable, could undoubtedly be utilized for uses other than personal.

If a gasoline-powered generator is part of the mechanical equipment, the gasoline from the tanks of the stored vehicles could serve as a reserve fuel supply if the automobiles are not removed from the shelter. Removing the gasoline from the tanks and handling would have to be carefully controlled because of the explosive and fire hazards involved.

Numerous other items should be considered as possible useful materials in an emergency. Batteries could be removed and combined as an emergency power source. Car radios could be placed throughout the shelter to be used as a communication system. In some cases, short wave transceivers found in some automobiles might be used for communications to Civil Defense headquarters. If the vehicles are to be taken from the structure, the seats should be removed to serve as seating in the shelter. Other helpful items such as tools, flashlights, and blankets should be stored in the shelter before the automobiles are removed.

4-5 Structure and Materials

4-5.1 Scope

The selection of the structural system and the materials, which depend upon the function to be housed within a structure, the location of the structure (i.e., aboveground, belowground, or partially buried), the desired spans, the exterior walls (i.e., completely open, partially open, frangible or non-frangible) etc., is an important planning consideration in conventional building design. It becomes even more important for a structure designed to resist low-level blast pressures and to provide radiation protection.
4-5.2 Type of Structure

Parking garages situated aboveground are of two general types: enclosed or open-air, or possibly a combination of the two types. Although the open-air type is most common, the reaction or response to nuclear blast effects and the nuclear radiation protection capability of both types will be discussed. Appendix A, Weapons Effects, contains a general discussion of the propagation of blast waves and their interaction with structures. For a more detailed discussion, the reader is referred to "Effects of Nuclear Weapons", and ASCE Manual No. 42.

a. A structure with wall openings, such as doors and windows, with an area of less than about 5 percent of the total exterior wall area, is considered to be an enclosed structure for purposes of determining the blast loading on the structural system, including the exterior walls, roof, supporting frame, shear walls, foundations, etc. It is further assumed that the walls are sufficiently strong so as to remain intact under the blast loading. The pressures on the interior surfaces of the exterior envelope and the supporting frames are assumed to remain at atmospheric pressure before the arrival of the shock front of the blast wave.

As the shock front strikes the structure, it is reflected, and the pressure in the wave is substantially increased. The resulting reflected pressure, which is the loading on the front face of the structure, is not only a function of the peak overpressure of the blast wave before reflection, but also of the shape of the structure (i.e., rectangular, arched, etc.,) and of the angle of incidence between the shock front and the structure. For a rectangular structure with a wall directly facing the shock front, this front face is loaded by a "reflected pressure spike." As the shock front passes over the structure, the reflected pressure rapidly decreases. The duration of the reflected pressure is a function of the initial peak overpressure and the dimensions of the face. The front face loading is subsequently caused by the ambient overpressure (similar to a hydrostatic pressure) of the blast wave and by the dynamic pressure of the blast wave due to the translational air movement within the blast wave, similar to the drag loading of wind forces.

As the shock front passes over the structure, the roof and sidewall surfaces are progressively loaded until it reaches the back face of the structure, at which time roof and sidewalls are fully loaded. The back face is not loaded until the shock front reaches the back of the structure, and the loading is progressively built up as the shock front spills over from the roof and around from the sidewalls. The roof, sidewall, and back face loadings are functions of the overpressure and the
dynamic pressure existing within the blast wave. While the dynamic pressure increases the loading on the front face, it decreases the loading on the roof, sidewalls, and back face.

The exterior walls and roof surfaces must be designed to resist these loads. The structural elements supporting these surfaces must in turn be designed for the reactions of the exterior elements. However, these reactions will not equal the loading on the exterior surfaces because of the dynamic nature of the loading and response of the exterior surfaces. In the design of any supporting system, the net horizontal loading (the front face loading minus the back face loading) must also be considered. After the back face has been loaded, the overpressure components of the loadings on the front and back faces are essentially that caused by the dynamic pressure or drag.

The loading on an aboveground enclosed structure is dependent on the areas of the exposed exterior surfaces, the overpressures, and the associated dynamic pressure.

b. At the opposite end of the spectrum from the totally enclosed structures is the open-frame structure without any wall covering, or with light, frangible walls (e.g., glass, asbestos, light steel, or aluminum panels) which shatter on impact and transmit only a small or negligible load to the supporting frame. In such a frame structure, only the individual structural elements of the frame are subjected to the blast wave.

For both the framing elements and the slabs (roof and floor), the overpressure is essentially balanced on all sides, and the primary blast loading on the structural members of an open-frame structure consists of the drag loading resulting from the dynamic pressure of the blast wave. Furthermore, depending on the relative size and spacing of the individual elements, e.g., columns, bracing, etc., the various members tend to shield each other to some extent from the full effects of the blast wave, and thus reduce the loading.

Therefore, the loading on the elements of an open frame structure is dependent on the area of the exposed members and the dynamic pressure. Since the area of the exposed elements of an open-frame structure is only a small percentage of the exposed wall area of an enclosed building, and since the dynamic pressure is relatively small compared to the overpressure of the blast wave, the loading is much less than for the enclosed structure. However, the increased mass and strength of the latter partially compensate for the increased load.
c. A belowground garage would either be located under an open area such as a plaza or park, or in the basement area of an aboveground garage or other building. The only significant difference in the loading would be that on the roof slab. The side walls and floor slab would be subjected to the same type of loadings in both cases.

A belowground garage under an open area would generally have a maximum earth cover of only a few feet, which would be insufficient to develop arching action and for any significant attenuation of the pressure to occur. With the roof slab flush with the ground surface or having only a few feet of earth cover, it is subjected essentially to the overpressure of the blast wave, without any contribution from reflected overpressure or from the dynamic pressure.

If a building is situated above the belowground garage, the roof slab loading on the garage depends on whether the building is enclosed or open. If the building is completely enclosed, the loading on the garage roof slab would approach zero, whereas if the building is open, the roof slab loading would be essentially that of the blast wave overpressure. The loading on the interior foundation of a closed building may be equal to or even greater than on the foundations of an open building.

Since the loading on the sidewalls of a belowground structure is dependent on the coupling between the soil and the structural element itself, the wall loadings will be a function of the physical properties of the soil (e.g., soil type, density, degree of compaction, placement procedure, the value of the horizontal stress component in the soil) and the mass and stiffness of the walls. If the sidewalls are fairly stiff, the lateral loadings are increased; if the sidewalls are relatively flexible, the loadings are decreased. The soil-structure interaction problem is very complex and must be evaluated for each design situation. The supporting structural system is, of course, in turn loaded by the reactions of the sidewalls as they respond to their loadings. Depending upon the pressure level, the structure will be subjected to various levels of acceleration and displacement.

A partially buried garage structure will be subjected to loadings similar to that of an enclosed aboveground garage structure, except for those portions of the sidewalls below grade line. If the cover is mounded around the portions of the sidewalls above the grade line, the resulting aerodynamic shape is improved, resulting in decreased drag loadings on these upper portions of the sidewalls. In addition, the increased mass of the earth cover probably would decrease the response of the sidewalls.
4-5.3 Structural Layout

The general structural layout of a garage is based on the parking requirements of the automobiles or a projection of the structural grid of the superstructure when the garage is part of another structure.

In a rectangular structure, shear walls are generally superior in performance to rigid frames and may be less expensive. However, the large openings required to facilitate car movements greatly reduce the effectiveness of shear walls. Shear walls could be used near the entrances and other facilities where open space is not demanded.

Arches and domes are superior structural shapes because of their inherent structural strength and their better aerodynamic characteristics which result in reduced structural loadings. However, it is generally inadvisable to use them for parking garages since the volume created cannot be fully utilized and their construction cost is higher. Either flat-slab or T-beam construction may be used, but the economy of headroom requirements makes the flat slab more desirable. Long spans should be eliminated wherever possible.

4-5.4 Blast-resistant Design Considerations

In blast-resistant design, there are three considerations which are significantly different from the commonly accepted design procedures of structures designed for conventional loads. (1) The increased loading rates on structural materials under the dynamic loads experienced in blast-resistant design generally result in increased material strengths, particularly in the yield of steel. (2) The inertia forces tend to reduce the resistance required of a structure and/or structural element to withstand a given level of load. (3) Structures have a large reserve of load-carrying capabilities beyond yield when they are designed to be ductile, i.e., capable of deflecting within the plastic range of behavior. However this is much less important for long duration loads as opposed to short duration loads.

Procedures for blast-resistant design recognize all three of these considerations. Preliminary design can be based on static resistance equal to the peak applied force using static yield resistances. However, the final design should be checked in accordance with blast-resistant design procedures in order to insure that the response is acceptable.
4-6 Openings, Entrances, and Ramps

4-6.1 Scope

Openings and entrances are particularly critical elements in garage-shelter design. The ventilation, pedestrian, and large vehicular openings in an enclosed parking garage require special attention. Since blast pressures on the order of 5 pounds per square inch can cause rupture of eardrums, seriously damage vehicles, interior partitions, and furnishings, and destroy ventilation systems, it is desirable to completely exclude the blast wave. For ventilation systems, either a manual or an automatic blast closure device is satisfactory. The large openings must be securely and positively closed prior to the arrival of the blast wave. Automatic actuation is not rapid enough to provide protection. Filtration of the incoming air after an attack would generally be required.

4-6.2 Blast Effects

When an air blast enters a tunneled entrance or an air duct, a new wave front is generally formed inside the tunnel and the shock propagates itself through the entrance or duct. Considerable research has been done on the problem of the entry of shock waves into tunnels and the subsequent behavior of these waves in various tunnel configurations. Because of the tremendous energy and the long durations of blast waves resulting from nuclear explosions, the lengths and/or configurations of parking garage entrances are not sufficient to provide other than a very minor attenuation of the pressures in the blast wave. Baffles and tortuous paths, although effective for reducing pressures from conventional high-explosive detonations, are ineffective for a nuclear explosion. Therefore, a positive closure of the large openings is required.

A through-ramp entrance, either open or covered, which can be entered from either end with the closure offset in a leg at right angles has definite advantage. There are no reflecting surfaces and the door is subjected essentially only to overpressure. (Figure 4-1 e and f)

For a non-through ramp entrance, a roofless ramp is best. However, if a covered ramp is required and turns are permissible, the pressure will be significantly reduced if the closure door is placed along the sidewall rather than in the end wall. (Figure 4-1d)

4-6.3 Radiation Shielding

Entranceways should be shielded in such a manner that the
contribution through the entranceway is minimized. Baffles, either interior or exterior, and right-angle turns are quite effective in reducing the contribution through entranceways. Closed or covered entrance ramps are preferred in that they not only provide additional attenuating mass, but also remove a contaminated plane from being immediately adjacent to the structure and provide a "tunnel" which further decreases the contribution received within the garage from other sources.

In order to minimize the fallout drifting down the ramp and lying against the structure and possibly the door, pits with open grilles in the ramp floor are recommended to trap the contamination.

4-6.4 Entrance Doors

Incorporating effective barriers to the blast front at the large vehicle openings is one of the main structural, architectural, and mechanical problems. The major expense and intricate detailing involved in providing a massive operating door that will remain operable is probably the critical design item in this type of blast shelter. Because of the expense of blast doors, they may be omitted from the initial construction, but the designer should plan the entrance closure details in advance.

Horizontal blast doors which would only be subjected to side-on overpressures may be used for the small openings normally used by pedestrians entering and leaving the structures.

Doors should be generally located so they are not subjected to reflected pressures. However, since the openings are smaller vertically than horizontally for ramped entrances, vertical doors should be used in this case. (Figure 4-1a) The designer should also consider installing separate doors for each lane of traffic in order to reduce the size of the door to be operated.

Large doors may be either hinged or sliding. There are advantages and disadvantages to each type. To gain maximum support against the positive blast phase, a top-hinged door would swing out and the structure used to resist movement of the door. The negative phase, assumed to assert a force equal to 50 percent of the positive pressure in the opposite direction, must be resisted by a series of bolts or pins. The simpler support system for an outswinging door must be balanced against the problems of opening the shelter door into the direction of traffic under emergency conditions. Horizontal sliding doors operate slower and require more energy to close than vertical sliding doors. As in the case of hinged doors, resistance to one phase of pressure
can be obtained from the structure while some device must be installed for the opposing action. A door sliding into a recess presents the special problem of maintenance since the recesses would probably be inaccessible.

Exposed parts of the door mechanism may be damaged by heat, fragments, rubble and dust. When the site or neighboring structures places the door in a vulnerable situation, it is preferable to locate the closure within the protected area of the shelter. In addition to direct weapon effects, the operating mechanism may be subject to very large forces transmitted from the door. The door mechanism should be isolated from these forces by supporting the door independent of the rollers or other elements of the operator.

Operation of the doors will require a power source. Small doors may be operated by hand or by an integral power source such as compressed springs, explosive cartridge, or power cylinder, but large doors may require a large power source for a short period of time. An emergency power source such as counterweighting, hydraulic-pneumatic accumulators or standby generators should be provided.

4-6.5  Ventilation Openings

Large shelters require a forced ventilation system consisting of air intake and exhaust passages and the means to circulate air. A blast valve or other mechanism restricting the flow of blast through these air passages is desirable. Manually operated air handling units are generally impractical because of the volume of air to be changed and the corresponding static air pressures required. In addition, quantities of air for cooling and for combustion will be required for any gasoline- or diesel-engine driven generators.

The ducts required to provide a minimum acceptable air flow will be reasonably small. These ducts may be incorporated as part of the entrance system, in which case additional fallout baffling is minimized. Alternatively, the ducts may lead directly from the shelter to intakes on the ground surface. In this case, sufficient bends or baffling must be provided to eliminate direct penetration of radiation. In addition, a small structure on the ground surface would be required to protect the entrance from debris and snow. It is recommended that blast valves be located on the interior ends of these ducts so that the valves are convenient for maintenance during an emergency. Blast valves to close the passage to blast pressures may be operated remotely by blast, light, or radiation sensors and by auxiliary power sources or by the blast itself.
The volume of air required by the emergency generators may be larger than that required for the sheltered personnel. Although locating the generator within the shelter area makes it accessible for maintenance, the increased cost of installing protected supply and exhaust ducts may be prohibitive. It is usually better to locate the generators outside of the shelter, but convenient to the shelter. In an outside area, normal air circulation will provide sufficient cooling and combustion air. Standard engine generators can be modified to withstand low-level blast pressures, but should be shielded against radiation contamination as much as possible to allow for maintenance. (Figure 4-1f)

4-7 Mechanical and Electrical Equipment

4-7.1 General

A closed parking garage is notable both as a massive structural building as well as having an extensive ventilating system. An open-air parking garage lacks enclosing walls and mechanical ventilating or heating system. Depending upon height and size, either type of garage might be equipped with an automatic sprinkler system, but probably would not be equipped with extensive water supply or sanitary facilities. Lighting levels are generally very low in all garages.

4-7.2 Effect of Large Volume

It is probably a unique characteristic of a parking garage that there is a large unobstructed air volume compared to most spaces available as fallout shelters. There are very few intermediate partitions or closed-off spaces. Due to the interconnecting ramps and the large parking and turnaround areas, there will probably be large open spaces available for occupancy even though the garage contains a large number of autos at the time of use. And, the spaces within and on top the autos may be used even if autos are occupying the garage. Consequently, the free volume per occupant will probably be large enough to control carbon dioxide concentration and to insure sufficient oxygen content for extended periods without mechanical ventilation. An open-air garage would have to be closed with tarpaulins (or other type of screening) to prevent dust penetration, but would allow some infiltration air, depending upon wind direction and velocity. Infiltration would be undesirable when there are high concentrations of radioactive dust in the atmosphere, but after this period it would be of some advantage.
4-7.3 Supply and Exhaust Fan and Filter Room

The supply fan and filter must be installed in a separately enclosed and shielded room. The fan system should be provided with a bypass that can be used during emergencies to filter out the smaller dust particles in a more efficient manner than would be required for the normal use of the building. Consequently, the main fan must either be selected so that the reduced output associated with higher filter resistances will still be sufficient for the use of the space, or a separate booster fan must be combined with the additional filters. Spare filters must be stored in an accessible and clean area so that they may replace the primary filters in case the first set is damaged during the initial stages of a nuclear attack. There should be at least two extra sets of filters to allow for possible blast damage. The air intake should be shielded so as to prevent direct wind pressure from forcing dust into the opening, and the air intake should be turned down so that the air must rise up into the opening, leaving the larger and heavier particles of dust on the outside. If blast is to be a consideration, some form of blast valve should be considered and some form of expansion chamber inside the ventilating air inlet should be provided to reduce the overpressure at the filter and at the supply fan.

4-7.4 Emergency Power

A typical commercial garage would not have emergency power available and would not normally have major heating or cooling equipment. Emergency power could be provided by a small gasoline- or diesel-engine-driven generator. Although gasoline storage poses some problems in deterioration, a gasoline engine generator is less expensive and somewhat easier to start than a diesel generator. In addition, most people are somewhat familiar with gasoline engines and a mechanic is likely to be available among the occupants in case of emergency. Spare parts might be found among the many automobiles; and extra gasoline could be obtained from the parked automobiles, if necessary. The only emergency power requirement would be the central supply fan and the building lighting. The exhaust system would not be operated in order to allow the supply system to maintain a positive air pressure within the building to assist in excluding dusty infiltration air and other contaminants.

The emergency generator should be located reasonably close to the supply air fan since this is the major load that it would serve. The main building lighting panel should also be located as close as possible to the generator. The generator should preferably be in a protected and non-contaminated area and should have sufficient air supply to satisfy its cooling needs. If this is not possible, a remote air-cooled radiator
should be considered so that the generator and its maintenance personnel would not be contaminated by the large quantities of air required for cooling. The water would have to contain anti-freeze.

The fuel supply must be located nearby and in a protected enclosure to insure that thermal radiation or blast does not damage the fuel supply system. Generally speaking, this would imply that the fuel supply should be on the lower floor or below ground, and the electrical generator would be somewhere in this vicinity. It is possible to supply the fuel by pump to higher levels. However, this not only consumes electrical power, but it provides another possibility for mechanical failure.

4-7.5 Water for Human Consumption

Fresh drinking water would not normally be available in any large quantity except on the ground floor level, and only if the garage contained public eating and lobby facilities. Therefore, an emergency water supply must be stored either in emergency containers on each floor or in some central storage facility. If the building contains a sprinkler system, it could be used as an emergency source of supply, however it would probably be of the dry-pipe type, since the building is generally unheated. A storage tank on the top floor, or in a penthouse on the roof, would insure a minimum supply of water for the sprinkler system without relying on electrical driven pumps which could fail in case of emergency. Under these conditions, water could be made available on each floor through a simple emergency hose bibb arrangement. The storage tank must normally be heated to prevent freezing.

4-7.6 Water for Waste Disposal

A typical garage will not have toilet facilities on each floor; however, emergency containers and chemical toilets could be provided for emergency use. The automobiles will contain large quantities of water in their radiators if there are automobiles in the garage at the time of occupancy. This water can be used for basic washing and cleansing purposes, and for general decontaminating purposes, even if it is not fit for human consumption.

4-7.7 Normal Lighting

The lighting levels in a parking garage are usually of such low level that the entire building lighting system could probably be operated by the emergency generator. The one exception would be advertising signs using large quantities of electrical current. The only other major
electrical load would be the elevators in a multi-story garage. During an emergency, these would be shut off. Therefore, the emergency generator would only serve the supply fan and the minimum building lighting system.

4-7.8 Emergency Lighting

An emergency lighting system designed for 6 and/or 12 volt power supply could be provided in addition to the normal lighting system. This would allow the use of batteries from the automobiles as required (and if available). However, if automobiles are available, the headlights and taillights are probably sufficient for emergency use.

4-7.9 Mass Fire

In case of a mass fire, the fresh air ventilating system would have to be turned off temporarily to guard against entry of noxious and dangerous fumes, smoke, and carbon monoxide. The fresh air intake should be properly located and designed with this in mind. However, the large volume of interior space should be sufficient to maintain livability for a period of a few days without a forced air supply. The space would become warm and humid due to human occupancy, but the mass of the building would absorb some of the heat and the rate of temperature rise would be reasonably slow. Naturally, an underground space would be better suited as a shelter in an area of mass fire; however, there is no reason to believe that a windowless garage would not endure mass fire without collapse and with reasonable safety for the occupants, assuming that openings such as major doors and ramps could be provided with some type of closure.
CHAPTER V

DESIGN EXAMPLES

5-1 General

The following examples are included to show various parking garage designs which incorporate some degree of protection. As well as illustrating various garage types and ramping systems, comment is made on the probable location of each type. For shelter purposes, the structures are reviewed for special thermal and structural resistance incorporated in the design and for adaptability as shelter area in a period of radioactive fallout.

5-2 Open Air Type
(Example A, Figures 5-1, 2, 3, 4)

5-2.1 Architectural Description

This design, representative of the most common type of commercial parking garage, is usually constructed by private interests in the center of large cities or is built by the municipality and leased to another party for administration.

A ramp system is used for vertical circulation in the eight-story fireproof structure illustrated. It is assumed to be an attendant-operated garage, with the first floor devoted to customer facilities. The structural system is reinforced concrete, and a bay size of 28' x 24' was selected to accommodate three cars per bay.

5-2.2 Mechanical System

Since this is an open-air garage, no mechanical ventilation is required. Heating is limited to offices and facilities on the first floor. However, with only minor expense, gas-fired unit heaters can be installed and, if the vehicle openings are temporarily closed, the shelter space could be heated and become usable in the winter.

Most codes require a building of this height and area to be equipped with a sprinkler system. Since the building is unheated, a dry-pipe system with a heated reservoir on the roof is recommended.
5-2.3 Thermal and Blast Resistance

Damaging thermal pulses will not be sufficiently reduced unless special attention is given to a screening device for the openings. Though the structure will not burn, a fire hazard exists since the automobiles may ignite.

As an open-air building the structure exposes a minimum area to the blast forces, making the structure itself less vulnerable to blast pressures than an enclosed structure. To further reduce the impulse loading transmitted to the frame, frangible siding could be installed. It is not practical to modify this structure to protect occupants from blast pressures.

5-2.4 Shelter Considerations

This type of garage could serve best as a fallout shelter. Temporary closing methods, such as the installation of vinyl sheets over the openings must be used to prevent drifting of fallout material into the shelter areas. The closure must be installed after the blast has passed, since these areas would be vulnerable to blast pressure. If some contaminated material entered the structure before closing, the sprinkler system could be used for decontamination.

Assuming no mutual shielding from neighboring structures, no contamination within the structure from drifting, and a negligible mass thickness for the exterior walls, the interior bay of the garage shown has protection factors above 40 for all floors except the ground floor. The third to seventh floors have protection factors of more than 100 in the central bay and over 40 in the two adjacent interior bays. A structure of the same general dimensions and capacity, but without the staggered floor system of ramping, would not provide as high a protection factor in the center bay. Ideally, the automobiles in the garage should be moved to those areas on the perimeter where protection factors are low. Doing this would free more area for shelter purposes and provide some additional mass shielding in the more exposed areas.

An emergency stand-by generator, located in a pit below the central aisle, is suggested for emergency lighting. Shelter supplies could be stored in an underground storage room opening off the generator pit. Both the equipment and storage areas could be located in the half-story space under the center slab if the structure is not intended to withstand blast pressures.
FIGURE 5-1 GROUND FLOOR PLAN OF BUILDING "A"
FIGURE 5-2  TYPICAL FLOOR PLAN OF BUILDING "A"
FIGURE 5-3  ELEVATION OF BUILDING "A"
FIGURE 5-4  SECTION OF BUILDING "A"
5-3 Underground Type
(Example B, Figures 5-5, 6, 7)

5-3.1 Architectural Description

The underground garage illustrated is typical of those included in major central business district projects or in urban renewal areas where an attempt is made to conceal automobile parking. The area above the garage is an open paved piazza, which enhances the area. If the garage is in an urban renewal area, the park-like green space could serve as a recreation area for the neighborhood.

In the scheme illustrated, it is assumed that the customer pays a fee but parks his own vehicle. The number of floors may be limited by problems of excavation, but three floors are shown in this solution.

Because customer parking is used, the structural bay size is increased above minimum standards to a 28' x 26' bay, allowing slightly more space to maneuver the vehicles.

5-3.2 Mechanical System

As an underground structure is completely enclosed, forced ventilation is used throughout the entire structure. Heating, however, is limited to the control areas near the vehicle entrances.

The fresh air intakes are housed in the structures over the four pedestrian entrances. Fan rooms are located in the first level below grade. One of these fan rooms could also house a generator for emergency use.

In this design, it is assumed that the sprinkler system is a wet-pipe system fed by the city supply.

5-3.3 Thermal and Blast Resistance

Since the structure is underground, the effects of thermal radiation will be negligible on the structure, vehicles, and personnel. Blast effects on the structure are minimized, and protection of personnel can be accomplished by some modification.

Blast closures at the openings are the only major modifications required by this structure. Commercially developed devices are available for passage doors and openings for the mechanical equipment, but at the
vehicle openings massive doors will be required. Opposing ramps are used, and the entrance doors are at right angles to the ramps in order to minimize blast pressures.

5-3.4 Shelter Considerations

With no ground radiation contribution except the small amount gained through the heavy overhead barrier, the scheme represents an almost ideal solution to shielding from nuclear radiation. Again, the major shielding problem involves the large openings of the ramp. Assuming no contamination within the structure from drifting, and when the overhead barrier consists of an 8-inch reinforced concrete slab, a protection factor of 50 is reached on the upper level away from direct contribution through the entrance. Increasing the overhead barrier to a 12-inch concrete slab raises the protection factor to 200. Using an 8-inch slab combined with 2 feet of earth fill, the upper level parking area becomes a shelter area with a protection factor in excess of 5000. The second and third floors below grade are sufficiently baffled by the ramp sequence, and the only special consideration is that of temporarily enclosing the space to exclude drifting fallout particles. If the structure is intended to be used as a fallout shelter only and no provision is made to close off the entrances to the ramps, the exhaust system would be shut down during shelter occupancy and air forced out vehicle entrances to eliminate drifting of fallout dust into shelter area.

If all vehicles are evacuated from this garage, the possible shelter occupancy would exceed 30,000 and a considerable area must, therefore, be assigned to house emergency supplies. It recommended that these supplies be stockpiled in the least convenient parking stalls on the lowest level. Construction cost of a special storage area would be approximately the same as additional parking space, and the space under ramps would only accommodate part of the supplies.
FIGURE 5-5 STREET LEVEL PLAN OF BUILDING "B"
FIGURE 5-6  FIRST BASEMENT LEVEL PLAN OF BUILDING "B"
FIGURE 5-7  SECTION OF BUILDING "B"
5-4 Office Building Base
(Example C, Figures 5-8, 9, 10)

5-4.1 Architectural Description

This example is typical of the many new high-rise office buildings where parking is provided on the lower levels of the structure. The stepped platforms in this scheme form a transitional element between the office tower and the open square. Three levels of parking are located in the platforms.

The structural system of the office building above has an influence on the structural bay size of the garage below. The long spans, giving flexible space to the office building, project into the parking area.

5-4.2 Mechanical System

The open-air garage is large enough to require mechanical ventilation. The office building above has heating and cooling equipment located on several levels, including one at the lowest floor above the lobby.

Water for the sprinkler system is supplied from a tank on the roof of the office building.

5-4.3 Thermal and Blast Resistance

As an open-air structure, the garage structure itself is not susceptible to overpressures except on the roof area. However, the superstructure will be subjected to reflected overpressures. Because of its openness, the garage structure will not completely shield occupants or vehicles from thermal radiation, but in a downtown area considerable shielding will be gained from neighboring structures.

The garage area cannot be used as a shelter against blast without extensive modification, but the blast resistance of the structural frame can be increased by reducing the long spans in the parking area. Using the same design, but with the garage below grade, a shelter similar to example B is evolved, and, by the addition of blast doors, shelter from all nuclear effects can be gained.

5-4.4 Shelter Considerations

The characteristics of the shelter are similar to example A, in that all openings must be closed to eliminate infiltration of fallout.
particles. The major advantage of this structure over examples A and B is the convenience to the shelter of the facilities located in the building above. In warm climates, where air conditioning is mandatory for large shelters, the additional expense for air conditioning equipment would be eliminated. The generator to operate this equipment would be the major additional expense. The core area of structure above, including the toilet facilities, would become usable as radiation intensities decrease.
FIGURE 5-9 PLAN AT STREET LEVEL OF BUILDING "C"
FIGURE 5-10  SECTION OF BUILDING "C"
5-5 Integral Type
(Example D, Figures 5-11, 12, 13, 14)

5-5.1 Architectural Description

The integral-type parking garage, though the least common type of parking arrangement employed, represents a scheme exceptionally well suited to a shelter structure. In the example, the parking area is enveloped on all four sides by an office building. The same scheme would work for a motor hotel. A continuous, ramped floor provides vertical vehicular circulation and parking space. The corridor around the parking connects the offices directly to the parking as well as to the other facilities of the structure.

Structurally, the reinforced concrete frame of the garage is integral with the office building.

5-5.2 Mechanical System

The garage is completely enclosed and mechanical ventilation is required. This can be supplemented in an emergency situation by the heating and cooling equipment serving other areas of the building.

5-5.3 Thermal and Blast Resistance

The parking area is completely shielded from the thermal pulse. Blast pressure resistance is minimal where standard office partition construction is used, and, because of the enclosing walls, the frame is subjected to higher loadings than example A.

5-5.4 Shelter Considerations

The exterior wall, the office partitions, and the two corridor walls offer several mass barriers for radiation attenuation.

The ramped floor with a slope of less than 5% is acceptable for emergency living conditions.

The toilet facilities of the building are convenient to the sheltered area.
FIGURE 5-11  GROUND FLOOR PLAN OF BUILDING "D"
FIGURE 5-12  TYPICAL FLOOR PLAN OF BUILDING "D"
FIGURE 5-13  ELEVATION OF BUILDING "D"
FIGURE 5-14 SECTION OF BUILDING "D"
5-6 Aboveground Type
(Example E, Figures 5-15, 16, 17)

5-6.1 Architectural Description

The aboveground garage type illustrated is located among new apartment buildings in an urban renewal project. It is assumed that the ground water level is high and aboveground construction is necessary. The solution frees the area used by the garage so that the land is available for playgrounds and green space for the residents of the area. The earth ramparts and landscaping also hide the unpleasant view of the parking. Access to the garage is from the ground floor of the apartment buildings by means of covered connecting links.

It is assumed that the residents park their own vehicles. Toilet facilities are provided in the garage structure as a convenience to the people in the park above.

A reinforced concrete flat slab is used on a structural bay 25 by 28 feet. Baffle walls at the entrance are concrete bearing walls.

5-6.2 Mechanical System

As a completely enclosed structure, forced mechanical ventilation is used. No heating is provided except in the toilet facilities.

As in example B, fresh air filters are located in low penthouses in the parks above.

A sprinkler system may not be available but the occupants will have access to the water system of the adjoining building.

5-6.3 Thermal and Blast Resistance

As a partially buried structure, the effects of thermal radiation will be negligible on the structure, vehicles, or personnel. In order to achieve blast protection for occupants, blast doors must be installed at the vehicle and pedestrian entrances and the ventilation openings. Vulnerability of the large doors to blast pressures can be reduced by designing the automobile approaches with right-angle bends.

5-6.4 Shelter Considerations

The cars within the garage can be easily moved outside the
structure since no ramps are involved and the road approaches and grounds provide adequate space for storing the vehicles without using any street parking. The dirt fill above the shelter and banked against the walls provides excellent mass shielding. Under emergency conditions, baffle walls are provided at the entrance to limit radiation penetration into the shelter. In areas away from direct contribution through the entrances, and assuming no contamination from drifting, the protection factors are in excess of 5000. As radiation intensities decrease, the occupants can move into areas of the adjoining apartment building.
FIGURE 5-15  SITE PLAN OF BUILDING "E"
FIGURE 5-17  SECTION OF BUILDING "E"

[Diagram of a section of building "E" showing multiple floors and trees along the front]
5-7 Residential Type
(Example F, Figures 5-18, 19)

5-7.1 Architectural Description

In the fringe areas of large cities, enclosed parking facilities of the many new low-rise apartment buildings offer good possible shelter locations. In the scheme illustrated here, the garage is in a half-basement beneath the dwelling units. Parking space for five cars is provided for six units. The remaining basement area is used for storage, mechanical equipment, and laundry facilities.

A reinforced concrete slab supported on masonry bearing walls forms the structural system and defines the shelter in the basement area.

5-7.2 Mechanical System

The garage area is unheated. The heating and air conditioning units for the apartments are within the shelter area and could be used in emergency conditions.

As conventionally designed, the mechanical system would probably limit the capacity of the shelter. Improvements for the shelter would include installation of a generator as well as fans and filters.

5-7.3 Thermal and Blast Resistance

The direct effects of thermal radiation will be negligible. Blast resistance of the shelter is minimal.

5-7.4 Shelter Considerations

A radiation barrier to ground contribution is provided by the planting area. The structure itself limits the overhead contribution. No permanent mass barrier is located at the vehicle entrance doors. However, the plane of contamination is limited to the driveway area. This area may be covered with vinyl or canvas on a trellis arrangement to prevent an excessive accumulation of fallout debris. Alternately, the drive may be decontaminated or, by using solid concrete blocks stored on the site, a temporary mass barrier may be erected in the openings by the shelterees. The protection factor in the laundry-storage area is above 200 without any improvements to the openings. If the temporary wall is erected, the protection factor in the garage can be raised from 25 to 100.
Approximately 150 people can be sheltered in each basement area assigned to six apartments. The shelter can thus be used by the surrounding neighborhood as well as the occupants of the apartment units.
Figure 5-18 Plan of Building "F"
FIGURE 5-19  ELEVATION AND SECTION OF BUILDING "F"
APPENDIX A

EFFECTS OF NUCLEAR WEAPONS


The material is limited to blast overpressures of less than 25 pounds per square inch (psi), and accompanying levels of initial nuclear, thermal, and fallout radiation.

A-1 General

All types of explosions - industrial, high explosives, and nuclear weapons - release a tremendous amount of energy within a relatively confined space over a very short interval of time. This energy release is largely in the form of heat energy; a portion appearing as a flash of light and a heat wave, and a portion converting the explosion products into high-temperature gases. Since these gaseous products are initially confined within a small volume, tremendous pressures exist. As the hot gases expand, a blast wave is developed which propagates outward from the center of the explosion. This blast wave is similar to a rapidly moving wall of water. As the wave speeds along, it first smashes against an object, then engulfs it with a squeezing action, and, finally, attempts to drag the object with a racking action. The vaporization of material when the fireball has touched the earth's surface, and the removal of material by the blast wave and winds accompanying the explosion, can result in the formation of a crater. The size of the crater will vary with the size of the weapon, height of burst, and the character of the soil.

The total energy release of a nuclear explosion is many thousand times that of a conventional high explosive, thus extending by many orders of magnitude the destructive range of thermal energy and blast wave. In addition, the nuclear explosion is accompanied by two entirely unique weapon effects. These are the initial nuclear radiation and the radioactive fallout. Whereas the effects of a conventional weapon are significant only within several hundred feet of the detonation, the tremendous energy release and the fallout of a single nuclear weapon make its effects significant for several hundred miles. Thus, weapons effects are no longer a point problem but an area problem.

A-1
Because of these fundamental differences, the effects of nuclear weapons acquire special significance in architectural and engineering planning.

**A-2 Yield of a Nuclear Weapon**

The size of a nuclear weapon is referred to as its yield. A one-kiloton (1 KT) nuclear weapon releases an amount of energy equivalent to that released by 1,000 tons of TNT; a one-megaton (1 MT) nuclear weapon releases energy equivalent to 1,000,000 tons of TNT. Nuclear weapons have been detonated with energy releases ranging from a fraction of a kiloton through the 20-kiloton weapons detonated over Japan in 1945 to multi-megaton weapons detonated in nuclear tests conducted during the past several years.

In the explosion of a nuclear weapon, the distribution of energy is determined by both the type of weapon (fission, fission-fusion) and the location (air, surface, sub-surface) of the burst. While the fission process maximizes the nuclear radiation effects, the fusion process maximizes the blast and thermal effects. An air burst below 100,000 feet tends to maximize the blast, thermal radiation, and initial nuclear radiation, while minimizing the fallout radiation. A surface burst maximizes the fallout radiation, at the expense of the other effects. A sub-surface burst maximizes the ground-shock effect, while little thermal or nuclear radiation escapes.

The distribution of energy in a typical air burst of a fission (KT) weapon is as follows: About 85 percent is in the form of heat energy, of which about 50 percent produces blast and shock, and 35 percent appears as thermal radiation (heat and light rays); 5 percent constitutes the initial nuclear radiation produced within the first minute after an explosion; and 10 percent is fallout radiation emitted over a much longer period.

**A-3 Blast Effects**

Although normal building loads are usually given in pounds per square foot (psf, 1 psi = 144 psf), blast pressures are expressed in pounds per square inch (psi). Inasmuch as conventional lateral loads, e.g. wind loads, are from about 20 psf (0.14 psi) to 50 psf (0.35 psi); and normal vertical loads, e.g. floor loads, are from 40 psf (0.28 psi) to 100 psf (0.70 psi), even low levels of blast pressure (2 psi to 10 psi) are overwhelming.
In considering the destructive effect of the blast wave, the two most important characteristics are (1) the overpressure (the pressure greater than atmospheric pressure caused by the compression of the air within the blast wave) and (2) the dynamic pressure (the wind pressure caused by the motion of the air particles behind the blast front). Most conventional structures will be damaged to some extent when the overpressure is about 1 to 2 psi, although glass windows will usually shatter at lower pressures.

When the blast wave encounters a building, there is at first a blast pressure on the front face. This is followed by a gradual unloading on the front face as the blast wave progresses past the face and sequentially loads the roof and sides, then the back face.

As the blast wave travels from the center of explosion, the overpressure at the front steadily decreases due to the increased volume of the pressure "bubble." The overpressure acts equally in all directions and tends to compress or squeeze any object engulfed by the blast wave. The dynamic pressure, which is caused by the motion of the air particles behind the blast front, acts in the direction of movement of the blast wave and tends to drag any engulfed object.

The difference in the air pressures outside and inside a building can cause damage. After the blast wave has completely engulfed a building, not only will the building walls and roof experience this pressure difference, but also the frame of the building will be subjected to a drag force caused by the dynamic pressure.

The structural damage sustained by a building will depend on the relationship of the loading to the structural strength and rigidity. This structural strength and rigidity will in turn depend upon the basic structural system, materials of construction, sizing of individual elements, connection details, etc. The blast loading will depend upon the size and location of the nuclear weapon detonation and the building size, shape, and position.

The blast wave can also inflict damage on exposed items such as utility lines and connections to the building and mechanical equipment installed outside the buildings. To prevent damage to people, material, and other items inside a building, it is necessary to provide some positive method of excluding the blast from entering, or to provide local protection within. The human body can survive pressures in excess of those required to destroy light buildings. However, the majority of blast casualties could come from secondary effects such as flying debris,
collapsing buildings, and fires resulting from the partial destruction of buildings. These secondary effects can occur at pressures far less than those required to destroy a structure. Broken windows, for example, can be expected for an area of over 2,000 square miles around a 5 MT burst.

Another aspect of the blast wave is the manner in which its energy is transferred into the ground, resulting in damage to underground structures and utilities. As the blast wave moves over the earth's surface, it exerts a downward force, which produces a ground shock. The strength of this shock at any point is determined by the soil properties and the overpressure of the blast wave immediately above it. At high overpressures this air-induced ground shock can cause the earth surface to suddenly move many inches at significant levels of acceleration. However, at overpressure levels less than 25 psi, such pronounced displacements are unlikely except in unusually bad soil conditions such as soft clay or marshy ground.

A-4 Thermal Radiation

Because of the enormous amount of energy liberated in a nuclear weapon, very high temperatures are attained. As a consequence of the high temperatures in the fireball (similar to those in the center of the sun), a considerable portion of the nuclear energy appears as thermal radiation.

Thermal radiation can contribute to overall damage by igniting combustible materials. This depends upon a number of factors, the most important of which are the nature of the material, thickness and moisture content of the material, amount of thermal energy falling on a unit area per unit time, and total exposure time. The thermal energy from a specified explosion received by a given surface will be less at greater distances from the explosion for two reasons: (1) the spread of the radiation over an ever-increasing area as it travels away from the fireball, and (2) attenuation of the radiation in its passage through the air. Except for a small scattered component, the thermal radiation from a nuclear explosion travels like light in straight lines from its source - the ball of fire. Any opaque material, such as a wall, a hill, or tree, located between the object and the fireball will act as a shield and provide protection from thermal radiation. Transparent materials such as glass or plastics allow thermal radiation to pass through only slightly reduced in intensity.

The proportion of the energy appearing as thermal radiation will be greater for an air burst than for a surface burst where the ball of fire actually touches the earth or water. In a sub-surface burst, either in the
earth or underwater, nearly all the thermal radiation is absorbed.

The thermal radiation is capable of causing skin burns on exposed individuals at distances from the explosion where the effects of blast and initial radiation are not critical. Direct thermal ignition can occur over an area greater than 700 square miles for a 5 MT weapon on a clear day. In addition, all the hazards of a nonnuclear fire (fire burns, heated air, noxious fumes, etc.) can be anticipated by occupants of a structure that has been ignited by thermal radiation. On cloudy days, when direct thermal ignitions are severely restricted, secondary fires started by blast effects can be of major significance in an area of about 500 square miles.

A-5 Nuclear Radiation

The nuclear radiations emitted following the detonation of a nuclear weapon are divided into two categories - initial and residual. The initial radiations (those emitted within one minute after the explosion) consist of gamma rays and neutrons, capable of penetrating large distances in air and producing injurious effects in living organisms. Residual radiations, or fallout (those emitted after one minute) consist of alpha and beta particles and gamma rays.

A-5.1 Initial Nuclear Radiation

Initial nuclear radiation, like the blast and thermal radiation, is a local effect, seriously affecting only the area within a few miles of the burst. For example, the initial nuclear radiation from a 5 MT weapon would probably cause no deaths to exposed individuals beyond two miles from ground zero, affecting an area of perhaps 12 square miles. For weapons above 10 KT yield, the lethal range of initial nuclear radiation is well within the envelope of lethality for both thermal radiation and blast. In contrast, the residual (fallout) radiations can cause deaths a hundred or more miles away, thus affecting areas of over a thousand square miles.

In general, a shelter with a fallout radiation protection factor\(^1\) (pf) of 100 or more is amply shielded from initial nuclear radiation from

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\(^1\) The relationship between the amount of radiation that would be received by an unprotected person compared to the amount he would receive if he were sheltered. For example, a completely unprotected person would be exposed to 60 times more radiation than a person inside a shelter with a protection factor of 60.
MT weapons in locations where blast overpressures are 25 psi or less.

A-5.2 Radioactive Fallout

When a nuclear weapon is detonated on or near the ground, so that the fireball contacts the ground, thousands of tons of pulverized and vaporized soil and other materials are carried into the atmosphere in the nuclear cloud. These particles are propelled by a strong updraft, caused by the rising fireball, and will rapidly attain a great height. For example, within less than ten minutes following a 5 MT surface burst, the cloud may reach a maximum altitude of about 15 miles. The cloud contains particles, many of which act as carriers of the radioactive sources created by the fission process. These radioactive particles range in size from sand to microscopic particles.

Radioactive fallout is the material which is carried aloft by a surface or near-surface nuclear explosion and falls back to earth. The rate and place of fall depends on the particle's size, shape, and weight, and the wind speed and direction at various altitudes. Under normal wind conditions, the particles of visible size will have settled to the earth within one day. This material is called "early fallout" which, from a single nuclear explosion, can extend several hundred miles downwind from a surface burst and blanket thousands of square miles with deposits (about 1/8" thick in dangerous areas) of radioactivity. The arrival of fallout outside the blast area is at least one-half hour after the blast and, at any given locality, can be expected to be deposited over a period of a few hours. The lighter particles are dispersed in the stratosphere and descend very slowly over large areas of the earth's surface. This is the "delayed fallout" which does not require radiation shields, but could be a long term hazard. Air bursts do not create a fallout hazard as such, because no significant amount of material is made available to the radioisotopes to act as carriers.

The radiation emitted by nuclear fallout primarily consists of beta particles and gamma rays. Beta particles have little penetrating effect and can be stopped by a layer of heavy clothing. Although these radioactive particles can cause cigarette-like burns if allowed to remain in direct contact with the skin, or are ingested or inhaled, they are of minor concern in radiation shielding design.

Gamma rays, which are high-energy electromagnetic radiations like X-rays, are very penetrating, and their intensity determines the amount of shielding needed against fallout radiation. Such a shield will also protect against beta radiation. For the shelter to be effective, the
fallout particles must be excluded from the protected area. This may require the filtration of air and decontamination of entering personnel.

The basic unit of radiation exposure dose is the roentgen (r). The dose rate, or intensity, measured in roentgens per hour (r/hr), is the time rate at which the radiation dose is received.

The intensity of radiation from fallout constantly decreases or decays with time. Radioactive fallout decays by approximately a factor of 10 for every multiple of 7 in time. For example: If the gamma intensity is 3000 r/hr one hour after the burst, its value 7 hours (7 x 1 hour) after the burst will be down to about 1/10 of 3000 or 300 r/hr; its value 49 hours (7 x 7 hours) after the burst will be down to 1/100 of 3000 or 30 r/hr; its value 14 days (7 x 2 days) after the burst will be down to 1/1000 of 3000 or 3 r/hr and so on.

A-6 Physiological Effects of Nuclear Radiations

In general, the biological effects of exposure to nuclear radiations result from the ionization of, and damage to, molecules of body tissue. The nuclear radiations of primary interest in protective construction are the gamma rays.

Some of the effects of nuclear radiations on living organisms depend not only on the total dose, but also on the dose rate. For example, 600 roentgens over the whole body delivered in a short time (less than a few days) would probably prove fatal to humans. However, if the same dose were delivered over a long period (1 year) at a more or less uniform rate, there would probably be no noticeable effects. This is because most of the cells damaged by radiation can be replaced by new cells provided the rate of damage by radiation is not too high. If recovery cannot keep pace with the damage, injury will result. One of the most characteristic features of radiation injury is the lag that usually occurs between even severe exposure to radiation and the development of symptoms. The effect of dosage rate is the reason shielding is most important during the initial period of early fallout when the dosage rate is highest.
APPENDIX B

GLOSSARY OF TERMS

Air Burst: The explosion of a nuclear weapon at such a height that the expanding fireball does not touch the earth's surface.

Fireball: The luminous sphere of hot gases which forms a few millionths of a second after a nuclear explosion and immediately starts to expand and cool.

Blast Loading: The loading (or force) on an object caused by the air blast from an explosion striking and flowing around the object. It is a combination of over-pressure and dynamic pressure loading.

Blast Wave: A pressure pulse of air, accompanied by winds, propagated by an explosion.

Contamination: The deposit of radioactive material on the earth's surface and other exposed surfaces following a nuclear explosion.

Core: That portion of a multi-story building assigned to the vertical elements required for distribution of mechanical services and for circulation, such as ductshafts, pipeshafts, elevators and stairwells. It may also contain other spaces which are repeated on each floor, such as toilet rooms and janitor's closets.

Radioactive Decay: The decrease in activity of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, sometimes accompanied by gamma radiation.

Fission Products: The complex mixture of substances (about 200 isotopes of more than 30 elements) resulting from nuclear fission.
Flash Burn: A burn caused by excessive exposure of bare skin to thermal radiation.

Fusion: The process whereby the nuclei of light elements combine to form the nucleus of a heavier element with the release of substantial amounts of energy.

Gamma Rays: Electromagnetic radiations of high energy and great penetrating power originating in the atomic nucleus and accompanying many nuclear reactions.

Initial Nuclear Radiation: Nuclear radiation, primarily neutrons and gamma rays, emitted from the fireball and the cloud column during the first minute after a nuclear explosion.

Net Area: Space usable for human occupancy excluding walls, toilets, storage and mechanical rooms.

Overpressure: The transient increase in pressure in the shock wave of an explosion, usually expressed in pounds per square inch.

Roentgen: A unit of exposure dose of gamma radiation.

Shear Wall: A stiff structural element incorporated as a wall or part of a wall in a building and designed to be capable of resisting horizontal forces such as those due to wind, earthquake and blast.

Shielding: Any material which protects personnel or materials from the effects of a nuclear explosion.

Shock Wave: A pressure pulse in the surrounding air, earth or water initiated by the expansion of the hot gases produced in an explosion.

Skeleton Framing: A system of construction in which the supporting elements of the building structure form an open framework and in which the exterior and interior walls carry no vertical load other than their own weight.
Surface Burst: The explosion of a nuclear weapon at a height above the surface less than the radius of the fireball.

Thermal Radiation: Electromagnetic radiation emitted from the fireball as a consequence of its very high temperature, consisting essentially of ultraviolet, visible, and infrared radiations.

Yield: The total effective energy (nuclear radiation, thermal radiation and blast) released in a nuclear explosion, usually expressed in terms of the tonnage of TNT required to release equivalent energy in an explosion.
APPENDIX C

REGIONAL OFFICES

OCD Region 1
Oak Hill Road
Harvard, Massachusetts

Connecticut
Maine
Massachusetts
New Hampshire
New Jersey
New York
Rhode Island
Vermont

OCD Region 2
Olney, Maryland

Delaware
District of Columbia
Kentucky
Maryland
Ohio
Pennsylvania
Virginia
West Virginia

OCD Region 3
P. O. Box 108
Thomasville, Georgia

Alabama
Florida
Georgia
Mississippi
North Carolina
South Carolina
Tennessee

OCD Region 4
Battle Creek, Michigan

Illinois
Indiana
Michigan
Minnesota
Wisconsin

OCD Region 5
P. O. Box 2935
University Hill Station
Denton, Texas

Arkansas
Louisiana
New Mexico
Oklahoma
Texas

OCD Region 6
Denver Federal Center
Building 50
Denver 25, Colorado

Colorado
Iowa
Kansas
Missouri
Nebraska
North Dakota
South Dakota
Wyoming

OCD Region 7
Naval Auxiliary Air Station
Santa Rosa, California

Arizona
California
Hawaii
Nevada
Utah
OCD Region 8
Everett, Washington

Alaska
Idaho
Montana
Oregon
Washington
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