CANCELLED 8/15/95 - program no longer exists

AC 150/5355-2

FALLOUT SHELTERS IN TERMINAL BUILDINGS

April 1, 1969

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

AC NO: AC 150/5355-2
DATE: 4/1/69

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: FALLOUT SHELTERS IN TERMINAL BUILDINGS

1. PURPOSE. This advisory circular furnishes guidance for the planning and design of fallout shelters in airport terminal buildings. It discusses radiological effects and certain environmental engineering factors related to shelter design.

2. BACKGROUND. As air travel becomes increasingly popular, the number of people to be found on an airport at any given time may often be numbered in the thousands. The number will include the fixed airport population, air travelers, and visitors. Because airports are generally located away from structures in which these people could take shelter in the event of a sudden nuclear attack or major storm, many lives could be lost. With either foresight in planning a new terminal building or minor modifications in an existing building, shelter space can be provided that would be usable for other purposes in peacetime and enable thousands to survive in wartime.

3. CANCELLATION. Airport Engineering Data Sheet, Item No. 36, Airport Terminal Building Fallout Shelter, dated October 1961, is canceled.

4. REFERENCES.

   a. The Effects of Nuclear Weapons, Revised Edition February 1964, may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, for $3.00.

   b. The following publications are available from the Office of Civil Defense, Department of Defense, Washington, D.C. 20301:

      (1) Shelter Design in New Buildings, reprinted December 1967.

      (2) Technical Memorandum 64-2, Creation of Fallout Shelter Through Slanting and Cost Reduction Techniques, dated August 1966.

Initiated by: AS-570

(3) TR-21, Industrial Architecture, Fallout Shelters, dated June 1963.

(4) TR-27, New Buildings with Fallout Protection, dated January 1965.

(5) TR-44, Shelter through Architectural Design, dated April 1967.

(6) Technical Memorandum 61-3(Revised), Technical Requirements for Fallout Shelters, dated March 1965.

(7) FG-F-1.3 - National Directory of Architectural, Engineering and Consultant Firms with Certified Fallout Shelter Analysts.

(8) FG-F-1.2 - National Directory of Fallout Shelter Analysts.

5. HOW TO OBTAIN THIS PUBLICATION. Additional copies of this circular, AC 150/5355-2, Fallout Shelters in Terminal Buildings, may be obtained from the Department of Transportation, Distribution Unit, TAD-484.3, Washington, D.C. 20590.

Chester G. Bowers
Director, Airports Service

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1. GENERAL. There are two reasons in particular why airport authorities should give serious consideration to the inclusion of a fallout shelter when planning the construction or expansion of airport terminal buildings. First, the transient population of an airport (passengers and visitors) and the static population (airport staff and employees of tenant organizations) can amount to considerable numbers of people who need to be protected in the event of a sudden nuclear attack. Second, a protected area is needed from which decontamination and restoration efforts can be launched as soon as the radiological environment permits. The first can be further complicated when aircraft in flight at the time of an attack warning are directed to land under the Security Control of Air Traffic and Air Navigation Aids (SCATANA) rules, adding an unanticipated influx of persons to an airport. The second also affords protection to highly skilled specialists whose abilities to put the airport back into operation will be sorely needed in the national defense and recovery.

2. DUAL-PURPOSE AREAS. While the planning considerations discussed in this advisory circular are concerned with those peculiar to fallout shelters, note that areas designated for this purpose can and should be planned for normal peacetime use as well. If the planning considerations are kept in mind before actual construction operations are begun, the cost of additional protection and facilities can be held to a minimum through the use of "slanting" techniques and by knowledgeable design not only in structures and equipment but in terrain modification. "Slanting" is defined by the Office of Civil Defense as "the incorporation of certain architectural and engineering features into new structures for little, if any, cost increase to protect personnel from fallout gamma radiation in event of an emergency." It often involves merely a special functional layout of areas that would be required in any case or increased density of walls or slabs required by the basic design. Recent studies have shown that even when special construction is required for fallout protection, the use of "slanting" techniques and planning foresight have held the average cost to less than one-half of one percent of the building cost. It is recognized that construction assigned for use only in the event of an attack cannot be justified economically; but some forethought given to the planning of spaces necessary for normal operations in providing extra wall thickness, thicker ceiling slabs, careful adjustment of openings, location of toilet facilities and the like, will afford usable shelter at little extra cost.

3. EXPERT ASSISTANCE. As a result of a program conducted under the aegis of the Office of Civil Defense (OCD), Department of Defense, large numbers of architects and engineers have been trained in fallout shelter design and analysis and have been certified by OCD as qualified shelter analysts. Many architect-engineer firms now have analysts on their staffs. The services of shelter analysts are available to others who may need expert assistance and it is recommended that advantage be taken of their services.

4. RADIOACTIVE FALLOUT.

a. How Fallout Occurs. When a nuclear weapon is detonated, the sudden release of energy creates so much heat that a ball of fire forms in which the temperature is measurable in several millions of degrees. If the detonation is close enough to the ground that the fireball touches the earth's surface, the material under the fireball is vaporized. The blast will pulverize other materials in the vicinity. The fireball immediately begins to rise and creates a thermal column of hot air, carrying the vaporized and pulverized materials up into the fireball where they are mixed with the radioactive debris of the bomb and the radioactive particles adhere to the materials thus carried up. As the fireball cools, the materials form solid particles, the average size of which may be compared to coarse beach sand. Depending on particle size, wind direction, and velocity, the particles may be carried for many miles before they return to the earth's surface as radioactive fallout.

b. The Time Element. The heaviest particles will, of course, descend to earth first, while small particles of dust may, in effect, remain in suspension for a long time and be carried for hundreds or even thousands of miles by upper winds. It is unlikely that significant amounts of fallout will reach the earth in less than 30 minutes after the detonation, allowing at least that much time for people to reach shelter (barring blast or thermal damage) and to "button up" the shelter.

c. Radioactive Decay. It is characteristic of radioactivity that a certain amount is lost with the passage of time, the amount lost over a given period of time varying with the particular element or radioactive isotope. The length of time required for the loss of 50 percent of the residual radioactivity is known as the "half-life." The average "half-life" of the various isotopes that make up radioactive fallout is such that a rough-and-ready rule of thumb can be used as guidance in planning the time people must remain in shelter: For every sevenfold increase in time, there is a tenfold decrease in radiation intensity. For instance, if the radiation level at one hour after detonation (H + 1) is 5,000 roentgens, the level seven hours later (H + 8) will be 5,000 ÷ 10, or 500 roentgens; at 7^2 hours later (H + 49) or about two days, the level will be about 500 ÷ 10, or 50 roentgens; at 7^3 hours later (H + 343) or about two weeks, the level will be approximately 50 ÷ 10, or 5 roentgens. Thus, while exposure in the early stages of fallout will be serious and can be fatal, the decay over a period of time will allow personnel to leave the shelter and begin civil survival, recovery, and restoration activities.

d. Planning Premises. Intelligence estimates have been developed in an effort to provide planning premises concerning probable targets and weapon sizes (yields) that might be used in an attack on the United States, and some indication of the possible vulnerability of specific airports can be obtained from OCD. These estimates must, of course, remain estimates because there is no guarantee that certain targets will or will not be struck or that winds at the time of attack will conform to the usual pattern. Plan for shelter occupancy, however, on the basis that an attack may last as long as two weeks from the first to the last strike; that another two weeks of shelter occupancy may be required before the radiological environment will allow free movement outside the shelter; and that the total occupancy may, therefore, be as much as four weeks. At the other end of the picture it can be assumed that radioactive fallout will not reach the earth's surface in less than 30 minutes after detonation, even in areas near the ground zero, and the time may be several hours depending on wind velocities. This, of course, provides time for survivors of blast and thermal effects to reach shelter and remain for the duration.

e. Characteristics of Radiation.

(1) Types of Radiation. There are three types or forms of radiation that are of special significance in the design of shelters.

(a) Alpha radiation is particulate in nature, each particle resembling the helium nucleus, and each has measurable size and weight. The energy of the alpha particle is relatively slight and generally cannot penetrate the skin. Even light clothing or a sheet of paper will serve as a shield. The danger lies in inhaling or swallowing the particles where they can affect tender and unprotected tissues.

(b) Beta radiation is also particulate, each particle resembling an electron. The energy level is somewhat higher than that of alpha radiation, but can be shielded by such materials as heavy clothing. The principal danger with beta radiation also lies in the possibility of inhalation or ingestion, but there is some possibility of skin burns.

(c) Gamma radiation is the principal and most deadly form of radiation with which the shelter designer must concern himself. It is not particulate but is pure electromagnetic energy. Shielding against gamma radiation requires the use of very dense materials or distance and will be discussed later in this advisory circular. It easily penetrates human tissue, destroying cell structure and causing serious illness or death, depending on the amount of such radiation received and the length of time exposed.

(d) Other types are neutrons and hard X-rays emitted in the early phases of the detonation as "initial radiation." These are not of great significance to the shelter designer; if one is close enough to the detonation to be affected by them, the odds are good that one will be killed by blast or heat.

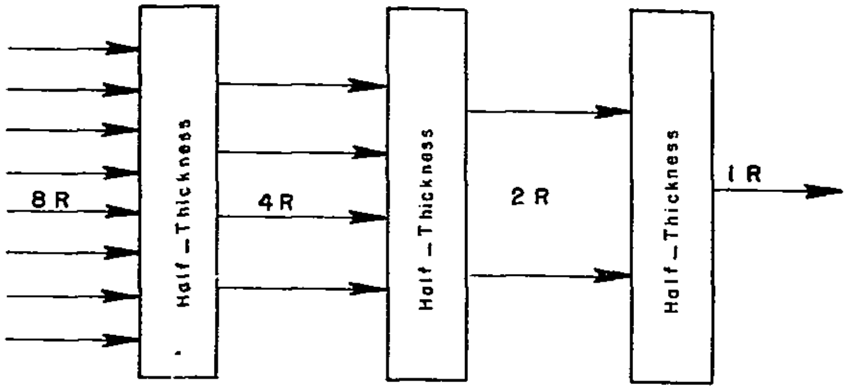
(2) Physiological Effects. The effect of radiation on the human body depends on the amount or "dose" the body receives and the period of time over which the dose is received. The amount, or dosage, is measured in "roentgens" and the rate in "roentgens per hour." The precise definition of a roentgen, usually indicated by the letter "R," is the amount of gamma radiation or X-rays that will form 1.61×10^{12} ion pairs when absorbed in one gram of air. The important thing to keep in mind is what physiological effects various amounts will have on the human body. For instance, a dose of 75R received over the entire body within 24 hours usually has no significant effect; a similar whole-body dose of 150R over a period of 24 hours will cause illness in 25 percent of the people so exposed; 200R will cause illness in 50 percent of the people. From 300R up, all of the people will be ill; at 450R, 50 percent of the people will probably die; and at 650R and up, all will be fatalities. The illness, itself, is one from which the human being can recover because the body is capable of repairing damage within limits; it is when those limits are exceeded that the body rebels and dies.

5. RADIOLOGICAL PROTECTION. Protection from radiation may be achieved in any one or a combination of three ways: by shielding or the interposition of barriers between personnel and the radiation source; by geometry or distance; and by the lapse of time and the accompanying radiological decay.

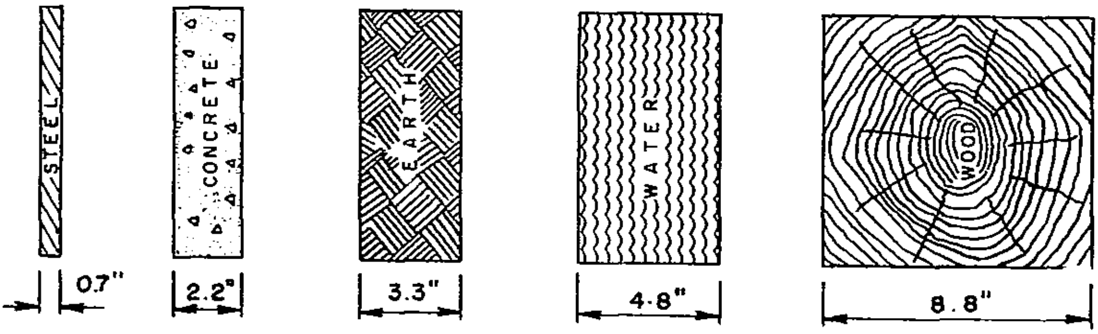
a. Shielding. Because of the high energy level of gamma radiation, it is capable of penetrating rather dense materials, but its penetrating power diminishes with density. The thickness of any given material required to act as a barrier that will stop the passage of one-half of the radiation is known as the "half-thickness" and varies with the density and energy of the radiation. For instance, the "half-thickness" of concrete is 2.2 inches; in other words, the radiation of the side of a 2.2-inch thick slab of concrete away from the radiation source will be 50 percent of the radiation on the side toward the radiation source. An additional 2.2 inches, or a total of 4.4 inches, will reduce the radiation by a total of 75 percent; a concrete slab 6.6 inches thick will reduce the radiation by a total of $87\frac{1}{2}$ percent. Thus, each "half-thickness" increment will diminish the residue by 50 percent; it is impossible to eliminate the radiation altogether, but the amount penetrating the barrier or shield can be reduced to a point where one can live with it. Other "half-thicknesses" of representative building materials, depending on their average density and based on the average energy level of a fallout field, are shown in Figure 1, Page 6.

(1) Solid Barriers. When gamma radiation impinges on a solid barrier, such as a concrete roof, floor slab, or a concrete wall, three things may happen to the radiation: Part of it will be absorbed in the wall or reflected from the surface; part of it may penetrate in a straight line through the barrier; and part of it, striking denser portions of the barrier or molecules within the barrier, may be "scattered" in random directions from the point of impact. These effects are shown in Figure 2, Page 7. Thus, a shelter area in a basement located below the finish grade and the plane of radioactive emitters may still receive significant amounts of radiation by scatter, as shown, and the intervening barriers must be designed with this in mind. However, since the dominant effect is that received from the radiation which travels and penetrates in a straight line, it is suggested that openings into the shelter area be designed with "traps" similar to those used at entrances to photographic darkrooms to prevent straight-line transmission into the shelter area.

(2) Skyshine. The radiation from a radioactive emitter emanates in all directions. When the emitter is located on the ground or on a roof slab, part of the radiation will be upward or at an upward angle from the ground or slab plane. It will strike and be reflected from air molecules, dust, moisture, and other impurities; and part of this reflection will be in a downward



EFFECT OF HALF-THICKNESSES



COMPARATIVE HALF-THICKNESSES OF COMMON MATERIALS

MATERIALS	DENSITY (lbs. per cu. ft.)	HALF-THICKNESS (inches)
STEEL	490	0.7
CONCRETE	144	2.2
EARTH	100	3.3
WATER	62.4	4.8
WOOD	34	8.8

FIGURE 1. APPROXIMATE HALF-THICKNESSES FOR GAMMA RADIATION FROM FISSION PRODUCTS (0.7 MEV ENERGY)

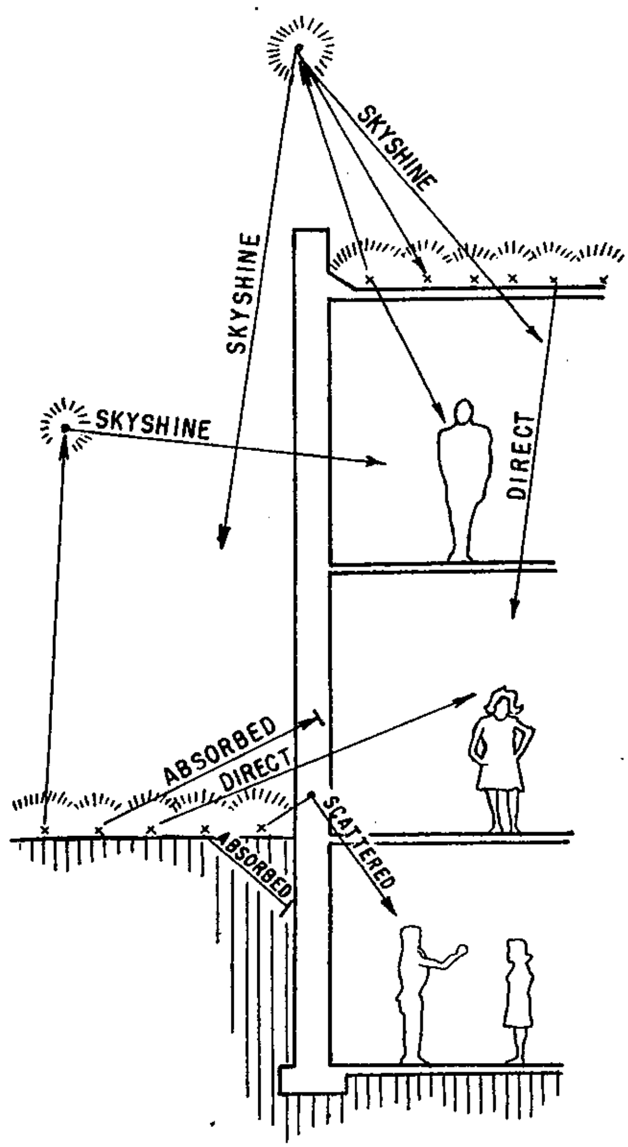


FIGURE 2. RADIATION AND STRUCTURES

direction. This reflection must be considered in the design of roof or wall slabs. The situation is somewhat analogous to a glow of light which sometimes appears over a lighted city when, even on clear nights, the light is reflected back from air molecules. The radiological effect is not great, amounting to about 10 percent of the total radiation, but design tables and curves used in the design of a fallout shelter should take the "skyshine" factor into consideration.

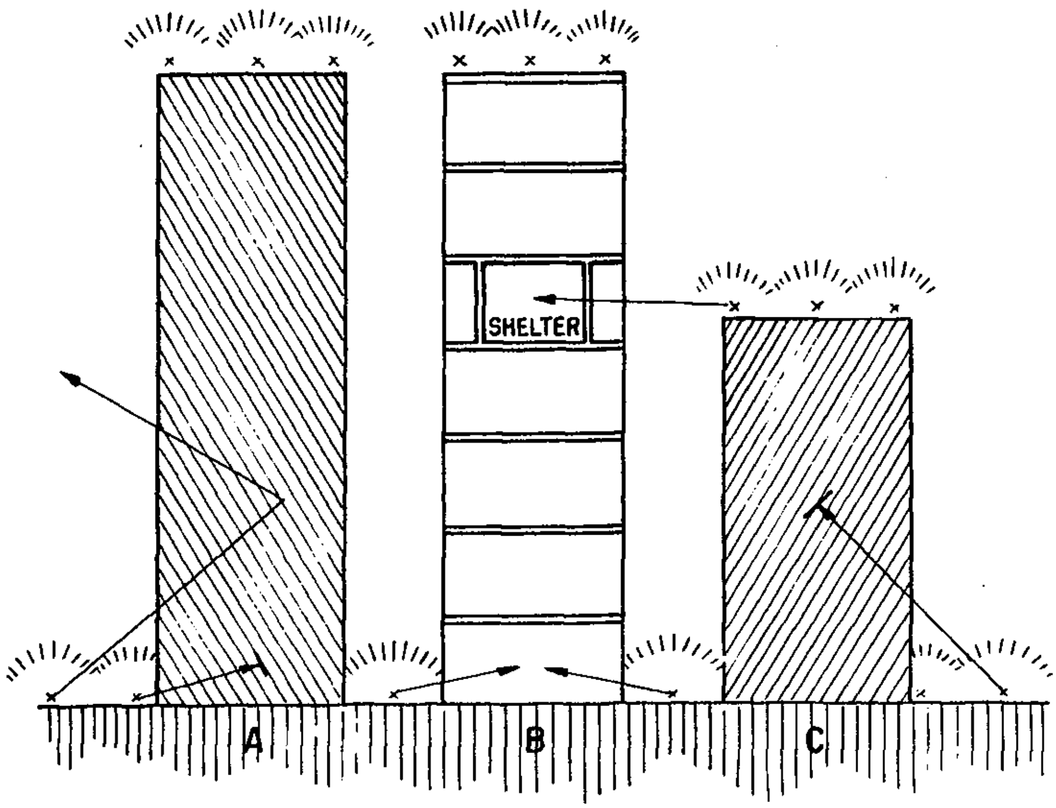
b. Geometry. The term "geometry," as used in design for fallout protection, relates basically to distance between the people protected and the source of radiation; and this can be introduced into the design in several forms.

(1) Square Versus Long Narrow Buildings. For an equal floor area, a square building will afford better shelter than a long narrow building. For instance, a building 40 feet square contains 1,600 square feet; the center, in which the shelter might be placed, is 20 feet from the nearest point on the perimeter. A building 80 feet long by 20 feet wide also contains 1,600 square feet, but the center is only 10 feet from the nearest point on the perimeter and this--not the 40 feet measured longitudinally--is the critical distance.

(2) Tall Versus Low Buildings. A shelter placed about midheight in a tall building can prove to be satisfactory with less shielding around the walls because the floor slabs below plus the floor and roof slabs above serve as shielding, while the distance from roof and ground surfaces attenuates the radiation by geometry. Conversely, a low (one- or two-story) building requires much heavier shielding above and around the shelter because of the proximity of the radiation fields at ground and roof levels where fallout collects. Providing adequate shelter at ground level is generally quite difficult.

(3) Mutual Shielding. In many cases, buildings adjacent to the shelter will contribute to the protection by keeping the radiation field farther removed. Exceptions occur when the roof of the adjacent building is at or near the shelter level; in such cases, the shelter must be designed as a ground-level shelter. These cases are shown in Figure 3, Page 9.

(4) Site Adaptation and Earth Sculpturing. While the operating surfaces of an airport and the areas between them must, of necessity, be kept as a plane to the maximum extent possible, landscaping of the terminal area may present an opportunity to grade the soil into berms and embankments that interpose solid earth barriers between the terminal building shelter and the surrounding radiation field. Take care, however, to insure that pockets that may retain concentrations of radioactive fallout are not formed by these grading operations and thus create worse problems.



BUILDING A PROTECTS THE SHELTER IN BUILDING B BY MUTUAL SHIELDING. THE RADIOACTIVE CONTAMINANTS ON THE ROOF OF BUILDING C ENDANGER THE SHELTER, AND THE SHELTER WALL NEAREST BUILDING C WILL HAVE TO BE HEAVIER AS THOUGH DESIGNED FOR A GROUND LEVEL SHELTER.

FIGURE 3. MUTUAL SHIELDING

c. Time. The radioactive decay described in Paragraph 4c will operate to the advantage of shelter inhabitants. The radiation intensity in the immediate post-attack period may be so high that heavy shielding will be required. Due to cost factors, the designer may find it expedient to limit the actual shelter area even though some discomfort to inhabitants may result. After a few days, the radiation level will decrease to the point where expansion into roomier but less protected areas may be permissible. Therefore, uniform protection need not be provided throughout the entire shelter area if there is adequate protection for all of the people (even with some crowding) based on the critical high-intensity period.

6. PROTECTION FACTOR. The "protection factor (PF)" of a shelter indicates the reduction in radiation intensity afforded by the shelter from that which exists outside. For instance, a PF of 100 means that the radiation intensity inside the shelter is 1/100 of the intensity outside the shelter; a PF of 40 means that the intensity is reduced to 1/40 of the outside intensity. According to standards established by the OCD, all shelters should have a minimum protection factor of 40. It should be recognized that, depending on the peak outside radiation intensity, some illness may be experienced. Additional protection should be built in if economically feasible. For emergency operating centers or command posts in which skilled or specialized personnel must continue operations in the interests of community safety or in support of national defense, the protection factor should be at least 100 because the importance of the mission cannot tolerate the disability, however slight, that may occur in a shelter with a lesser PF.

7. BLAST PROTECTION. Generally speaking, provision of protection against blast overpressures is an extremely expensive undertaking to be reserved for the most critical facilities. In the case of the airport terminal building, the chances are good that severe blast overpressures would not be sustained because of its distance from the target city it serves. The above-ground parts of the building may be damaged, but a below-ground shelter should survive unless the enemy's aim is poor and the weapon detonates much closer to the airport than originally intended. However, there may be sufficient movement of the structure due to seismic effects to rupture any rigid utility connections or ducts that pass through the shelter walls or slabs. This can be corrected at little cost by the use of flexible connections and spring-mounted equipment in the shelter area.

8. ENVIRONMENTAL DESIGN CONSIDERATIONS. When the problem of providing adequate radiological protection has been met, there still remains the matter of providing an environment in which the inhabitants can live in reasonable comfort for a period of two weeks or longer. The expression "reasonable comfort" does not refer to creature comforts such as upholstered furniture but to the elements of environmental engineering necessary to sustain life and keep morale at an acceptable level. Life in a shelter cannot be expected to go on in the same manner as preattack living outside the shelter, but it may not go on at all unless there are adequate life-support systems installed. It is also necessary to give attention to such allied problems as area requirements and spatial relations in order to insure the most efficient operation of a more or less self-sustaining and self-reliant community under what, at best, can only be described as trying circumstances.

a. Area Requirements.

(1) Calculating Shelter Spaces. Base the number of shelter spaces needed on the estimated peak-hour population of the terminal building, including passengers, visitors, and employees. These are normally distributed throughout the building in the public waiting areas, eating facilities, airlines offices, service areas, and other concession areas. Studies indicate that the total of passengers and visitors is approximately twice the number of peak-hour passengers alone. The number of employee occupants varies so widely between terminal buildings that no ratio has been determined; however, a reasonable estimate would be one-half the number of peak-hour passengers. Hence, the number of shelter spaces to be provided should be about 2.5 times the number of peak hour passengers; and it may be assumed that at any given time, one-half the shelter occupants will be in bunks and the other half will be sitting, standing, or otherwise occupied.

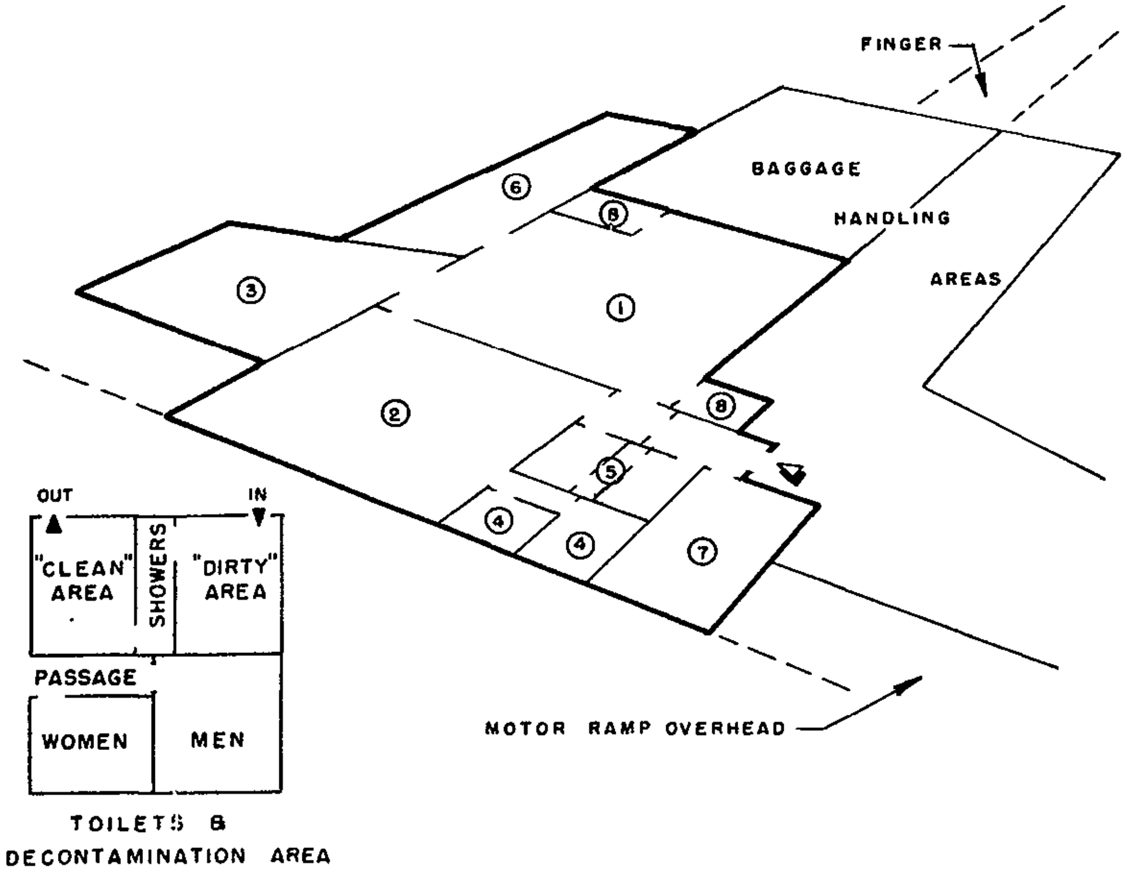
(2) Calculating Shelter Area. The area required per shelter occupant will be somewhat modified by the plan for shelter management and operation. For instance, the actual area needed for sleeping arrangements will be affected by the decision to use single, double-decker, or triple-decker bunks and whether to use a "hot-bed" system in which one-third of the occupants are sleeping while the other two-thirds are engaged in other activities in separate areas. Single cots, including circulation spaces, will require 30 square feet per occupant; double-decker bunks require 15 square feet per occupant; and triple-decker bunks require 10 square feet per occupant.

Cooking, eating, and recreation areas require 10 square feet per occupant, and storage areas should be calculated on the basis of two square feet per occupant. Except under conditions of extreme emergency in which humanitarianism demands some crowding to save life, allocate a minimum space for shelter of 10 square feet per person, but recognize that so small a space may lead to serious shelter management problems over periods of from two to four weeks.

(3) Emergency Operating Centers. If it is anticipated that a portion of the available shelter space in the airport terminal building will be used by airport management as an emergency operating center (EOC) for directing on-airport activities in connection with State and Regional Defense Airlift (SARDA) or War Air Service Program (WASP) or as a "nerve center" for damage assessment, decontamination, or rehabilitation, that area will require more floor space, a higher protection factor, and better lighting. For persons bearing such responsibilities, a slight case of radiation sickness such as might be tolerable in other shelter occupants could seriously affect efficiency. Provide a minimum of 50 square feet per EOC occupant, while 85 square feet is desirable. A PF of at least 100 should be the design goal.

(4) Equipment Space. The floor area required for such mechanical equipment as emergency engine generators, air conditioning, sanitary facilities, life-support systems, and the necessary appurtenant shop spaces cannot be easily calculated on a per capita basis. The amount of space reserved for these will be largely dependent on what equipment is normally used on a day-to-day basis and whether it may be reasonably assumed to remain in operation during and after an attack. Design criteria for these items will be discussed under the appropriate headings.

b. Space Relationships. Unlike the bomb shelters of the Second World War, to which people moved and in which they remained at the most for a few hours, fallout shelters may be occupied for as long as four weeks before egress would be safe from the effects of residual radiation. It is neither desirable nor practical to partition off and reserve certain areas set aside for shelter use. The emphasis should be on multiuse space that meets the criteria for protection, that is either equipped or to which emergency equipment can be easily and quickly moved, and which is also usable under normal peacetime conditions. It will be necessary to identify the proposed shelter use of the various protected areas and to plan for their partitioning to provide functional efficiency or privacy even though the partitioning may only be opaque curtains.



EMERGENCY USE	PEACETIME USE
1. GENERAL ACTIVITY AREA	EMPLOYEES' DINING ROOM
2. SLEEPING AREA	STORAGE AREA
3. FOOD PREPARATION & STORAGE	EMPLOYEES' KITCHEN
4. TOILETS	EMPLOYEES' TOILETS
5. DECONTAMINATION AREA	EMPLOYEES' SHOWERS & DRESSING
6. EMERGENCY OPERATIONS CENTER	AIRPORT OPERATIONS OFFICE
7. MECHANICAL EQUIPMENT	MECHANICAL EQUIPMENT
8. VERTICAL CIRCULATION	VERTICAL CIRCULATION

NOTES: 1. AREA WITHIN HEAVY LINE IS SHELTER AREA, INCORPORATING PROTECTIVE CONSTRUCTION.

2. PLACE BAFFLES AT ALL OPENINGS BETWEEN PROTECTED AND UNPROTECTED AREAS TO PREVENT DIRECT PENETRATION OF RADIATION.

FIGURE 4. SCHEMATIC DIAGRAM SHOWING SPACE RELATIONSHIPS IN A TERMINAL BUILDING BASEMENT FALLOUT SHELTER

(1) General Activity Area. Set aside an area for eating, reading, talking, and general recreation large enough to accommodate two-thirds of the occupants of the shelter at any given time; conversely, shelter occupants may be expected to spend two-thirds of their time in the general activity area and the other third sleeping each day. It should be the core of the shelter area to which the terminal population will first report and where shelter management will be exercised. It should be adjacent to, but separated from the food preparation areas and sanitary facilities. Because two-thirds of the time of each occupant will be spent here, and if there must be any significant difference in protection factors over the shelter area, locate the general activity area in the portion with the highest protection factor.

(2) Sleeping Areas. Since it is impossible to estimate the ratio of male to female occupants, the total sleeping area should provide sufficient space for the total number without discrimination as to sex, but with opaque curtains or other movable partitioning that can quickly be adjusted to meet the needs at the time and afford adequate privacy. Much floor space can be saved by using double-decker or triple-decker bunks and a further saving in space can be realized by using a "hot-bed" system; that is, assigning two or three persons to the same bunk to occupy it in rotation. The latter course may occasion some objections, but overfastidiousness has little place when lives are at stake. The sleeping areas should be convenient to toilets but sufficiently removed, either by distance or sound insulation, from the general activity area to allow minimum disturbance for those who are sleeping.

(3) Food Preparation Areas. The emergency food supplies with which certified shelters are stocked require very little cooking. Any food preparation that requires the application of heat will throw an extra burden on the ventilating system, may upset the oxygen balance, and will tend to create odors that should be suppressed. These problems will be discussed under "Ventilation," but enclosure and isolation of the area can do much to alleviate the problem as long as convenience in food service in connection with the general activity area is not sacrificed.

(4) Mechanical Equipment Areas. In the construction of new airport terminal buildings, locate equipment areas so that maintenance and repair can be carried on without undue radiation hazards to maintenance personnel. While certain modifications for emergency services may be required, the only equipment that is peculiar to emergency conditions will be life-support systems. These should be located in or contiguous with the shelter. Engine generators and ventilating machinery may be noisy or produce heat (or both) and should be located as far from the occupied shelter area as possible without sacrificing efficiency of operation or safety of maintenance. In the modification of existing buildings, these criteria should be followed as far as possible, but they should not be the sole determining factor in locating shelter areas or considered as requiring expensive relocation of equipment.

(5) Sanitary Facilities. The types and numbers of the various fittings needed will be discussed under appropriate headings but, in general, the area set aside for sanitary facilities should be located so as to be readily accessible to both the sleeping and general activity areas. A provision for personnel decontamination, including showers and dressing areas, near the shelter entrance will be necessary to prevent bringing radioactive matter into the shelter area when cleanup of the airport begins. This will be discussed in Paragraph 8f.

c. Ventilation. Based solely on the oxygen demands of a human being, a mass flow of three cubic feet per minute of uncontaminated air per shelter occupant will suffice. There are certain conditions of temperature and humidity that may affect the physical qualities of this air flow to absorb the energy and moisture released in the shelter or to control the carbon dioxide concentration. Economic considerations must be evaluated as well as determining the degree of sophistication in climate control that can be justified. There are, however, certain parameters within which systems must be designed to support life and maintain morale, and it must be assumed that an enemy attack will come when climatic conditions are at least favorable to long-term shelter occupancy.

(1) Filtration. Fallout particles may be as small as three microns in diameter. Generally speaking, a good commercial filter will remove fallout adequately; in very critical areas, such as EOCs, the interposition of a positive filter in the ventilating system is desirable. It should be noted that fallout particles trapped in the filter will result in a very highly radioactive concentration into what is, to all intents and purposes, a point source. Special care must be taken to insure that there is adequate shielding between the filter and the shelter area and that the intake of the ventilating system points downward to minimize the influx of fallout particles.

(2) Temperature Control. The purpose of controlling temperature in the shelter is to maintain tolerable conditions under which appreciable heat storage or rise in body temperature will be avoided. An effective temperature of 85°F is about the maximum under which this objective can be reached for sedentary persons during the anticipated shelter staytime. The American Society of Heating, Refrigeration and Air Conditioning Engineers' (ASHRAE) index indicates several combinations of temperature and humidity that will produce an effective temperature of 85°F with still or slowly moving air.

Effective Temperature	Dry-Bulb Temperature	Wet-Bulb Temperature	Dew Point	Relative Humidity
85	85	85	85	100
85	90	82	80	72
85	95	79	73	50
85	100	76	66	34

The maintenance of an effective temperature not to exceed 85°F is significant not only for the supply of oxygen and the removal of carbon dioxide, but in the control of undue rise in body temperatures, moisture, and odors.

(3) Humidity Control. The major portion of the moisture in a shelter will originate with the occupants. Other principal sources will be the ventilation air, leaks in the shelter structure, and evaporation from exposed water surfaces, such as wash basins and toilets. Humidity control to achieve the optimum effective temperature can be accomplished either with mechanical equipment (compressor, condenser, and evaporator) or chemicals (calcium chloride, silica gel, activated carbon,

etc.) Unless there is some method of ejecting the heat generated by the dehumidification process or unless the equipment or chemicals can be placed outside of the shelter, the resulting temperature rise will be such that the effective temperature will also increase with a resulting loss in habitability and a worsening of environmental conditions. Because of the cost of packaged mechanical cooling units designed for an effective temperature of 85°F, the designer may wish to consider systems to provide a dry-bulb temperature of 78°F and relative humidity in the range of 55 to 65 percent.

(4) Odors. In a confined space, such as a shelter in which a number of people are living, certain odors will occur. Toilet facilities and food preparation create odors that, under conditions of nervous tension, may become intolerable; and the nervous tension itself may result in perspiration that may cause odors. Smoking produces odors that are unpleasant to some people under normal conditions and even to smokers themselves when concentrated. Some shelter inhabitants may become nauseated. For most people, the odors will be unnoticed after a certain length of time, except to those who have come in from fresh air; but in the early stages of shelter occupancy, there may be deleterious psychological effects. Prolonged exposure may also have physiological effects. If possible, isolate those processes that contribute to the creation of odors from the generally inhabited shelter area (though still within the general shelter area), and the rate of interchange of air in ventilating systems should be such as to minimize odor retention. Chemical sprays, for all their advertised merits, generally only disguise one odor with another.

d. Life-Support Systems. Since the detonation of a nuclear weapon may kindle fires over large areas (250 square miles for a one-megaton weapon and 2,000 square miles for a ten-megaton weapon), mass fires must be considered in relation to their effects on the design of ventilating and life-support systems. If such fires occur in the immediate vicinity of a shelter, it will be necessary to shut down the ventilating system for a period of time, including the intake of fresh air.

(1) Temperature. In mass fires, the temperature of the fire can be over 2,600°F; and air temperatures can reach 200°F to 300°F at the intake vent. Burning and smouldering rubble may produce dangerously high temperatures for hours or even days. For this reason, locate air intake vents, if possible, away from combustible materials.

(2) Carbon Monoxide. Large amounts of carbon monoxide can be drawn into the air intake vents unless they are "buttoned up." Concentrations as high as 7 percent have been measured in experiments; one percent will cause death in from one to three minutes.

(3) Closure. To insure that extremely hot air and carbon monoxide are not taken into the shelter, close all external openings. These include air intakes and exhaust vents, vents from plumbing fixtures, and exhaust piping from standby engine generators. This creates a closed system, requiring the elimination of several enviornmental hazards.

(a) Depletion of the oxygen supply must be prevented by introducing enough to replace that which is used.

(b) Remove too high concentrations of carbon dioxide.

(c) Remove concentrations of odorous and toxic substances.

(d) Prevent an excessive rise in effective temperature.

(4) Oxygen Concentration. Maintain volumetric concentrations of 17 to 21 percent of oxygen and not more than two percent for carbon dioxide as closely as possible. Life can be sustained with oxygen concentrations as low as 12 percent and carbon dioxide as high as four percent, but with some discomfort. If life is to be sustained for 24 hours or longer in a closed system, means must be found to supply the oxygen and remove the excess carbon dioxide.

(5) Oxygenation. Of some eight methods that have been tested and examined in relation to reliability, cost, and safety, two appear to hold a definite superiority over the others.

(a) High-Pressure Oxygen Cylinders. Oxygen may be obtained and stored in steel cylinders of various sizes and under various pressures. The usual commercial cylinder is nine inches in diameter by 52 inches long and is pressurized to 2,000 pounds per square inch. Each cylinder holds about 244 cubic feet of oxygen under standard pressure and temperature. The consumption rate should be computed at one cubic foot per person per hour. A regulator and flowmeter are required, and a manifold if more than one cylinder is to be used at a time. Care must be exercised to prevent the valve being knocked off by using appropriate racks to hold the cylinders; any breakage of the valve could make a self-propelled projectile of the cylinder.

(b) Chlorate Candles. The United States Navy has used chlorate candles in submarines, consisting of a mixture of sodium chlorate ($NaClO_3$) with about 10 percent of powdered iron plus smaller amounts of barium peroxide (BaO_2) and powdered fiberglass. The complete unit includes a furnace in which the candles are burned and a filter to remove the nontoxic, but irritating, smoke. The candles used by the Navy are six inches in diameter by 12 inches high, weigh 28 pounds, and produce a little over 100 cubic feet of oxygen. Two candles are used at one time and burn about one and one-half hours. Thus, two candles will produce sufficient oxygen for 100 people for two hours, leaving one-half hour to cool the furnace and replace the candles. The temperature of the reaction varies from 1,300°F to 1,500°F. The heat liberated varies from 83 to 100 BTUs per cubic foot of oxygen produced, and the heat load must be considered in design of the ventilating system.

(6) Removal of Carbon Dioxide. At least 16 methods of carbon dioxide removal have been tested, of which the following two appear to be most practical. Tests have indicated that approximately 0.82 cubic feet of carbon dioxide will be produced for each cubic foot of oxygen consumed.

(a) Baralyme. This is a mixture of 20 percent barium hydroxide and 80 percent calcium hydroxide, with trace amounts of wetting agents and dye. The wetting agents prevent release of irritating dust, and the dye changes color to warn of depletion of absorbing power. Used in conjunction with a blower, the recommended rate is 10.5 pounds of baralyme per man-day.

(b) Soda-lime. This process is often used in hospitals in rebreathing apparatus. The chemical is primarily calcium hydroxide with small amounts of sodium hydroxide, potassium hydroxide, and moisture added to prevent caking. It is used in a cannister-blower system at a rate of about three pounds of soda-lime per pound of carbon dioxide, or eight pounds of soda-lime per man-day. A filter is needed to reduce dust that is irritating to eyes and mucous membranes. The heat liberated by the process is about 105 BTUs per man-hour.

(7) Summary. These processes for oxygenation and removal of carbon dioxide are relatively inexpensive. The length of time during which life-support systems may be needed is limited, and the shelf-life of the chemicals used is from four to seven years. Before making any decision to provide these systems, investigate the environment carefully to determine whether mass fires can be originated and sustained in the vicinity of the shelter area.

e. Water Supply. Without water, life cannot continue. People who have potable water but no food can survive longer than can those who have food but no water. It is essential, therefore, to consider the problem of water supply, either from the regular water distribution system, from stored containers of water, or from wells. A complete dependence on the existing water distribution system is impractical, not so much because of damage that might occur in the distribution piping but because of the damage that would almost certainly be inflicted upon the plumbing stations, water treatment plants, and elevated tanks and reservoirs.

(1) Potable Water. Water of potable quality is needed for drinking, food preparation, and medical purposes. Tests have shown that there is a direct correlation between drinking water consumption and effective temperature in the shelter. Drinking water must not only be free of bacteria but also protected from the introduction of fallout particles to prevent ingestion of radioactive matter by the shelter occupants. For food preparation, little additional is required because the amount needed for preparing coffee, tea, and dehydrated milk is included under the drinking water allowance, and additional fluid is available in canned soups, stews, and vegetables. The water used for washing dishes should be of sufficient purity to avoid contaminating the

utensils. Some water of potable quality should be available for washing the hands of first-aid attendants, and for cleansing wounds preparatory to treatment. The minimum amount of water for drinking purposes should be two quarts per person per day; an optimum amount would be three quarts per person per day, if possible. Water for dishwashing should be calculated on the basis of one gallon per person per day; for large groups this will be more than adequate, but any excess may permit relaxation of water consumption discipline. If the supply of potable water is not critical, allow two gallons per person per day, of which one and one-half gallons would be used for hygienic purposes and one-half gallon for drinking.

(2) Nonpotable Water. Water which need not necessarily be of potable quality may be needed for washing and bathing (including personnel decontamination), cooling water for engine generators, air conditioning, sewage disposal, and firefighting.

(a) Washing and Bathing. While it is desirable that water for washing and bathing be of potable quality, it is not essential. Waterless chemical compounds for hand washing may be placed near toilet facilities. The inclusion of bathing or showering facilities inside the shelter area may add significantly to the moisture content of the shelter air, thus complicating the ventilation problem; and shelter occupants should be prepared to accept lower standards of personal cleanliness during their confinement. Arrangements for personnel decontamination near the shelter entrance will be discussed in Paragraph 8g, and these require showering facilities; but the moisture resulting from showers can be discharged outside the shelter area if the ventilation system is properly planned. Under normal peacetime conditions, the average shower requires fewer gallons of water than a tub bath. Showers in personnel decontamination will require significantly more because of the more thorough washing necessary to insure that all fallout particles and dust are removed.

(b) Mechanical Equipment. The amount of water needed for engines and air conditioning will, of course, vary with the design of the equipment. Polluted water may be used as long as the pollution does not clog piping, valves, or other parts of the system. If water contaminated with radioactive material is used, adequate shielding from the shelter area must be provided. Note that air passed over surfaces cooled by contaminated water will not itself become radioactive; however, air blown through a spray of contaminated water may carry radioactive matter into the ventilation system.

(c) Sewage Disposal. Water requirements for sewage disposal will be discussed in Paragraph 8f. If water and sewer systems remain in operation and toilet flushing is permitted, an allowance of 25 gallons per person per day is required for flushing of toilets and urinals.

(d) Firefighting. Although the possibility of fires exists and water is the most commonly used fire extinguishing agent, discourage its use for this purpose unless unlimited supplies exist. Certainly, the use of radiologically contaminated water must be discouraged inside the shelter area lest the entire shelter becomes contaminated. Provide hand type fire extinguishers.

f. Sanitation. A reliable sewage disposal system is essential to the maintenance of health in a shelter area. Normal sewerage and sewage disposal systems depend on the availability of water and power, and these may be lacking following a nuclear attack or a major natural disaster. If possible, basic planning will locate the shelter area so that full advantage may be taken of existing toilet facilities in the terminal building; but always make provision for emergency facilities in case the regular ones become inoperative. A water closet that will not flush is as bad as no water closet at all. Provide a minimum of one toilet per 50 persons.

(1) System Requirements. Any emergency method of sewage disposal should have the following characteristics:

(a) Ease of maintenance by persons without special training.

(b) Independence of water and power supply.

(c) Provision for proper disinfection to prevent disease, and ventilation to prevent odors.

(d) Ease of expansion, preferably on a modular basis to take care of overcrowding.

(e) Provision for privacy and segregation of sexes.

(2) Types. In consideration of these system requirements, there appear to be three types of sewage disposal that can be used effectively in emergency conditions.

(a) Pit Privies. The simplest method is the pit privy, similar to the outdoor convenience in use on many farms, with a pit or vault of sufficient capacity to accommodate the human waste accumulated during the shelter staytime. Fluids leach out into the soil, and solids are reduced by digestion.

(b) Dual Container Method. The containers adopted by the OCD for storage of drinking water can be used for the reception of human wastes when the water has been used. This method requires that water be consumed at a faster rate than human wastes are produced. Tight fitting lids and disinfectants are essential.

(c) Chemical Toilets. Prefabricated chemical toilet units, complete with toilet seats and lids and with built-in vents, are also satisfactory. They, however, like standard toilet fixtures, require floor space that cannot be used for other purposes when the shelter is not needed.

(3) Capacity. The ratio of urine produced to water consumption is generally higher in the summer than in the winter. The quantity of fecal matter will remain more or less constant throughout the year. Water consumption will generally be higher in the summer. Waste disposal should, therefore, be based on the winter usage rate and water supply on the summer rate. A good average figure in computing capacity of sewage disposal systems is 0.50 to 0.75 gallons per person per day of combined fluid and solid waste.

(4) Disinfection. The gases resulting from human waste produce objectionable odors; may be toxic; and in concentrations of one part gas to five or ten parts of air, can be highly explosive. These effects can be minimized by the use of a mixture of cupric sulfate, sodium bisulfate, and mineral oil; saponified cresylic acids and mineral oil; or boric acid, sodium perborate, and mineral oil. All three mixtures are about equally effective in controlling odors, but the first is more effective in disinfection. Odors may be released into the atmosphere; in a closed system such as that described in Paragraph 8d, they can be removed by recirculation through a filter using activated charcoal.

g. Personnel Decontamination. From time to time during the period of shelter occupancy, it will be necessary for a limited number of persons to leave the shelter to reconnoiter, to engage in radiological monitoring, or to assist in decontamination of the airport in preparation for resuming operations. When returning, each person may introduce radiological contamination into the shelter area by carrying dust and fallout particles on his clothing and person. Both for the sake of such persons and to safeguard those remaining in the shelter, the introduction of contaminants must be prevented by providing decontamination facilities at or near the entrance.

(1) Personal Decontamination. Shower baths are the best method of removing contaminants. Arrange them so as to form the "connecting link" between the outer or "dirty" area and the inner or "clean" area. Walls of the shower stalls or room should be smooth, free of cracks, and impervious to moisture. Slope floors as steeply as possible, consistent with safety, to floor drains designed to carry water and any solids, such as dust and fallout particles outside the shelter area and to prevent ponding or sedimentation. Seats may be provided in the shower area so that bathers may sit down to give particular care to washing the feet and legs.

(2) Clothing Decontamination. There are two methods of decontaminating clothing that are generally readily available and easily adopted for shelter use. The simplest is the vacuum cleaner, carefully applied to all surfaces and seams. The receptacle will receive a high concentration of radioactive material; disposable bags are recommended, and they

should be removed from the shelter area and treated as radioactive matter. The other method is the washing machine, equipped with an effective drain to remove any radioactive residue from the vicinity. Brushing may remove contaminants, but it is not to be recommended because it may result in resuspension of dust in the air to be ingested by shelter occupants. Place clothing or other objects that do not respond to decontamination procedures in covered containers (garbage cans, etc.) outside the shelter area for later disposal.

(3) Space Relationships. The decontamination area should consist of three more or less distinct subareas: a "dirty" area into which personnel come first from outside the shelter, remove their clothing, and place the clothing in containers for later decontamination, and where vacuum cleaners or washing machines may be located; the shower area, where personal decontamination procedures are followed; and an inner "clean" area between the showers and the shelter, where clean clothing is stored and put on. The "dirty" area should have hose connections for periodic floor and wall flushing.

h. Electrical Power and Illumination. In all probability, if the United States is placed under nuclear attack, central power generating stations will be seriously damaged or destroyed. For this reason, those items of equipment that are essential to sustaining life in the shelter, such as ventilating systems, should be capable of manual operation. In addition, consider providing emergency power, either by engine generators or batteries, to carry certain minimum essential loads, such as lighting, that are needed for safety, morale, and panic prevention. Even if central power supplies escape damage by a nuclear attack, day-to-day experience shows that distribution lines and substations are quite vulnerable to thunderstorms during the summer, a season in which the power requirements are most critical in a shelter.

(1) Storage Batteries. While storage batteries are used extensively in telephone exchanges and similar installations, their use as an auxiliary power supply in shelters is not advocated. The initial cost is high; they require charging equipment; they occupy considerable amounts of floor space; and since most use acids as working fluids, they may produce explosive gases during the recharging process. They are suitable for starting internal combustion engines on engine generators or for emergency lighting. In the latter case, portable self-contained battery-powered lights may be more effective.

(2) Engine Generators. Many civil airports have a standby engine generator for use in an emergency. If it survives the attack and if it is so located that it can be repaired, inspected, and maintained without exposing personnel to radiation hazards, it should be used. Lacking these conditions, consideration should be given to the installation of an engine generator in a radiologically protected location near the shelter. All internal combustion engines emit noxious gases that must be vented outside the shelter, all create heat loads, and the heat exchange equipment may create pockets of radioactivity. Economics must be considered also since the unit may rarely be used, even in a dual-purpose space. There are three types that may be considered for shelter use, each with its own merits.

(a) Gasoline Powered. Prime movers powered by gasoline are the most easily obtained, especially in the sizes suitable for shelter use, and are lowest in first cost. For intermittent operation over long periods of time, they are not as reliable as may be desired. This is due to two factors: Gasoline stored for long periods of time will deteriorate and become gummy, clogging the engine's fuel system; and the ignition system, if exposed to high humidity, may not respond to the starting sequence. The highly volatile nature of the fuel may also create an explosive mixture in the shelter atmosphere if leaks in the fuel lines result from blast damage.

(b) Liquefied Petroleum Powered. Gasoline-powered engines can easily be fitted with a carburetor for the use of liquefied petroleum gas as a fuel. The fuel does not become gummy as does gasoline but is more dangerous than gasoline. The deficiencies in the ignition system are the same as for gasoline-powered engines. The cost is approximately the same.

(c) Diesel Engines. These units use low volatility fuels that are safer, from the vapor standpoint, than gasoline. Having no electrical ignition system, moisture presents no problem. Fuel costs are approximately 30 percent less than for gasoline or liquefied petroleum. The diesel engine is, therefore, superior from the standpoint of safety, dependability, and operating cost. It is not as readily available in small sizes.

(d) Fuel and Lubricant Storage. Make provision for sufficient capacity for storage of fuel and lubricants to keep the engine generator(s) in operation 24 hours per day for not less than two weeks and preferably for four weeks.

(3) Illumination. The following levels of illumination are suggested for areas within the shelter with due regard to safety, convenience, and morale:

(a) Sleeping areas, 2-foot candles at floor level.

(b) General activity area, 5-foot candles at floor level.

(c) Food preparation area, 20-foot candles at work level.

(d) Toilets and decontamination areas, 5-foot candles at floor level.

(e) Emergency operations center, 30-foot candles minimum.

i. Floor and Wall Finishes. Materials and finishes chosen for the interior of the shelter should be impervious to moisture, easily cleaned and maintained, and of pleasant colors to keep occupants from being unduly depressed.

(1) Provide walls in sleeping areas, general activity areas, and corridors to resist soiling. Control this by careful consideration of color and texture.

(2) Provide wall surfaces in toilets and food preparation areas that are resistant to moisture penetration and absorption of odors.

(3) Provide walls in the decontamination areas that are impervious to moisture and free of recessed joints that may accumulate radioactive matter.

(4) Use wainscoting, whether painted or of a different material, to reduce soiling and to introduce pleasant color changes.

(5) All floors should lend themselves to scrubbing and hose flushing.

(6) Limit all interior finish and structural materials to noncombustible materials since evacuation into a hostile radiological environment is not feasible.

9. PSYCHOLOGICAL FACTORS. Confinement in a shelter is an experience strange to most Americans, who have never been brought under attack. Add to this the fact that nuclear weapons and their effects are only partially understood, if at all, by the average person and psychological problems may really develop among shelter occupants who, at an airport, may cover the entire spectrum of the populace in age, experience, emotional response, and ethnic and social background. Most of the people who take shelter at an airport will be separated from their families and will be understandably concerned for the safety and welfare not only of themselves, but of their families as well. In a number of tests conducted by various Government and private agencies, it has been apparent that some of the particular irritants in shelter living can be corrected at little cost but with careful planning.

a. Noise. In almost all of the tests, excess noise has been the principal complaint, especially in sleeping areas. This is especially true if lack of space or beds requires scheduling for sleeping in shifts; i.e., the "hot-bed" system. The problem is, of course, primarily one of shelter management. However, the use of vibration mountings on fans and blowers, adequate lubrication of bearings, sound insulation of duct work, and flexible connections in ducts can help. The use of acoustical materials on ceilings should be considered, and isolation of sleeping areas from general activity areas can be provided in the planning of spatial relationships.

b. Congestion. Most complaints about crowding have arisen from the necessity for going to one food-dispensing center at one time, and when occupants had to stand in line to use toilets. This, again, is primarily a problem in shelter management, but minor changes in layout or numbers of facilities can change the traffic pattern and alleviate some of the congestion.

c. Lighting. Excessive lighting in sleeping areas is a source of irritation, and provision should be made to screen these areas off with just enough light to avoid stumbling over things. This level of light should be maintained at all times; constant low level lighting is less annoying than turning lights on and off. In the general activity area, plan "pools" of light in addition to the general illumination to allow for reading or recreational pursuits. The general illumination may be afforded by fluorescent lamps, which use less power and emit less heat than incandescent lamps.

d. Temperature and Humidity. The maximum effective temperature is discussed in Paragraph 8c. Experience has shown that, if economically feasible, the optimum effective temperature during shelter occupancy is in the range of 78°F to 80°F.

e. Confinement. Even the most phlegmatic people will, after extended shelter confinement, experience what almost amounts to claustrophobia. Some occupants will still experience feelings of anxiety and depression no matter what is done to improve the environment. Much can be done, however, to make the shelter area appear roomier by selective use of color and the arrangement of spaces by use of screens, wing walls, or space dividers. Most interior wall and floor surfaces will need some kind of interior finish in any event; and the addition of carefully chosen pigments to the paint, or thoughtful selection of the color and pattern of floor tile, will cost little, if any more.

I. COST. Generally speaking, the added cost of providing a survival shelter in the form of dual-use space in new buildings has not been broken out of the total bid price in construction reports. Protective construction is not achieved so much through additional expenditures as through the exercise of ingenuity and resourcefulness by the designer. If the shelter is planned for space needed for other uses in peacetime, if full advantage is taken of the presence of facilities and utilities required by those peactime uses, and if the possible need for the area as a survival shelter in war is kept in mind during the planning stages, very little modification is needed to provide a shelter that may save thousands of lives.