INTEGRATING CIVIL-DEFENSE SHELTER SPACE
IN NEW UNDERGROUND CONSTRUCTION*

by

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At the present time, the population of the U.S. is approximately ten times more vulnerable to nuclear weapons than the Soviet population. This vulnerability can be reduced rapidly by urban evacuation in a crisis. However, the need to keep the essential economy running in a crisis, as well as coping with attacks on short warning, makes the construction of shelter space where people live very desirable. This can be done most economically by slightly modifying underground construction intended for peacetime use.

The designer must consider all elements of the emergency environment when designing the space. Provisions must be made for emergency egress, light and ventilation (without electric power), blast closures, water, sanitation, and food. The option of upgrading the space in a crisis should be considered. An example is given.

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Improvement of the survival capability of the West should reduce the temptation for a confrontation, and with it the risk of a consequent miscalculation leading to catastrophe.

INTRODUCTION

Underground construction has obvious utility as protection against nuclear weapons effects in a civil defense emergency. This paper presents a brief review of factors that should be considered by the underground space designer when considering use of the space as emergency shelter against weapons effects. It is directed to members of the underground space community who have had little experience with the nuclear weapons environment.

We will attempt to provide a rationale for building shelter, an indication of the location of different types of shelters, factors that need to be considered in the design of shelter space, and we will present an illustrative example of special features in an earth-sheltered residence that make it better adapted to the civil defense environment.
RATIONALE--WHY BOTHER?

At the present time, the population of the United States is considered by knowledgeable people to be of the order of ten times more vulnerable to a nuclear war than the population of the Soviet Union. Under many plausible scenarios in which the Soviet Union has time to occupy its extensive shelter system and implement its well planned urban evacuation, their population losses in a full exchange could be a few percent -- less than they lost in World War II. In the same scenarios, casualties in the United States could range from 50 to 80 percent (CIA 78, Sullivan 78).

This disparity in civil vulnerability cannot avoid providing a temptation for the leadership of the Soviet Union to take greater risks in a confrontation to extract diplomatic and geopolitical concessions from the United States leadership. This same disparity will bear heavily on the decisions made by the U.S. leadership in a severe crisis.

The vulnerability of the U.S. population can be reduced very rapidly by a combination of evacuating our own cities and the use of what is called expedient shelter (i.e., shelter against weapons effects constructed in one to two days with materials and tools at hand). Plans for an urban evacuation in the United States, called Crisis Relocation Planning, would deal with the most worrisome aspect of the Soviet Civil Defense plans -- their use of an urban evacuation in a diplomatic confrontation. However, an evacuation in the United States would take a day or two for most of the urban population and up to a week for the
very large cities such as New York and Los Angeles. This planning, which is in progress, would have no capability of protecting the population against attacks on very short warning. Perhaps more seriously, it would require that the entire U.S. economy be shut down during the crisis while the population was evacuated -- at least until shelter could be constructed in the emergency for essential workers. A program to construct shelter for high-priority populations begun in the near future could, over several years of steady effort, gradually reduce the shortcomings of the evacuation plan. Incorporating provisions for emergency shelter in new underground construction can be done much less expensively than constructing underground structures whose sole purpose is that of shelter. Typically the additional cost of the structural modifications will run only a few percent of the cost of single-purpose shelters, which in the experience of Switzerland cost from $400 to $700 per space.

WHERE TO BUILD IT?

Fallout

Fallout shelter, which is obtained essentially for free in underground construction, is needed everywhere in the United States. Figure 1 shows an idealized fallout pattern that would be obtained from one hypothetical, 5000-megaton attack with a constant 20-mph west wind over the whole country (Haaland 76). Shelters are needed in the shaded areas
Fig. 1. Fallout patterns from a hypothetical, 5000-MT attack, 20-mph west wind.
which cover most of the area of the country. The location of these areas will change with the variation of wind direction and speed. There is no area of the country which can be considered safe from fallout.

Blast

Figure 2 is a map showing, in shading, areas of the country believed likely to experience at least 1/7 of an atmosphere (2 psi) of blast overpressure in a large attack on U.S. military and industrial targets. Blast must be considered a potential threat anywhere within 10 miles of:

- missile bases,
- 7000-ft runways,
- submarine bases,
- conventional military bases,
- strategic and industrial assets (including 1000 MW(e) plants or 40,000-barrel-per-day oil refineries), and
- population centers over 50,000.

Design Hardness

Moderate levels of hardness (ability to withstand 1 to 3 atmospheres of overpressure), which can be obtained quite inexpensively in underground construction, can dramatically reduce the risk area from megaton weapons. Figure 3 shows the 2-psi circles from one hypothetical attack in the New England area (Haaland 76). Compare this with Fig. 4 which shows the 1 atmosphere circles from the same attack. The population at risk has been reduced by at least a factor of two. From Fig. 5, it can be seen that increasing target hardness from a seventh of an atmosphere to one atmosphere reduces the effective area of the weapon by
Fig. 2. Two-psi risk areas in the U.S.
Fig. 3. Two-psi blast circles on the northeastern U.S.
Fig. 4. Fifteen-psi blast areas in the northeastern U.S.
Fig. 5. Area covered vs overpressure for a one-megaton weapon.
a factor of ten. Because of the overlapping of weapons effects in most targeting patterns, the net reduction of the area at risk is lower, but still very significant.

VITAL CONSIDERATIONS

Threat

How much of which weapon effects must be designed for will depend on the distance, direction, and nature of the nearest potential target. Fallout protection must be included in any case; if there are targets within ten miles, blast must be considered.

In all areas subjected to blast and in all areas within 20 miles of targets likely to be attacked by high-yield weapons, fire must be considered. While this will not affect underground structures, it may cause buildings above the underground space to burn and collapse. Particular attention must be given to ventilation air intakes and access passages in this situation. If blast is a possibility, the presence of buildings with large amounts of combustible material upwind (i.e., toward the target area) must be considered. The possibility of smoldering debris blown from a nearby structure against or over air intakes must be considered. This is usually handled by having the air intake protrude some distance above the ground. Provisions must be made for a quick temporary sortie from the shelter to deal with the problem if it arises.
Loss of electric power is a very important factor in the design of underground shelter space. Most spaces for peacetime use depend on electricity for ventilation. It must be assumed that commercial electric power will not be available after a nuclear attack. The concurrent loss of illumination also must be dealt with.

Vital Requirements

**Emergency Egress.** As a matter of prudence and psychological acceptability, any underground space expected to be used for shelter of more than a few people should have at least two methods of egress. Only one of these need be a normal door. The other can be a hatch and ladder or can be blocked with a frangible partition or even sand-filled until needed. In many designs one ventilation port is constructed large enough to permit exit via crawling.

**Ventilation With Power Out.** Underground spaces normally ventilated by mechanical systems must be provided with some means of emergency ventilation if they are to be used as shelter against weapon effects. If crowded to the recommended civil defense limits (i.e., approximately one square meter of floor per person) heat prostration can become a life threatening factor in many parts of this country in the summertime. To meet the most severe conditions, ventilation air of up to a cubic meter per minute per occupant can be required. This can be best done if an
air inlet and an air exhaust are available on opposite sides of the space. One of these can be the normal door to the space and the other can be the emergency exit or a specially designed ventilation port.

Some means for moving the air must be provided. This can be a commercially supplied, manual blower. If outside temperatures are not too high, proper arrangement of the inlet and exhaust port will provide enough ventilation for low population densities by natural thermal convection. Air can be driven through a sufficiently low pressure drop ventilation channel by proper manipulation of a stiff piece of cardboard. A device which can be fabricated in a few hours (Fig. 6) is the Kearny Air Pump (Kearny 79). One of these built into a door can move 20 cubic meters of air per minute (6000 cfm) when operated by a man working only moderately hard.

Air filtration is required only in areas subject to blast and then only dust filters are needed. The requirements for these are minimized if there is enough shelter volume for the occupants so that the ventilation system can be shut down for a few hours until the air clears.

Light. Habitability, safety, and efficiency of shelter space is enormously increased if there is some provision for a minimum amount of light when the power goes off. This can be provided by emergency generators in elaborate shelters, or by emergency lighting powered by large storage batteries, flashlights, candles, or improvised oil lamps. While
Fig. 6. Kearny Air Pump installed in a doorway.
people can survive without light, they have great difficulty in coping with unexpected conditions in total darkness.

**Water.** Without water in a shelter, occupants will be forced out to seek water in four days or less. At least one quart and preferably one gallon per occupant per day should be accessible to the occupants of the shelter. This can be stored in a specially designed tank or a tank with some other peacetime use, e.g. a hot water heater. In an emergency, water can be stored in garbage cans or pillow cases which have been lined with a plastic garbage bag of the appropriate (slightly larger) size. For residences, the most economical strategy would be to locate the hot water heater in the planned shelter space with provision for valving it off and venting and tapping the water in it.

**Blast Closures.** If a shelter is in a blast area, it would be much more efficient in protecting the lives and safety of the occupants if the access areas have been designed to exclude high-pressure blast waves. This is particularly true as the overpressures exceed one atmosphere and the ratio of door area to shelter volume is at the larger end of the spectrum. While a human being can survive two atmospheres of blast overpressure, many people would be killed or injured at one atmosphere or below by being thrown against something by the blast wind or by being hit by debris. Eardrums are damaged or destroyed at approximately 1/3 of an atmosphere overpressure. The design of valves and doors is relatively straightforward and commercial models are available from foreign
countries, notably Switzerland and Finland. The thing that is sometimes overlooked is that the loads developed by doors and valves in operation must be supported by the structure.

Sanitation. Some provision for removal or storage of human waste must be made. Failure to deal with this problem in larger shelter populations can run the risk of a variety of severe health problems. While principally an aesthetic and psychological problem with small groups, failure to deal with it is a mark of very poor planning.

Food. Food is not normally considered a life-threatening factor for the period of shelter confinement. Most Americans can survive two to four weeks without food. In fact, since the majority are overweight, a week or two on half rations would be beneficial. Most Americans keep about a two-week supply of food of miscellaneous types in their house.

However, a nuclear war would disrupt the food distribution system in this country on a scale that is completely without precedent in our history. While there is ample supply of food in the country to feed the population (Haaland 76), reestablishment of the transportation system and an emergency distribution mechanism might take several weeks in some areas. There is little point in bringing people through an attack only to have them starve to death a few weeks afterwards. Prudence would suggest the storage of several weeks of supply of some very simple food such as wheat, if there are no food stocks in the area.
Pacetime Use. In order to be economical, the shelter space should have an economic peacetime function. This will require some type of convenient access, usually a horizontal entryway. If the peacetime use entails the presence of hazardous materials in the space, a provision must be made for their removal at the early stage of a crisis, or the valving off of any lines carrying them. If this can't be done, then some other space should be considered for dual use as a shelter.

Information. Shelter occupants who have some information about the hazards of nuclear war and the methods of dealing with them are going to have a better chance of survival than those who don't. A book or two with this information in it would be a small-cost addition to the shelter with potentially a large payoff. The best information we know about is Nuclear War Survival Skills by Cresson Kearny (Kearny 79), available from the American Security Council Education Foundation, Boston, Virginia 22713. While this book is intended for people in a crisis with no shelter, it has a great deal of useful information for people with shelter.

Crisis Upgrading

There are a variety of actions which can be taken during a crisis to improve the blast resistance and/or fallout protection of almost any structure. Underground structures are particularly adaptable to this
strategy which can permit deferral of cost until its need is readily apparent. The structure or its access can be modified to improve greatly its shelter suitability with measures which would make the shelter much less suitable for its peacetime function.

**Shoring Spans.** The unit bearing capacity of a one-way span is inversely proportional to the square of the distance between supports. Cutting the unsupported span by a half or a third with the addition of columns and lintels can increase its load-bearing capacity by four to nine if the supports and the deck are designed for the loads. In wooded areas, the materials for doing this can be improvised. Specially prepared columns and lintels can be fabricated and stored. Materials which are adaptable to this function can serve some other function in peacetime use -- for example, cribbing for retaining embankments.

**Adding Earth Cover.** A reinforced horizontal surface may have additional earth cover added to improve its shielding factor. Earth may be piled up against exposed walls.

**Closing Openings.** Windows, doors, and corridors can be designed for retrofit with fabricated blast closures (i.e., blast doors and blast valves). Improvised closures to increase the shielding factor can be constructed from sand bags, earth-filled boxes or other containers, concrete blocks, or shelter supplies.
AN EXAMPLE

The application of the principles above is demonstrated on a 2000-sq-ft, passively solar heated, earth-sheltered house of the general design which is being built by many contractors today. The floor plan is shown in Fig. 7. It is designed (by H. B. Shapira of ORNL) to be acceptable to most building codes. The layout is intended to minimize the perception of being underground and this eliminate one of the most common concerns about earth-sheltered construction.

Covered with two feet of earth on the roof and constructed of post-tensioned concrete, the structure as it stands is quite tornado- and fire-resistant and offers very good fallout protection. It is designed so that one or two rooms can be fitted with blast closures. Alternatively, the entire structure can be hardened against blast in a crisis if enough labor is available.

The building is designed with the minimum exposed surface consistent with passive solar heating. Only the south wall is exposed. North, east, and west walls are completely buried.

The corridor walls down the center are load-bearing walls to keep the roof span short. Partition walls are load bearing and tied to the roof, floor, and connecting walls to provide shear strength as well.

The overhang shielding the south windows against the summer sun is designed for light construction or to be a trellis. This way it provides no heat path into the building such as a solid overhang might, and it is designed to transmit no stresses to the building if hit by a blast wave from the south. It would simply blow away.
Fig. 7. Earth-sheltered structure adapted to crisis upgrading plan.
The steel in the structure can be arranged for expedient shoring. This involves putting the prestressing tendons in the midplane of the roof slab and putting negative steel at the appropriate points in the roof slab and the floor slab.

The front wall can be designed for blast by appropriate design of the steel in the columns between the windows. The windows are designed for blast closures or additional fallout protection—this can be sand bags or specially designed concrete blocks.

Skylights are indicated for the corners of at least two rear rooms. These are located to minimize the effects or the strength of the structure. The diameter selected, 75 cm (30 in.), was predicated on emergency exiting. Knockout panels can be incorporated in the partition walls toward the rear to allow for emergency exit and through ventilation of the rooms in the rear. The location of the skylights and the doors was selected to permit through ventilation. One rear room is designed to accept blast closures -- a blast door and a blast valve to go in the skylight.

The walkway or patio is made of concrete blocks which are sized to stack in front of the windows. By incorporating the appropriate size rebar in these blocks they can be designed to resist blast overpressure. Alternatively, a patio in front of the building can be designed with its pavement in strips which can be tilted up against the building prior to piling earth against it. The retaining walls are intended to be
constructed of stacked cribbing and/or planters which can be rearranged in a crisis to support earth piled against the front of the building (Figs. 8 and 9). Ideally, grading of the berms on either side of the building would be done in a way to provide a convenient supply of soil for banking against the front of the building in a crisis.

The water heater and food storage should be located in the rear room that is intended to be used as a blast shelter.

The air intake would be low on the front door and would exhaust through the skylights. With this arrangement at low population densities or cool temperatures, natural circulation should provide enough ventilation. The low air flow rates should permit removal of any airborne particles by settling in the front of the house.

POSTSCRIPT

The foregoing illustrates the considerations that must be made in adapting underground space for nuclear shelter. This is not an exhaustive text.

It is our personal opinion that a nuclear war between the United States and the Soviet Union is extremely unlikely. Even with their shortcomings, our strategic nuclear forces could do terrible damage to the Soviet Union. While it likely the Soviets would emerge from the war vastly stronger than the United States, it is unlikely that they would willingly accept this level of damage. This is particularly so because
Fig. 8. Earth-sheltered structure perspective.
Fig. 9. Crisis-hardened earth-sheltered structure section.
they believe in, and their strategy is pointed to, obtaining the fruits of victory without having to fight the war.

The universal perception of the terrible state of unpreparedness of the United States and the Soviets' belief in their own ability to survive a nuclear war cannot help but affect their calculation of what is an acceptable risk in international adventures. The perception of third parties of this disparity or vulnerability must affect their perception of overall military strength. It will affect their calculation of who should have the biggest influence on their future policy. These perceptions dovetail very comfortably with the Soviet strategy of slow-but-steady, spreading influence and hegemony by a variety of means.

If we can correct our strategic vulnerability and institute a program of steady improvement in our survival capability, it will help enormously to correct the growing perception of Western weakness. This should greatly reduce the temptation to the Soviet Union to provoke a confrontation. The risk of a consequent miscalculation and catastrophe is proportionally reduced.

The paradoxical nature of civil defense preparedness is that if you have it you are unlikely to need it; if you don't have it, then you are more likely to need it. Incorporating shelter space in new underground construction built for other purposes is one way of improving civil defense preparedness and survival capability while making the most efficient use of resources.